UNIVERSITY
OF OSLO

Master's thesis

Teach Me How To Dance

An exploration of motion translation methods using the ZTL framework
for use with children with autism in educational settings

Claudia-Andreea Badescu

Robotics and Intelligent Systems
60 ECTS study points

Department of Informatics
Faculty of Mathematics and Natural Sciences

Spring 2024

Claudia-Andreea Badescu

Teach Me How To Dance

An exploration of motion translation methods using the ZTL framework for use with children with autism in educational settings

Supervisors:
Trenton Schulz
Diana Saplacan
Jim Tørresen

Abstract

Social robots for children with autism has been a prominent area of research for a long time, especially because of their positive effects. Evidence suggests that, in the presence of a social robot, children with autism elicit less stereotypical behaviours, and experience increased motivation and communication, which are typical areas of challenge. Robots that are employed in work with children might be prone to breakage, maintenance, and updates, and thus replacement of the robot could be necessary. Additionally, social robots often have various strengths, so it could be relevant to employ different robots in the same setting to take advantage of their individual capabilities. A common problem in robotics has traditionally been that each robot comes with its own interface, which makes unified control of the robots challenging. This warrants the need for generalisation of robot control, creating an simpler path for the use of multiple different robot platforms in the same context.

This has been a topic of concern that the ROSA (Robot-supported education for children with autism) project at the Norwegian Computing Centre has seeked to address. Within this project, a remote control has been used for simple control of the NAO robot, but now it has become relevant to use the same remote for a set of other robots as well.

In this thesis, the development of a robot-independent control for robots with diverse morphologies has been addressed. An user-centered design approach has been used, to include the perspectives, expectation, and requirements of the users of the remote. Thus, background interviews were performed, before the implementation of a remote control for the NAO and Misty robots. The implementation involved two parts, one where the ZTL framework was used for communication and dispatching of behaviours and another for translating behaviours between robots, where different methods of motion translation were explored.

The methods of motion translation were evaluated through a questionnaire and the system in its entirety was tested with its users. The results of the implementation indicate successful motion translation between the NAO and Misty robots. Despite the limitations and areas for improvement that were highlighted in the evaluation of the remote, the results also suggests that this is a potentially useful remote control implementation for use with children with autism.

Acknowledgements

As I am writing this acknowledgement section, 5 hours remain until the deadline of this thesis and I do not know how I managed to finish. What I do know, however, is that I would not be here without the support from everyone around me. I owe a huge thank you to everyone who have been in my life the past year; in some way or another, you have helped me reach this point and I am super grateful.

Firstly, I would like to offer my deepest appreciation to my supervisors, Trenton and Diana, for your unwavering support throughout the whole period, valuable advice, honest feedback, and most of all, your motivational talks. I am very grateful for the great guidance you have provided!

Additionally, I want to extend my gratitude to the staff involved in the ROSA project at Frydenhaug School for allowing me to conduct interviews. I am grateful for the valuable insights regarding your important work at Frydenhaug, which has helped me greatly in this thesis. Also, I am extremely grateful to the respondents on the questionnaire and the fact that you sacrificed some moments of your day to help me. I really appreciate it and your responses have contributed greatly to the evaluation of this thesis.

I am also thankful to my family for supporting me in all ways possible throughout the whole thesis and my life. I owe it all to you and without you, none of this would have been possible!

Moreover, there are so many people that deserve an honourable mention for their contribution to this thesis. First, a huge thanks to Melinda and Trui who have worked with me either at the library or remotely from Japan! You have truly helped me through the harder days! Also, I am so grateful to Lars, Melinda, Sondre, Simen, Trui, Liselotte, Afsah, Akvile, and my roommates for tolerating my rants, keeping me distracted, and inviting me to do fun activities with you. You guys have made this period lighter and fun and it is what has kept me sane!

I am also very grateful for the IN3140 gang! Thank you for all the motivation, cake and doughnuts, and last but not least, for carrying the course while I attempted to finish my thesis.

In additions, thank you to my robots, NAO and Misty, for being cute and cooperative! And a honourable mention to Taylor Swift, whose music has been on repeat throughout the entire last year and whose concert has kept me going.

Contents

1 Introduction 1

1.1 Motivation 2

1.2 Problem Statement and Objective 2

1.3 Main Contributions 3

1.4 Declaration of the Use of Generative AI 4

1.5 Thesis Structure 4

2 Literature Review 5

2.1 Social Robotics 5

2.2 Social Robots and Children with Autism 7

2.3 Platform Independent Robotics Software 9

2.4 Strategies for Robot Movement 11

2.4.1 Using Machine Learning for Teaching Robots How To Move . 11

2.4.2 Using Motion Capture Methods for Robot Control 13

2.5 Generalisation of Robot Movement 14

2.5.1 Anthropomorphic Robots 14

2.5.2 Non-anthropomorphic Robots 14

3 Methodology 17

3.1 The Philosophy of Research Methods 17

3.2 User-Centered Design 19

3.3 Research Design 19

3.3.1 Background and Closing Interviews 19

3.3.2 Questionnaire 20

3.4 Data Analysis of Interviews and Questionnaire 21

3.5 Robot Remote Control Development 21

3.6 Ethical Considerations 22

4 Contextual Understanding 23

4.1 The ROSA Project 23

4.2 Background Interviews with Personel at Frydenhaug 25

4.2.1 Participants and Recruitment 25

4.2.2 Interview Design 26

4.2.3 Data Collection from Background Interviews 26

4.2.4 Analysis of Interview Data 27

4.2.5 Ethical Considerations 28

4.2.6 Findings From the Background Interviews 28

5 Implementation 33

5.1 Relevant Robots 33

5.1.1 An Overview of NAO's Hardware and Software 34

5.1.2 An Overview of Misty's Hardware and Software 35

5.2 Initial Remote Control Implementation on NAO 36

5.3 Remote Control Implementation using ZTL 38

5.3.1 Description of ZTL 39

5.3.2 Application of ZTL in a Remote Control Implementation . . . 42

5.4 Collecting Motion Data from NAO 46

5.4.1 Obtaining Angles and Positions Using NAOqi 46

5.4.2 Using Video Analysis for Measuring Quality of Motion 46

5.5 Motion Translation Methods 49

5.5.1 Direct Mapping of NAO's Joint Angles 50

5.5.2 Motion Mapping Using End-effector Positions 52

5.5.3 Mapping Using Torso Positions 55

5.5.4 Implementation using Quantity of Motion 56

5.5.5 Combination: Direct Mapping and QoM 57

5.5.6 Details on Misty Programming 59

6 Evaluation 61

6.1 Closing Interview at Frydenhaug 61

6.1.1 Participants and Recruitment 61

6.1.2 Interview Design 62

6.1.3 Data Collection 63

6.1.4 Data Analysis 63
6.1.5 Ethical Measures During Closing Interview 63
6.2 Online Questionnaire to Evaluate Robot Movement 63
6.2.1 Questionnaire Design 64
6.2.2 Recruitment and Respondents 66
6.2.3 Analysis of Questionnaire Data 66
6.2.4 Ethical Measures for the Questionnaire 67
7 Results from the Implementation and Evaluations 69
7.1 Result of the Motion Translation Methods. 69
7.1.1 Graphs Presenting the Method Using Joint Angles 71
7.1.2 Graphs Showing the Method Using End-Effector Positions . . 71
7.1.3 Graphs Presenting the Method Using QoM 74
7.2 Evaluation of the Motions From the Questionnaire 74
7.2.1 RoSAS Scores 76
7.2.2 Ranking of Dances 77
7.2.3 Matching of Gestures 82
7.3 Evaluation Interview at Frydenhaug 83
8 Discussion 85
8.1 Advantages and Limitations of Motion Translation Methods 86
8.1.1 Personal Differences 86
8.1.2 Discussion of the Direct Mapping Method 86
8.1.3 Discussion of the QoM Method 88
8.1.4 Discussion of Direct Mapping with QoM 89
8.1.5 Key Factors in the Scoring Process. 90
8.2 Relevance for Children with ASD 91
8.3 Generalisability to New Robots 92
8.4 Biases in Data Collection and Analysis Methods 94
8.4.1 Evaluation of Interview Methods 94
8.4.2 Evaluation of Questionnaire Method 95
9 Conclusion 97
9.1 Future Work 98
Bibliography 111
Appendices 113

List of Figures

2.1 Structure of ROS communication between nodes.. 9

3.1 The user-centered design process based on ISO 9241-210:2019 [2] and inspired by Schulz et al. [90]. 22

4.1 The NAO robot that is used in the ROSA project. 24

4.2 Image from the interview with one of the participants. 27

5.1 Misty 34

5.2 Motor placement on NAO 35

5.3 Degrees of freedom of Misty's joints 36

5.4 A part of NAO's remote control, in Norwegian. The image shows the buttons for different behaviours, such as gestures or dances. The remote also has a text-to-speech box for giving the robot speech prompts. 37

5.5 Structure of the server-client communication in ZTL 41

5.6 ZTL system flow 43

5.7 ZTL configuration file 45

5.8 Example of a task description file showing the commands sent do the different robots. Misty's command consists of the translated behaviour from NAO. . . 45

5.9 NAO output YAML file 47

5.10 VideoAnalysis application 48

5.11 Original and interpolated values of the left arm during the robot dance for NAO and Misty respectively. 53

5.12 Movement of NAO's left arm in 3D space 54

5.13 Movement of NAO's torso 55

5.14 QoM values from the robot dance 57

5.15 Cumulative sum from the robot dance 58

6.1 Image from the evaluation interview with the two participants. 62

7.1 Part 1 of the sequence of the robot dance performed by Nao. 70
7.2 Part 2 of the sequence of the robot dance performed by Nao. 71
7.3 Sequence of the robot dance performed by Misty. Direct mapping, as explained in section 5.5.1, was used to mirror NAO's dance.. 72
7.4 Joint angles for NAO and Misty's joints during the robot dance.. 73
7.5 General direction and magnitude of movement of NAO's left arm and the mapped angles for Misty's head for the robot dance.. 75
7.6 Head angles for Misty during the robot dance 76
7.7 Average RoSAS scores for the NAO robot before (pink bars) and after (blue bars) watching gesture and dance videos. The standard deviation is shown through black error lines. 78
7.8 Average RoSAS scores for the Misty robot before (pink bars) and after (blue bars) watching gesture and dance videos. The standard deviation is shown through black error lines. 79
7.9 Box graph showing the median score and distribution of scores for each dance and method.. 80
7.10 Matrix showing the distribution of answers for the matching of gestures task. The numbers represent the gesture number for each of the robots and the colours represent the number of people choosing each pairing. The orange colors represents the pairing chosen by most participants. 83

1 Data retrieved from NAO for the standing-up motion 127

List of Tables

4.1 Overview of the participants in the interviews 26

5.1 Mapping between NAO and Misty for gestures 51

5.2 Mapping between NAO and Misty for dances 53

5.3 Mapping between NAO and Misty for their lower bodies 56

6.1 RoSAS dimensions and variables of interest in this thesis 65

7.1 Mean and standard deviation for RoSAS attributes for NAO before and after watching the motions 78

7.2 Mean and standard deviation for RoSAS attributes for Misty before and after watching the motions 79

7.3 Table showing the matching pairs chosen by the majority of the participants and the correct matching pairs. 83

List of Acronyms

ROS Ros Operating System

NR Norwegian Computing Center

ROSA Robot Supported Education for Children with ASD

SDK Software Development Kit

API Application Programming Interface

OS Operating System

QoM Quantity of Motion

ASD Autism Spectrum Disorder

RoSAS Robotic Social Attributes Scale

STD Standard Deviation

Chapter 1

Introduction

Robotics is an area that has intrigued researchers for a long time and has experienced significant advances over the years. Robots have been developed and researched for a multitude of purposes, to aid humans in physically demanding, dangerous, or repetitive tasks. Examples include the da Vinci robot used to perform teleoperated surgeries [60], robots used in industrial settings [40], or disaster handling [64]. The robots provide support and serve as tools, either through collaboration or independent work, in settings where they outperform or aid humans. In these cases, the robots are designed to provide physical, rather than mental and social, support.

Social robotics is one of the branches of robotics that has grown significantly in recent years, where social robots have been developed for uses such as therapy, elderly care, or education. Social robots, in comparison to the aforementioned robots, are designed to closely interact with humans and offer mental and social support [18]. Humans are highly social and emotional beings, which entails that social robots must be able to understand and react appropriately in the complex environments that humans live in. This has led to social robots being among the more advanced robots, exhibiting rich behavioural traits [18]. Because of this development, social robots have been applied to a multitude of different areas, such as therapy for children with autism or with various medical conditions, in providing companionship for elderly people, or in rehabilitation for adults [31]. The goal of social robotics is to use robots as additional resources, motivational factors, and emotional and social support, rather than replacing human interaction altogether.

An extensive area of research within social robotics has been the use of robots in therapy and education of children with autism. In these contexts, robots can act as a playmates, be used to create interesting and meaningful child-robot interactions, or teach and practice difficult skills [22]. Due to the benefits, research has primarily focused on creating different interactions with children with autism using a wide range of robots [48] and exploring the effects these interactions might elicit. However, areas such as the use of multiple social robots in the same context have received less emphasis. This might be a significant aspect because it would allow interchangeability between robots within the same context, as well as leveraging the different features that the robots might embody.

1.1 Motivation

In education and therapy settings, a specific robot is usually chosen based on its capabilities and the context in which it will be used. The robot usually runs a program that is tailored to its platform which entails that interchangability between robot platforms becomes challenging. In contexts where the use of multiple robots would be advantageous, the platform-dependability of robotic software creates a barrier and forces users to either bind themselves to one robot or extend their effort learning several robotic platforms. Considering aspects such as dramatic price ranges and capabilities, damage, and maintenance, it would be a great advantage to be able to switch between various robots while still maintaining the same basic functionality of a robot program. This highlights the need for a method of creating robot-independent solutions that simplifies the integration of new robots in a system.

This would result in the development of a structured and automatic way of integrating new robots into existing systems, facilitating execution on different robots without the developer having to implement the system from scratch. This is a relatively unexplored field, as limited studies have been dedicated to the integration of robots with different morphological features and capabilities into a common system. This is especially interesting in the context of children with autism. This is a vulnerable group with special requirements, which entails that the implication of adding new robots to their environment should be considered. Thus, it is compelling to explore the necessary considerations for a system used with children with autism, in which robots of varying capabilities are employed and interact with the same system.

The field of using social robots with vulnerable groups, especially children with special needs, is interesting to me. Social robots can in many cases provide support and entertainment in areas where humans cannot, potentially alleviating some of the challenges faced by the children. Moreover, because of the increased focus on integrating robotic tools into society over the last few years, it is also increasingly important to explore how interaction affects vulnerable groups, what the interaction consists of, and how it can be improved. To me, this fast-evolving and relevant field, with the potential to shape the course of our future, is very intriguing.

1.2 Problem Statement and Objective

The objective of this thesis is to explore the considerations needed to integrate a new robot into an existing remote control system used with children with autism in an educational setting. This includes factors such as communication, movement, and specialisation for children with autism. This thesis will address this objective through the following research questions (RQs):

> *RQ1:* **How can a common interface be used for the control of several robot platforms?** In robotics it is widely known that each robot has a separate platform, with its specialised API (Application Programming Interface), method of communication, unique hardware, and so on, which presents a challenge in interoperability between different robot platforms. Thus, a generalised interface is needed that operates independently of the robot platform and can provide overall control and communication for

different robots.

RQ2: **What strategies can be used to translate movements between robots with varying morphological features?** Usually, robot programs involve the control of a robot's behaviour. This can involve the control of movements, gestures, and dances. Integrating a new robot into a system therefore entails the replication of the original movement on the new robot in a more or less automatic way. This question addresses the development of such methods.

RQ2.1: **How can the motion of a robot effectively be described?** To integrate a new robot in an existing system more systematically and automatically, one would need to have an understanding of how the robot behaves such that its behaviours can be replicated on any new robot that is integrated into the system. It is important to find a way to effectively capture all significant aspects of the movements of the original robot so that they can be replicated by a new robot with respect to its capabilities.

RQ3: **What factors need to be considered in the integration of a new robot into a system used for children with autism?** Children with autism must typically navigate an educational context with different challenges and needs. Some of these include the need for consistency, clarity, and emotional and social support. When developing tools for a vulnerable group with special requirements, it is important to consider these needs to create a solution that is as tailored to them as possible and that covers their needs.

Answering these research questions will contribute to the objective of exploring the social considerations of integrating a new robot into a remote control system for children with autism, as well as the technical aspects of the integration.

1.3 Main Contributions

The contribution of this thesis lies in exploring different motion translation methods between robots with different body morphologies considering children with autism as the main users and testing ZTL, a framework for task dispatching and communication, in this context. To the best of my knowledge, the proposed system, based on ZTL and motion translation methods has not been explored in its entirety in previous research, nor has ZTL been thoroughly tested for this purpose. This work thus aims to investigate these topics and how they can be used in an educational context with children with autism.

This is an important research topic because it can allow for simpler integration of multiple new robots into existing systems without much effort and time spent by the developer. This can make it easier to leverage the benefits of multiple robots within the same system. This could also be an important step towards a more general system, favouring scalability and adaptability to new contexts.

1.4 Declaration of the Use of Generative AI

In this scientific work, generative artificial intelligence (AI) has been used. All data and personal information have been processed in accordance with the University of Oslo's regulations, and I, as the author of the document, take full responsibility for its content, claims, and references. An overview of the use of generative AI is provided below.

- The service ChatGPT-4, developed by OpenAI, has been used to improve the content of the report/assignment. It was used for translation between Norwegian and English, finding synonyms, and rephrasing some sentences. At most one or two sentences were rewritten by the AI at a time, and the text was not processed in its entirety at all.
- ChatGPT-4 was used for finding mistakes in the code and suggesting improvements, but not for generating any code.
- ChatGPT-4 was used to understand challenging studies by providing summaries and clarifications.
- ChatGPT-4, has been used for brainstorming ideas related to possible implementation methods and for discussing potential advantages and pitfalls. The model did not provide the implemented methods in their entirety, but potential approaches were discussed, entailing that ChatGPT-4 was used as a conversation partner.

Please note that for this thesis, AI has not been used to generate new data. This means that it was not used to produce any text or code, only for improvement and brainstorming purposes.

1.5 Thesis Structure

The structure of this thesis is organised into the following chapters:

Chapter 2 - Literature Review presents an overview of social robots and the previous work that has been done regarding mapping between robots with various morphologies, platform-independent software, and strategies for movement capture and generation.

Chapter 3 - Methodology outlines philosophical assumptions in research and briefly describes the research methods used in this thesis.

Chapter 4 - Contextual Understanding introduces the ROSA project, background interview, and initial findings.

Chapter 5 - Implementation describes the use of ZTL and motion translation methods between the robots in detail.

Chapter 6 - Evaluation outlines the research methods used for evaluating the implementation.

Chapter 7 - Results from the Implementation and Evaluation presents the results of the motion translation methods and the findings from the data collections.

Chapter 8 - Discussion discusses the results in light of the research questions.

Chapter 9 - Conclusion summarises this thesis.

Chapter 2

Literature Review

The intended use of the remote control system developed in this thesis is with children with autism in an educational context. It is, therefore, crucial to have an understanding of the needs and challenges of children with autism, when developing social robots for this particular vulnerable group. It is equally significant to have an overview of how social robots have previously been used with children with autism, particularly in terms of the capabilities of the developed robots and their interactions with the children, to better develop tools that can alleviate some of their challenges. This creates an understanding of what considerations need to be taken in the implementation to target the needs of children with autism.

These factors target the social and educational influence of the implementation of the system, however, several technical aspects need to be considered. When including a new robot in a remote system, the development of a common interface that can interact with various robots is needed, as well as a method for triggering behaviours on robots with different morphological features. This also covers how motion can be represented in a way that enables developers to easily replicate it across different robots. This chapter addresses the previous work that has been done within these areas, shedding light on their area of focus, challenges, and solutions.

Some studies have been dedicated to exploring each of these fields separately, but little research has focused on developing and testing a whole system similar to this thesis. Therefore, this chapter will highlight several interesting studies related to the themes addressed in this thesis, thereby providing context for the work that was conducted.

2.1 Social Robotics

Social robotics is a wide branch of robotics that addresses the use of robots designed for personal interactions with humans. These robots can be used in areas such as education, entertainment, or healthcare to engage with humans on a social, emotional, and cognitive level in the natural environment of humans. Such robots should communicate in a way that is easy and intuitive for humans to understand, for example through gestures, verbal language, or touch [18]. Due to the variability of their forms and communication methods, social robots can be used in a multitude of contexts.

Some social robots are designed with inspiration from the human body and are able to mimic human movement. An example is the WEBIAN-2 robot [69], whose objective is to provide support in the development of medical instruments for people with physical disabilities. With its humanoid body, it plays the role of human test subjects and aids engineers in the development of tools. Another example is the ASIMO robot, which is another humanoid robot equipped with modern sensor systems for sensing its environment that closely resembles the human sensory system [85]. Its purpose was to work in indoor settings, such as working in receptions. These types of robots are designed to mimic human movement, and they excel in communicating via body language in a way that stimulates intuitive understanding. However, many humanoid robots do not have expressive and humanlike faces and thus are not able to communicate using facial expressions. Considerable effort has been put into creating robots with human features that can express and communicate via emotions, such as Kismet [17], who can express feelings, desires, and intents through verbal language and facial expressions, or the android robot ROMAN [15]. These robots were used in research to gain a deeper understanding of the social interaction between humans and robots.

The aforementioned robots typically serve practical and serviceable roles in society, and they possess traits that are advantageous for their purposes. However, some social robots, many of them soft or zoomorphic, have been developed for entertainment purposes only. AIBO [37], for example, is a dog-like social robot that simulates the experience and benefits of having a pet, but without the disadvantages. It was reported that the robot showed positive interactions in terms of health, communication, and emotional support. Another example is Paro, which is a soft animal-like robot used in therapy settings for both children and adults [58]. The use of this robot has shown some positive effects in terms of for instance social interactions, reduced loneliness, and reduced symptoms of dementia.

This shows that social robots have been developed for a multitude of different settings, with the main objective of interacting with humans. Their design and capabilities are highly dependent on their area of use, but a common aspect is that their purpose is to provide support in some aspect of everyday life. Today, a widespread application of social robots is in the education of children. Important benefits of using robots instead of other technological tools for learning have been found, such as improved learning outcomes and increased social behaviours that enhance learning [13]. Belpaeme et al. highlighted also that robots are physical entities that are more exciting and engaging, and therefore are more prone to elicit favourable behaviours from children. Moreover, the need for robots in education stems from several aspects, such as the fact that a robot can play multiple roles in the classroom, that there is an increased number of students per teacher and a high number of children with special learning and social needs. Taking these aspects into consideration, social robots are ideal companions in education to increase the learning experience for children.

For instance, numerous previous studies have been dedicated to investigating the benefits of using social robots for language learning. One study explored the motivation, engagement, and learning outcomes of using social robots for educational purposes [55]. The researchers found that a substantial number of studies report that generally, children are interested in robots and are motivated to learn with them, at least in the early stages of language learning. This study also concludes with the benefits of using a robot as an additional tool in learning to add an element to the learning, a role that the teachers alone cannot complete. Although, the robot alone cannot act as a replacement for human teachers either. Other studies also report the use of robots opens up the possibility of creating an interesting and engaging learning scenario together with the teacher and allowing the teacher to focus more on the individual children [27]. Lastly, robots are also able to provide personalized content to children and help develop self-regulated learning (SRL) skills, which include skills such as goal setting and self-assessment [53]. This is significant as there is evidence to support that there is a connection between SRL skills and a person's academic performance [53]. The presented studies indicate that children in general respond well to robots and that there are observed positive effects of using robots in the classroom, promoting further research on the use of social robots in an educational context.

2.2 Social Robots and Children with Autism

An area within social robotics that has received significant attention is the use of robots in education with children with autism. Autism is a developmental disorder that is characterised by challenges with social interaction, communication and language, and intense interests [63]. Although autism is a spectrum and children can experience a variety of challenges, common issues include understanding other people's perspectives, empathy, and interpreting social contexts and norms, which can lead to difficulties in developing relationships with peers [51]. In addition, children with ASD may also lack language skills, which entails not being able to communicate effectively, having no desire to communicate, or lacking the desire to use nonverbal communication methods such as gesturing or body language. These aspects can create social and educational barriers for children, and for this reason, a lot of research has been dedicated to the use of robots with children to aid them in navigating these challenges.

Several studies have shown the positive potential of using robots in therapy settings with children with autism, and have observed results that are significant and applicable to educational purposes too. In a study, the attention, imitation, and repetitive and stereotyped behaviours of children with ASD when interacting with a social assistive robot, QTrobot, were observed [32]. The purpose of the study was to compare interactions between the children and a robot versus a person, and the researchers found that the children paid more attention to the robot and engaged in less stereotypical and repetitive behaviours when interacting with the robot in comparison to the person. These results can be important in a school setting because they allow us to recognize the potential benefits of using social robots with children with ASD to enhance the learning environment and focus.

In another study, interactions between a Pleo robot dinosaur, children with autism, and adults were researched, and it was shown that children are more willing to speak more in general and communicate more with an adult when the robot is present [56]. Other researchers investigated the effect of the KASPAR robot on the interaction between children with autism who prefer to be isolated from others and adults [81]. This case study involving children with low-functioning autism showed that the children seemed to interact physically with the robot and with others present, as well as to some level include others in the interaction with the robot. This shows how a social robot can be used to encourage the social behaviours of children with autism to others around them.

These results can be significant in a school context, as the robots play different roles in the interaction and can be used as social mediators to elicit communication and social interactions between the children and interaction partners.

Children with autism also often have difficulties with joint attention and imitation [87]. Duquette et al. found that children who interacted with the Tito robot displayed more signs of joint attention and imitation towards the robot than towards a human [33]. A different study used a small robotic toy with children with autism and found that the children engaged in imitation of the robot, as well as initiated social interactions with their educators [82]. These findings support the notion that social robots of various forms can aid children with autism in engaging in common behaviours during social interactions.

Moreover, Alemi et al. investigated the effect of using the NAO robot to teach English to Iranian children with ASD [4]. The children were given tests throughout the learning period and the results showed that the children's knowledge of English had improved over time, and even managed to retain the knowledge after the learning period ended. NAO was also used as a teacher assistant to teach children with high-functioning autism the fundamentals of music [96]. The researchers found that the robot was successful in teaching the children with autism about music, the children improved their social and cognitive skills from the interaction, and the robot provided increased motivation to participate in the education. These studies reveal that social robots have the potential to increase motivation and eagerness to participate in learning, and thus can be important learning tools for children with autism.

A review of studies involving children with autism summarised the positive effects of social robots, where it was shown that children in all studies focused on the robot and had less stereotypical and repetitive behaviours when interacting with a robot [71]. Several studies also showed improved social behaviour, imitation, and language. These studies also indicate the potential of social robots aiding with motivation, engagement in social situations, communication, and less repetitive behaviours. These are important factors in an educational setting, and therefore social robots can aid in fostering a more stimulating and focused learning environment for children with autism.

This section has outlined the use of social robots in educational settings with children with autism, and the positive effects on children have been documented through numerous studies. However, to fully take advantage of the potential of social robots in education, it is important to address the relevant technical aspects that further improving and expanding robot software for children with autism entails. One of the aspects that potentially can improve the educational experience is the integration of multiple robots, as previously discussed. This consideration can imply the implementation of robot-independent software that allows for controlling multiple robots, generalisation of movement commands sent to the robots, and methods for animating the robots. The next sections will give an overview of studies that have addressed some of these challenges, and the technical findings and methods of the studies will be discussed concerning the aim of this thesis.

2.3 Platform Independent Robotics Software

Traditionally, most robotic applications are tied to specific robots and are developed based on a robot's hardware and software specifications [19]. This makes applications usually not reusable in other contexts and thus requires reimplementation to fit in other scenarios. An example of this phenomenon is the fact that many commercial robots, like NAO [75], Misty [100], Vector by Digital Dream Labs [92], or Lego Mindstorms [45] all have separate platforms that are tailored to the hardware and software specifications of the robots. This entails that whenever developers are working with a new robot, they must spend time understanding all aspects of its API, including aspects such as communication or how behaviours are created. The robot platforms might differ greatly, so it requires some effort for the developer to understand their different usages when developing behaviours, and this can create barriers when switching between robot platforms. The robots are often also running different operating systems, and have different communication protocols, and software, which entails that programs written for one robot are not easily transferrable to another robot [44].

Therefore, an important area of focus has been developing standardised robotics software that can bridge the gap and generalise the workflow between the different robotics platforms. One of the most significant frameworks has been the Robot Operating System (ROS), which more and more robots nowadays support. ROS is an open-source framework designed to provide a more general and flexible approach to the development of robot-independent systems [78]. ROS was built to be a network consisting of modules that can communicate together, where its main components are topics, services, messages, and nodes. Nodes are modules that perform a specific task, and a ROS-based system typically consists of many nodes. The nodes can communicate using messages published and received on topics, where the topics act as communication channels for specific purposes. Figure 2.1 shows how the nodes communicate. Developers can therefore create nodes for performing actions, such as driving or capturing sensor information, and set up communication based on topics and services by following the same principles and rules for any robot that supports ROS.

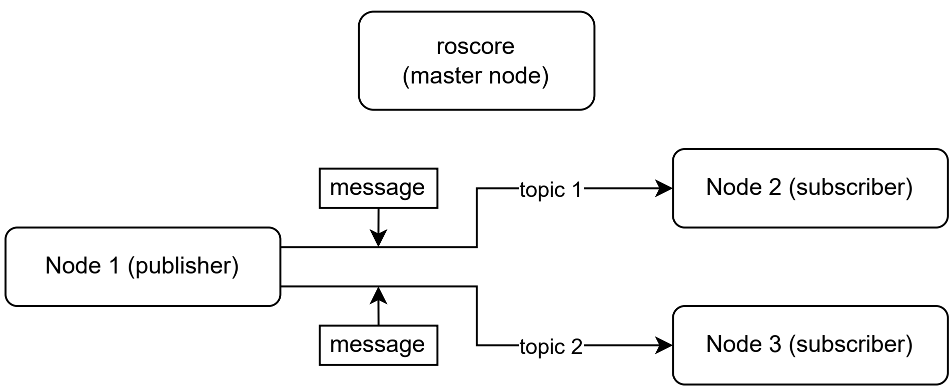


Figure 2.1: Structure of ROS communication between nodes.

Because of the standardised way of communicating within the ROS framework, it simplifies the workflow with different robot platforms and lowers the barrier to working with different robot platforms. This framework also allows for easier integration of several robots into a system, because they all rely on the same communication protocols and development of behaviours. These are some of the advantages that have led ROS to be a widespread framework for robotics development that many robots support. For instance, even though NAO, Pepper, and QTRobot have their software stacks, they also have ROS support, which allows them to be controlled through the ROS framework. Other examples are QTRobot by LuxAi and TIAGo by PAL Robotics which do not have their separate software stacks but rely solely on ROS.

Within the context of this thesis, the system on which this thesis is based was already implemented using NAO's API, in addition to the Misty robot not offering ROS support. This would require both adaptation of the application itself within the ROS framework, as well as creating a ROS bridge for Misty. That is because robots that do not support ROS would require a ROS bridge that relates the original communication method of the robot to the ROS framework. This is a daunting and time-consuming task itself, as it requires an in-depth understanding of both the robot API and the ROS framework, as well as the effort to connect the two. For this reason, a ROS implementation was not feasible for the scope of this thesis.

A similar idea is the OROCOS (Open Robot Control Software) project, where the objective was to address the lack of interoperability between robotic platforms [20]. The researchers aimed at developing platform- and computer-independent software libraries and a configurable environment where robots can be simulated and controlled in real time. The goal of the project was to create a framework based on modularity and flexibility that consists of stand-alone robotic components and other supporting modules for various tasks. These are tools that developers can use to build a system tailored to their requirements. In contrast to ROS (ROS1), OROCOS supports real-time motion control [21], making it suitable for more sophisticated scenarios that require precise robot control in real-time, but both frameworks target robot independence and modularity.

A more advanced system is RAPP (Robotic Applications for Delivering Smart User Empowering Applications), which provides a comprehensive API that the developers can use to create robot applications for a variety of robots [76]. This framework has a middleware stack that is compatible with different robots and allows developers to easily access their sensors and actuators, as well as create platform-independent applications. The RAPP framework has a complex architecture, but one of the main contributions is the division of the system into a RAPP platform that runs in the cloud and a robot platform that runs on the robot itself, as well as the API which is the connection between all units of the system. RAPP also leverages the benefits of ROS and thus provides another level of abstraction on top of the robot's functions, in addition to facilitating connection and execution to non-ROS robots through other services. In comparison to the aforementioned frameworks, RAPP is a more comprehensive system suitable for creating advanced robot applications.

The concept of platform-independent software offers several advantages. Firstly, it eliminates restrictions on specific robots, enables interchangeability between robotic platforms, and allows for the exploitation of the capabilities of different robots for various applications. For this reason, it offers greater flexibility and enables developers to create a system adapted to specific requirements, in addition to standardisation and platform independence. Developers can leverage this framework to develop an application capable of operating across different robotic platforms, as the robots receive, interpret, and execute commands within a shared framework regardless of specific robot capabilities. This is a great advantage when the relevant robots offer support for the same framework, but it becomes a problem when a robot platform does not.

Furthermore, even though both OROCOS and RAPP promote the development of platform-independent robot applications, they are complex systems that are suitable for complex applications. Thus, both demand considerable effort to comprehend and incorporate from the developers' side. In addition, in cases where a working setup already exists, as in this thesis, additional work is required to either integrate these frameworks into the existing system or implement the system from scratch. The system on which this thesis is based is quite simple in nature, and using these frameworks would add unnecessary complexity. The advantages could have been to leverage the frameworks to develop robot-independent behaviours, but one must balance the complexity and effort with the advantages using such a framework gives.

Although the mentioned frameworks are advantageous for many applications, there are still cases, as here, where integrating the system to use one of these frameworks would require more effort, which would outweigh the benefits. Therefore, in this thesis, the focus will remain on leveraging the robot's APIs and relying somewhat more on the developer to create a behaviour for the added robots based on their capabilities.

2.4 Strategies for Robot Movement

When working with robots, a fundamental question is how to enable their movement. Naturally, one approach involves direct programming using own creative insights or hardcoding, while more systematic approaches involve using techniques such as machine learning and human imitation. Examining previous work can provide a useful context regarding how robots can be animated automatically, without the need for manual programming of movements. This section addresses how robot motion can be captured for replication and how machine learning and motion capture methods can be used for creating robot motions.

2.4.1 Using Machine Learning for Teaching Robots How To Move

As we are well within the artificial intelligence era, machine learning is becoming a promising way of programming robots, as it allows them to both learn from experience and imitation, as well as to adapt to the environment, without much intervention from humans. This is an evolving and promising field, but research has shown that it comes with a great set of challenges.

Studies in robotics have traditionally focused on using machine learning, especially reinforcement learning, for tasks like walking, grasping, or manipulation tasks, where a vast number of the studies have been done in simulation. In recent years, simulation tools have become better at representing the real world, but there still exists a reality gap between simulation and reality as we cannot always represent the complex dynamics of a robot in an environment correctly in simulation [46]. The reality gap implies that there is a discrepancy in the robot behaviour between simulation and real life, due to the aspects of reality that cannot be modelled in the simulation. However, reinforcement learning has shown great promise in robotics learning for tasks where rewards and policies can be clearly defined and learned.

For example, there have been studies that have focused on using machine learning for tasks like grasping, manipulation, or locomotion with physical manipulators. Kleeberger et al. [57] did a review of machine learning techniques used for grasping and manipulation, and found that methods such as model-based approaches or reinforcement learning have shown promising results for these tasks. Furthermore, Manschitz et al. [59] used imitation learning and classifiers to teach a robot how to unscrew a lightbulb, and their method proved to be successful in this application. Lastly, Tan et al. [97] taught a quadruped robot to walk leveraging deep reinforcement learning. Manipulation, grasping, and walking are seemingly simple tasks for humans, but quite complex in the robotic world. Machine learning indicates success in controlling physical robots, however, their algorithms are tailored and optimised for specific tasks.

An interesting strategy has been to use meta-learning for teaching robots that can perform a variety of different tasks, instead of robots that specialize in a specific task like grasping. Finn et al. [35] suggested an approach based on meta-learning to teach a robot to perform various tasks from one observation only, which implies a human operator showing the robot how to perform a task and the robot using its learning period to imitate the motion. This would allow a robot to essentially learn how to learn from a dataset of various tasks, and thus be able to perform a new task by observing a demonstration.

Meta-learning thus allows for the creation of more general learning algorithms, where a robot can learn to perform a variety of tasks, instead of specialising in one area. This poses as an interesting solution to the problem addressed in this thesis since it presents the opportunity to teach the robot motion through various dances and gestures in the learning period and then provide it with a demonstration of the motion to imitate performed by another robot. Thus, a robot could potentially learn to move from different robots and in a multitude of ways, all according to its constraints. This is a challenging notion, though, as it involves complex tasks such as obtaining a diverse enough dataset for demonstration and attempting to generalise the algorithm to work for different robot morphologies. Another limitation is the fact that this should work on humanoid robots as well. Humanoid robots often have complex dynamics, which makes using machine learning especially challenging.

However, some work has been done involving humanoid robots too. For instance, Muzio et al. [65] used deep reinforcement learning to teach humanoid robot skills required in football by using a policy for learning to control an already-existing model for walking instead of learning joint commands. In a simulation, one of the tested algorithms showed learned the intended behaviour, however, the researchers mention that transferring the experience of the agent to a physical robot is a great challenge due to the complex dynamics of a humanoid robot. Despite this challenge, reinforcement learning with decision trees was successfully used to teach a NAO robot to do penalty kicks in football [42]. Although the examples are fewer, some researchers have reported success in using machine learning approaches for humanoid robots.

In the context of this thesis, machine learning could be an interesting approach, as it would allow for teaching robots to move based on their specific constraints. For instance, reinforcement learning would remove the need for a relevant dataset, and create the opportunity for the robot to learn by experience how to best imitate another. However, up to now, such approaches have been applied to problems where the goals and rewards are clear and quantifiable, such as grasping, walking, or even playing football. In this thesis, however, the focus is on movement such as gestures or dances where success cannot be as clearly determined. This is especially because the goal is not to achieve a perfect replication of the original movement, and this makes it hard to define what a successful imitation is quantitatively. Thus, even though machine learning could be an intriguing approach for this purpose, it comes with complex challenges that are out of the scope and time frame of this thesis.

2.4.2 Using Motion Capture Methods for Robot Control

Some research has focused on capturing human motion using motion capture methods and transferring the motion onto the body of a robot. This direct transfer of motion is a challenge because the body of a human and a robot have different structures and physical properties [66]. Nevertheless, it poses an interesting approach to describing motion with the purpose of replication. In this section, some relevant studies are outlined to set the context around the tracking of motion of robots.

Stanton et al. [93] devised a method where they used a neural network for each of NAO's joints and particle swarm optimisation to learn a mapping between human motion captured with a motion capture system and NAO's body. The mapping proves to be successful and indicates that this is a great way for the teleoperation of robots. Another method consists of capturing human movement using a motion capture system and converting this data into joint trajectories of the robot, where motion primitives are extracted from the data and adapted to the robot's joints and constraints [66]. In a third study, the researchers used motion capture and applied constraints to the degrees of freedom as well as applying limits to the joint angles and joint velocities of human motion to match the constraints of the robot's joints [74].

These studies suggest different techniques for using motion capture data of human movements and translating it to the motion of a humanoid robot. The idea is intriguing as it makes it possible for a robot to imitate human motion. While most methods have focused on capturing human motion, it could be possible to record a robot's motion using a motion capture system. This approach would entail placing markers in appropriate places on the robot's body and recording the trajectory of the markers in space. Calculations based on this data can be performed, for instance through joint angles. This allows for effectively recording robot motion and reflects a viable method. However, in this thesis, the robots are accessible and it is possible to obtain joint data directly from the robot without external measurements.

Furthermore, while the transfer of motion remains a challenge, the presented studies use robots that have fairly similar morphology to humans, making the exact mapping between the human and robot more intuitive. In this particular setting, however, the bodies we are transferring the motion between are quite dissimilar, making direct transfer of motion methods difficult to apply.

2.5 Generalisation of Robot Movement

2.5.1 Anthropomorphic Robots

Other studies have attacked the human imitation problem and focused on avoiding using motion capture to map data directly to a robot. Van de Perre et al. [72] claim that the mappings are highly dependable on the robot configuration and that can make it difficult to perform the mapping on robots with various morphologies. Van de Perre et al. aimed to find a method for creating gestures that are independent of robot configuration, to ease the workload needed when transferring the motion to new robots. In this study, the authors chose to divide the gesture into two modes: *block mode*, where the overall focus of the robot is the whole arm, and an *end-effector mode*, where the gesture is dependent on the end-effector, a distinction that is important to create as humanlike gestures as possible. *Block mode* works for robots which have similar body blocks as a human body because the joints of the robot are grouped into blocks similar to a model of the human body. Furthermore, the joint angles needed to do a certain gesture were calculated using the Denavit-Hartenberg (DH) parameters to describe the chosen robot's configuration. The textitend-effector mode uses the Cartesian coordinates of the desired end-effector position for the desired gesture and uses trajectory planning and inverse kinematics to reach this position. For both modes, the principal point is that the mapping between the robot configuration and the method itself is done at execution time, only when the type of robot has been specified. This method showed promising results on different robots in simulation in terms of the mapping of gestures.

These methods were applied in a real-world scenario, where it was found that the behaviours done by the robot are comparable to when it is controlled manually by a therapist [24]. This shows that the proposed generic gesture system can generate motions that are just as clear as when controlled by a human operator, and this indicates the success of the method in this context. The researchers also argue that this method is applicable for robots with simpler or more complex upper body morphologies, involving more or less degrees of freedom than the model, due to the addition of virtual joints or elimination of joints.

This might be useful for mirroring robots with different upper body morphologies, however, some robots differ greatly in morphology. Therefore, it is not given that the robots will be able to capture the model movement with the mapping suggested here, as it is targeted to robots with comparable morphology to a human. This can cause problems and inconsistencies for mappings between very different robots.

2.5.2 Non-anthropomorphic Robots

Furthermore, studies have traditionally focused more on imitation and mapping between humans and robots, such that humans teach the robot how to move by doing the movements themselves. In the previously discussed studies, the proposed methods were based on the robots sharing some similarities to humans, and in such cases, the task of mapping motion between humans and between robots can be solved by performing a direct mapping on some level. However, direct mapping for non-anthropomorphic robots is not necessarily possible, so alternative ways have been devised.

Some of the work that has been done is by Alissandrakis et al., who sought to address the correspondence problem, which is the problem of creating mappings between dissimilar bodies in an imitation task [6]. They suggest a mathematical approach using simple kinematic models of the bodies and correspondence matrices. The matrices denote the influence of each joint of the model body on the imitator body, which allows for creating mappings between the degrees of freedom, either using one-to-one, many-to-one, or one-to-many types of mapping. The matrices include weights that determine the relationship between the human and the imitator. The matrices are task-dependent and lead to the human and imitator doing equivalent motions within their body morphologies.

Furthermore, some general imitation frameworks have been created, such as ALICE [5] and JABBERWOCKY [7]. In the ALICE framework, the idea is to allow the robots to imitate and learn from demonstrations by building a library of action correspondences while observing the demonstrator, which is a library of learned behaviours it has observed. The imitator uses the library to transform the actions of the demonstrator into actions of the imitator and takes its embodiment and constraints into account. The JABBERWOCKY framework, on the other hand, focuses on understanding the actions and results of human movement and creates a library of what it has learned using different metrics/rules based on the situation so it can adapt its learning for different contexts. This library contains instructions for the robot to achieve similar effects performed by the demonstrator and is used at run-time when the robot needs to imitate. This highlights possible approaches to the mapping between humans and robots across dissimilar and provides a structured framework for doing so.

Defining a mapping between joints between two bodies is an interesting approach because it allows a developer to define appropriate mappings in the correspondence matrices based on their context and the bodies they are working with. The work in this thesis is inspired by this approach, but it is based on a simplified and less mathematical approach. This method also takes joint limits into account, in contrast to the original method. An alternative simpler approach was chosen, where mappings are defined textually, instead of in weighted matrices, and joint limits are taken into account.

Furthermore, when using robots that resemble the human body, we are capable of identifying the intent behind the motion despite the bodies being different. As we have seen earlier, the methods for creating generic gestures seem to create good and understandable gestures However, the question is whether motions will be recognisable when they are performed by a non-anthropomorphic robot. Interestingly enough, some researchers have used various methods of animating non-anthropomorphic robots and shown that the motions are recognisable by humans. This serves as evidence that the robot's body does not need to be similar to a human's to be understandable.

For example, Laban notation is a notation system for describing human movement, and it was proven to be a successful way of mapping human movement to robot movement [47]. The idea is that the Laban notation is independent of the robot platform so that any robot can use one observation module based on the notation and have robot-specific task-mapping modules based on the body morphology of the robot. A study captured ballet performances of different characters using Laban notation and used the Laban notation to translate the movements to two vastly different robots: a Bebop drone and the humanoid robot NAO [10]. The Laban notation of the dances was modified to fit the range of motion and degrees of freedom for the different robots. Since the drone and the robot are very different, two different techniques were used to do the motions on them. For the NAO robot, the focus was to apply the Laban Movement Analysis (LMA) concepts of the performances and not strictly copy the human movement to NAO, while for the drone, only some LMA concepts could be used and only velocity and position of the drone was manipulated to recreate the performance. The unprofessional participants reported a good representation of the performances of both the robot and the drone, which shows that the transfer of motion to the drone could be understood.

These studies suggest that people generally can draw meaning from the robot's motion despite their non-human morphologies. This also underlines the possibility of using a wider range of social robots that can express the same message through their unique capabilities and be understood by the people whom they are interacting with, which is not a unique ability of humanoid robots. This implies that within the scope of this thesis, various types of robot models can be used for the same purpose, indicating the potential for these robots to effectively communicate the same message despite their individual capabilities.

This related work section has outlined some of the previous work done in the context of this thesis, especially in areas involving standardised robotics software, describing and generalisation of motion, and methods of animating robots. These are components that require consideration to integrate a new robot into an existing remote control and thus are the areas of interest. In previous studies, researchers usually have focused on one of these areas in isolation and found promising solutions, as presented earlier. Some of the proposed studies have disadvantages that make them unsuitable for use in this thesis. For instance, frameworks such as ROS, OROCOS, and RAPP are quite complex systems and would require great effort in understanding and integrating with the initial implementation, and for this reason, are out of the scope of this thesis. Another part of this thesis addresses how this remote control can send motion commands to robots with different capabilities. In this area, researchers have attempted to use machine learning, but it is a challenging task for humanoid robots. Motion capture Laban notation and various other mapping techniques have also been used to capture human motion and map it onto robots of different morphologies. This has indicated success for both anthropomorphic and non-anthropomorphic robots, but relatively little work has been done on the latter. As previously described, inspiration was drawn from some of the proposed methods.

These studies have focused on specific areas of research and created interesting methods for solving a certain problem, however, few of the studies have addressed real-life contexts. This thesis, in addition to creating a robot-independent remote controller, addresses the use of this system in an educational context with children with autism and sheds light on the implementation considerations needed to be taken for a system used in this context. Before the details of the implementation are presented, the user requirements are addressed, following the user-centered design process.

Chapter 3

Methodology

Until now, the focus has been on how researchers previously have solved the problems of translation of motion between different robots, and how they have collected data from robots and programmed their motions. However, before implementing a system intended for users, it is important to understand the context of the system and the user requirements. In the development of technology systems, it is important to include the end user to create the best product, and often, the failure of such systems comes from the lack of inclusion of the user in the development and implementation phases [95]. The user-centred design principles define four phases of software development that ensure the inclusion of users in each step.

This thesis followed the user-centred design process, where background interviews were conducted, a prototype of a remote control was implemented, and the system was evaluated by its users. This has ensured that the implementation is consistent with the user's expectations and requirements. A mixed-methods approach was employed to both get an in-depth understanding of the context and the initial requirements of the staff at Frydenhaug and the children through the use of interviews. A questionnaire was also used to collect both numerical and textual data indicating the success of the implementation.

This chapter presents the relevant research methods for conducting this thesis. It starts with viewing the philosophical assumption which this thesis is based on, and then outlining the research methods of the data collection and system development used in this thesis.

3.1 The Philosophy of Research Methods

Three different basic research paradigms on which researchers usually base their work upon [79] exist. A principal factor within research paradigms is a researcher's view of reality and how knowledge about reality is obtained. This is important to understand to fully understand and validate a piece of research. The research paradigms presented are positivism, interpretivism, and critical theory.

Positivism and interpretivism are the relevant paradigms in natural sciences, while critical theory is most often employed within social sciences. Critical theory, as Rehman et al. explain, entails that reality is influenced by various factors, such as culture, religion, or politics. The heart of critical theory is to instigate change in society and researchers encourage critical thinking about structures in our society and the knowledge shared by the leaders [79]. Qualitative data in the form of dialogues or interviews are employed, to alter reality.

Positivism, on the other hand, entails that reality exists independently of humans, and that we have no influence over it. This allows for accurately studying reality independently of the researcher, context, and time. This entails that reality is not changing and will always yield the same result to the same phenomena regardless, the reason why quantitative research is a part of this paradigm. Researchers adopting a positivist outlook will strive to create controlled experiments where variables can be detached and cause-and-effect can be studied, using research methods such as questionnaires to collect numeric data [79]. This thesis employs some of the methods within positivist research, as questionnaires are used as a research method. The purpose of the questionnaires is to gain insight into the opinions of people on the different methods used to generate motion for the robot. The participants are presented with different videos showing the movements of two robots, acting as the controlled variable, and the dependent variable being the ratings within different scales on the questionnaire. This method will provide insight into how the different movements affect the ratings and will enable us to get numeric values that describe this relationship.

The last paradigm, interpretivism, says that multiple realities exist and that they are constructed instead of existing independently of us. This entails that we bring meaning and interpretation to research so that the realities are affected by how they are observed by different people, as Rehman et al. state. The point is therefore to understand the interpretations of reality of different people instead of aiming to discover an absolute truth. For this reason, researchers employing the interpretive approach seek to use research methods such as interviews and observations to collect people's interpretation of reality and observe a phenomenon in a set context [79]. This thesis also relies upon the interpretivistic approach, as it uses qualitative research methods in the form of interviews. Interviews of different structures are used to gain an understanding of the context of my thesis, namely to understand how social robots are used in education with children with autism and how a robot toolbox can be created to fit the needs of its users in this context.

Rehman et al. [79] conclude that when conducting research, it is important to choose the research methods one sees fit for the phenomena that are researched, even if it is a combination of different methods. Therefore, the research in this thesis follows a mixed-methods approach. Qualitative methods are employed in the form of interviews for an initial understanding of the context and the requirements for a robot prototype in this setting, as well as for a general evaluation of the prototype. Quantitative methods provide a more detailed evaluation of the implementation. These research methods contribute to an overall understanding of the reality where this prototype would be used, by involving people directly interacting with it, in addition to acquiring numeric data indicating how well the implementation worked. The use of these research methods will be explained in more in-depth in the following sections.

3.2 User-Centered Design

In the development of any software tool, it is important to include its end-users in the design process. This is important because, ultimately, it is the users that will interact with the system and if it does not meet the standards and needs of the users, the system becomes frustrating to use and useless. User-centred design is a software design methodology for developers that aids in creating software solutions that are better suited to the requirements of the end-users [94]. It is concerned with including the end-users in the development of technological tools and letting the end-users influence how the tool is formed, a practice that has been shown to lead to more usable software tools [3]. The way and when the user is included in the design of a system can vary, but the developers must receive feedback so that they can continuously improve the systems, as developers cannot imagine all the features that are important for a system's users.

The users can be included at different stages in the process through different means, such as interviews. Developers can conduct background interviews early in the process which entail gaining information about the needs and expectations of the users and interviews in the final stages to find out to what extent these expectations are met [3]. The advantages of following the user-centred design principles are that it ensures the usability of the system from the users' side [94], as well as developing a system that is as suitable as it can be for the context in which it will be used [3]. However, involving users can be quite costly, it can prolong the development process, and require the involvement of other parties as well [3].

In this thesis, an existing robot remote control system used by school personnel with children with autism was further improved by adding a new robot. The involvement of these users in the improvement of the system is crucial because provides insights into the requirements and expectations of the school personnel who will interact first-hand with the remote. In addition, they can provide insights into how to shape the remote and robot behaviours to best benefit children with autism. With the user-centred design principles in mind, background interviews will be performed before the implementation with school personnel who have experience with the robot remote control. Closing interviews with the school personnel will also be performed, in addition to a questionnaire, to evaluate the implemented system.

3.3 Research Design

To be able to gather in-depth information about the context of this thesis, as well as to evaluate the results of the remote control implementation concerning its users, both qualitative and quantitative methods were employed. By following the user-centred design principle, the research design of this thesis will help in developing a prototype that best suits the needs of its users.

3.3.1 Background and Closing Interviews

On one hand, qualitative research is occupied by understanding the social world through the eyes of the participants, which is an interpretive approach [12]. This entails that data about a phenomenon is gathered from the participant's subjective point of view about their interpretation of said phenomenon, for example through an interview. Interviews have the advantage that they can provide a deeper insight into the context of this thesis and the use of this implementation with the actual user group, as well as it can allow for probing respondents to elaborate [12]. Semi-structured interviews are one of the most common interview types in qualitative research, where an interview guide with questions that cover the desired area of research is created. This entails forming a set of questions that define a loose structure for the interview while allowing the researcher to stray away from the original plan to follow up on the participant's responses. Thus, semi-structured interviews offer the advantage of flexibility, allowing for exploring interesting topics that might arise. Another benefit is that the interview type is suitable for cases where existing research has been done in the field to some degree, as this allows for shaping of specific and covering interview questions [54].

Using semi-structured interviews is, therefore, suitable for this thesis, where studies have already been conducted within the ROSA project, allowing for shaping the questions of these interviews with a base in the previous work. It also allows for gathering in-depth information about the context in which the prototype developed in this thesis will be implemented, and allows for letting the interviewee's responses guide the conversation through interesting themes. This is also suitable for the closing interviews, where the purpose is to let the participants explore the implementation in a less structured manner.

3.3.2 Questionnaire

On the other hand, quantitative research is a positivist approach, where a phenomenon exists despite its observers and its measurements can be quantified through numerical data. In quantitative research, one is preoccupied with the measurement of phenomena and the relationships between them [12]. This entails that some phenomena should be observed (an independent variable) and another phenomenon that is dependent on the first (a dependent variable), which we want to measure. This gives numeric values that indicate the nature of the relationship.

A questionnaire is a data collection method that fits both quantitative, but also qualitative research. Its advantage is that it allows for collecting a large amount of data quickly, simply and conveniently for the respondents [12]. The questionnaire used a mixed-methods approach, where both qualitative and quantitative data were collected. This makes it possible to both measure the relationship between two variables, as well as further question the participants for their thought processes. This results in a comprehensive view of the phenomena that are studied, since it includes both numerical relationships that can be analysed, but also reflections that can aid in decoding possible reasons behind these relationships.

In this thesis, questionnaires were a helpful medium to gain insight into how a wider population perceive the robots and the movements that arise from their implementation. This enabled the possibility for both discovering whether the robot behaviours influence people's perception, in terms of numerical values, as well as a textual evaluation of the implementation.

3.4 Data Analysis of Interviews and Questionnaire

Choosing the correct data collection method is crucial to collecting meaningful data that can uncover a phenomenon reliably and validly. However, analysing data is of equal importance, because analysis provides meaning to the data [61]. Because of the differences in the structures of the data for quantitative and qualitative research, these methods employ different data analysis methods.

A popular way of analysing qualitative data is to use thematic analysis. Thematic analysis entails identifying theme patterns in the data through a six-step process [16]. Braun and Clarke note that a theme in this context counts as a piece of information from the participants that holds meaning in relation to the research questions. Some of the important steps in identifying these themes involve creating shortcodes that summarise the data and using these to identify the occurring themes in the data, creating and refining a thematic map based on both the data set and each piece of data, and using these themes to analyse the data. The advantages of this process are that it offers a structured way to analyse quantitative data and identify similarities and differences in themes in the data set [16].

For quantitative data, however, statistical methods are usually employed to test the statistical power of the results. A null-hypothesis is normally formulated, that states that there is no effect or no significant relationship between the measured phenomena. The aim of the statistical methods is usually to prove or disprove the null-hypothesis through the calculation of the p-value. The p-value indicates whether there is a high probability that the measured effect of the phenomenon occurred by chance or if the phenomena affected each other. The statistical significance is found by comparing the calculated p-value against an alpha value (usually $\alpha = 0.05$), where p-values lower than the threshold serve as evidence against the null-hypothesis and indicate that there is a low probability of the results occurring because of random chance alone. In that case, the results are interpreted as statistically significant. Conversely, p-values higher than the alpha value prove the null-hypothesis and indicate that it is highly likely that the results happened because of random chance [61].

3.5 Robot Remote Control Development

According to the principles of user-centred design, background interviews should be conducted before the design and implementation of a system, and evaluation should happen either at the end or iteratively through the process. The activities and the relationship between them in user-centred software development can be visualised through the user-centred design process model, based on the ISO standard ISO 9241-210:2019 [2]. As figure 3.1 shows, the implementation of a user-centred system is comprised of four steps, where the user is involved in each step [90]. The phases include understanding the context of the users, their requirements for the system, and designing a system that meets the requirements. The last phase is an evaluation of the system concerning the users. Software development at its core is an iterative process because the design needs to be continuously adapted as new requirements and themes appear. The model presented in figure 3.1 supports interactivity and shows how several iterations through the different phases might be performed. Thus, this provides a structured way of working with software development with the user in focus.

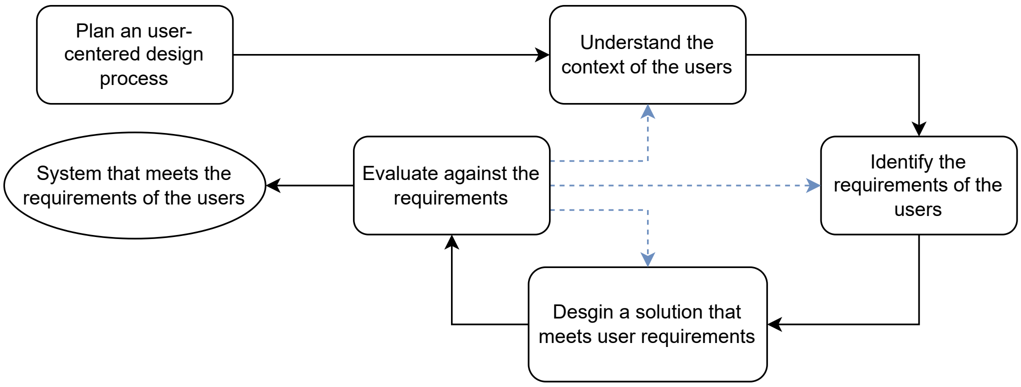


Figure 3.1: The user-centered design process based on ISO 9241-210:2019 [2] and inspired by Schulz et al. [90].

The phases of the user-centred design model are followed in the development of the remote control system in this thesis. This is an appropriate approach because it allows for iterating through the steps once within the time frame of this thesis. At the same time, additional iterations can be done at a later point to improve the system further. The system was implemented with the user in the centre, so the first step was to explore the context and the requirements through interviews before the existing remote control system was redesigned and implemented. Participants were also involved at the end to evaluate the system based on their expectations and needs. Thus, this model has provided a structure for working with the implementation and involving users in the process.

3.6 Ethical Considerations

The involvement of human subjects in research studies requires that ethics be taken into consideration. Ethical principles vary greatly between research methods and areas, but it all reduces to respecting the participants. When participants are involved in activities such as interviews or questionnaires, data about them is collected. In such cases, it is important to take measures to, among other things, ensure confidentiality, and save and handle data safely to respect the privacy and rights of the respondents. This also entails that the participants are informed about their rights and have full control over how their personal data is handled. These measures are important to implement in user-centered research, to ensure that the rights and privacy of the participants are not violated. The ethical considerations will be addressed in further detail for each of the data collections.

Chapter 4

Contextual Understanding

As the user-centred design principles indicate, involving the users in several steps of the project process is important for creating a useful solution. The first phase of the user-centred design model is to gain an insight into the requirements of the system to be implemented. By following these steps, the first stage of this thesis is to understand the context. This thesis is part of an ongoing project at the Norwegian Computing Centre (NR) called Robot Supported Education for Children with ASD (ROSA) [89], where a remote control system with the NAO robot has already been tested. Because of the previous work that has been conducted and the experiences the personnel have gained with the system, it is important to develop an understanding of the project and results thus far. This will aid in the further development of the system and ensure that it meets the expectations and requirements of the users.

Interviews with the school personnel were therefore conducted and the context was explored. This section will provide an overview of the ROSA project and background interviews, as well as findings from the data collection that can be relevant to the implementation of the remote control.

4.1 The ROSA Project

The ROSA project aims to research how social robots can be used as support in teaching settings for children diagnosed with autism spectrum disorder (ASD) [89]. The focus is on how robots can contribute to developing communication and social skills, as well as hold attention, create motivation, and stimulate learning. For this purpose, a toolbox running an educational program on a social robot has been developed.

More specifically, the idea is to create a toolbox that should run an educational program on a chosen social robot that the children can interact with. The end goal is to create a program that is tailored to each child's needs and that can assist in navigating the challenges that come with the diagnosis. It is important to note that the goal is not to replace the role of the educators, but rather be a tool that the staff can leverage to help children with ASD handle several aspects of the school environment. The user requirements are crucial when developing a system involving social robots. The researchers have therefore included children, parents, and school personnel throughout the development of the toolbox.

This project is in collaboration with Frydenhaug Elementary School in Drammen, among several other partners. This school is specialised for children with various developmental disabilities and who need additional support in the educational environment [1]. The development of the toolbox was done at this school and in collaboration with school personnel and parents with experience with children with ASD. A pilot study was conducted where a prototype of the toolbox was tested separately with children with ASD, where the children interacted with the robot through a language learning program [36]. Observations showed positive interaction between the children and the robot and the children were eager to participate in learning language with the robot. Thus, the researchers gained useful insights into the important aspects to consider to building a toolbox for this specific user group, as well as the initial reactions of the children both from the initial study and the pilot. These uncovered several technical challenges, while also revealing the children's interest and curiosity in the robot, which showed promising results for the further advancement of the project.

The toolbox that has been developed thus far consists of several parts such as a content creator for creating customised lessons for a child and for running robot skills. Additionally, a remote control was created for basic control of the robot's behaviour. Until now, the NAO robot in figure 4.1 has been used in this project, so the content and remote control are tailored to run on this specific robot. However, a further goal is to integrate additional robots that are capable of running the same toolbox, facilitating transitions between different robot types while maintaining software compatibility.

Figure 4.1: The NAO robot that is used in the ROSA project.

Although this toolbox was developed in collaboration with a specific school, a long-term objective is to expand its scope so that it can benefit a wider user base and thus open the possibility of adding other robots while still running the same program. Social robots come in a wide variety of models, capabilities, and prices, so it would be beneficial to avoid restricting the software to a single robot model. This will allow schools to benefit from this platform while adapting to their budget and requirements so that any robot they acquire can be integrated into the toolbox.

In addition, this would make it possible to leverage the unique capabilities of a variety of robots, while still depending on the core functions of the toolbox. For example, the NAO robot that is currently in use has a static face with a neutral expression that can be beneficial in instances where emotions are not in focus. Other robots have faces or screens that can display emotions, which broadens the scope of the toolbox while maintaining its original functionality. This also creates the opportunity for tailoring the toolbox experience to different requirements in various settings.

Furthermore, the intended use for the robots is in an educational setting with younger children with special needs, and in this setting, the robots are more prone to damage and breakage. Another benefit is therefore that if a robot breaks, it can easily be replaced and still maintain similar functionality. Therefore, developing a software platform that is compatible with various robot models allows us greater flexibility in selecting robot models, enhances the toolbox with more robot capabilities, and offers the possibility of replacement if necessary.

4.2 Background Interviews with Personel at Frydenhaug

The previous studies within the ROSA project give some insight into the findings and initial experiences that can be helpful in the implementation of this thesis. However, more information, especially regarding the integration of a new robot with children with autism, would benefit the tailoring of the implementation. This will uncover the requirements and expectations of both school personnel and children.

Thus, the purpose of the interview is to obtain knowledge on how the remote control has been used, as well as a reflection on the personnel's experiences with the robot and children with ASD. The remainder of this section will provide the details of how the background interview was conducted and what relevant findings were uncovered.

4.2.1 Participants and Recruitment

The participants recruited for the interviews were personnel from Frydenhaug School who are or have been involved in the ROSA project and have experience with the robot and remote control, as well as children with disabilities. These participants were recruited for the interviews as they have experience with the project can provide insightful information about its context and can come up with perspectives on how to create technology that is best adapted to their needs.

To recruit participants, an email was sent to the head of the project at Frydenhaug School, who then contacted the relevant personnel according to the aforementioned requirements to set up the time for the interviews. This resulted in three staff members. participating in the initial interviews, as shown in table 4.1.

Some of the participants are or have been a part of a technology group at the school, where the purpose was to become familiar with the robot and its functions as well as the remote control that was developed for it. This group closely collaborated with NR to further develop the software and functionalities of the robot and tested out new versions together with the children iteratively.

Variable	Number of participants
Participants	3
Technology group	2
Experience with disabilities	3
Social environment therapist	2
Teacher	1

Table 4.1: Overview of the participants in the interviews

4.2.2 Interview Design

The interviews were semi-structured, which allowed for following interesting themes and inquiring the participants for more in-depth answers. This was a natural method of inquiry because the main topics of the interview revolved around the interviewees' experiences and reflections, and the flexibility of the semi-structured interview allowed for letting the participants guide the direction of the interview. Thus, through this data collection method, the context of this thesis could be thoroughly explored.

An interview guide was developed based on knowledge from previous studies done within the ROSA project, as well as the research questions for this thesis. Therefore, the themes for the interview sessions were three-fold: experiences with the robot toolbox in use with children with ASD, opinions about robot movement for different robots, and reflection on the effect of social robots on children with autism. Example questions from the interview guide were:

- Which of the robot's capabilities do you believe stimulate the children's motivation?
- Can you describe a typical session where the robot is used?
- What influence do you think interacting with different robots has on the children?

These questions, along with the ones in the interview guide, are aimed at providing insights into the aspects that need to be taken into account in the implementation of the prototype. The original version of the interview guide in Norwegian can be found in appendix A.

4.2.3 Data Collection from Background Interviews

The background interview took place at the Frydenhaug school in Drammen, Norway in November 2023. The data collection consisted of three one-hour interviews with different school personnel. Each interview started with informing the participants of the interview structure, reading the information sheet, and signing the consent form. The information sheet and consent form are attached in appendix B. The information note contained information about the purpose of the data collection, the participant's rights, and data processing, among other things. In the consent form, participants could give their consent to different activities during the interview, like answering questions or taking pictures.

The main part of the interviews consisted of following the questions in the interview guide. All participants were asked similar questions, however, the order of the questions was decided by the flow of the participants' answers. Follow-up questions were also asked for clarification purposes or to follow a new and interesting direction. The interviews were recorded using an audio recording device and notes were taken along the way. Figure 4.2 shows an image taken during the interview with one of the participants.

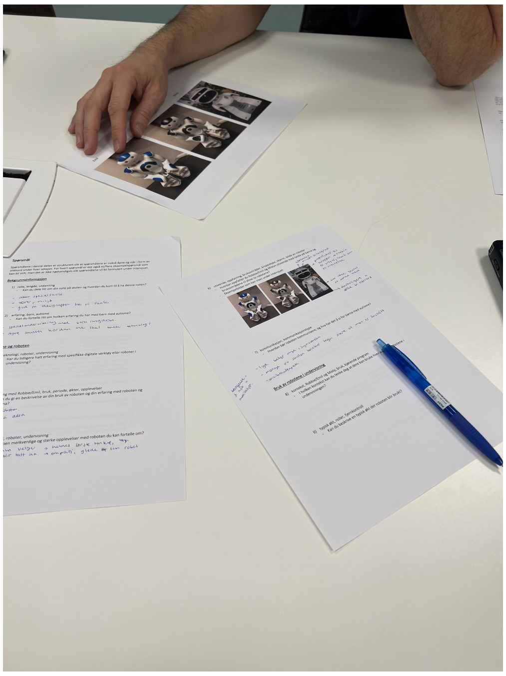


Figure 4.2: Image from the interview with one of the participants.

4.2.4 Analysis of Interview Data

The voice recording data from the interviews was transcribed using the whisper.cpp software [38] for easier analysis. This software was run locally in a terminal using the chosen language model and an audio file, and it outputted the transcribed audio file. As this software makes some mistakes, the transcribed files were corrected manually too.

As previously seen in 3.4, thematic analysis is an appropriate way of analysing qualitative data. Performing a thematic analysis can be a rigorous process, but it allows for digging deep into the data set. However, providing an in-depth analysis of this data collection is out of the scope of this thesis. The purpose of the background interviews was to gain an overall understanding of the application of the prototype, the experiences of its users, and its influence on children with autism. It will serve as an anchor point for creating an implementation that matches the requirements of its user as closely as possible. Instead, the process of thematic analysis was loosely followed, entailing that the transcribed data was thoroughly reviewed and themes were identified within each interview. The focus was on determining themes that might be relevant to the implementation and the research questions. The themes were also reviewed in relation to all interviews, to identify common and differentiating patterns in the themes that were discussed. These were used to produce an analysis, containing the similar and contrasting points that were brought up during the interviews.

4.2.5 Ethical Considerations

Firstly, an application was sent to the Norwegian Agency for Shared Services in Education and Research (SIKT), to be allowed to perform the data collection. The application consisted of a detailed plan of the data collection, including the interview guide, information note, consent form, technology, participants and so forth. The data collection was thus approved by SIKT before it was conducted and the assessment can be found in Appendix C.

Informed consent was obtained from all participants before the data collection, where the participants consented to be interviewed, recorded, and taken pictures of. The participants were also informed about their rights, such as being able to withdraw from the interview at any time access to one's data if asked, and information about how their data will be treated.

Furthermore, the personal data collected was the name and signature of the participants on the consent form, in addition to audio data from the recording device. The filled consent forms were stored safely and unavailable for outsiders and will be destroyed when the project ends.

The interviews were recorded on an audio device that cannot be connected to the internet. This data was transferred and stored in an encrypted vault on my personal computer. The vault was locked with a password, ensuring confidentiality through only being available to me. The audio recordings were transcribed locally using the whisper.cpp [38] software. This software transcribes audio files directly from the computer terminal, making it possible to transcribe without being connected to the internet. In addition, the transcription process anonymised the data. Voice is considered personal and identifiable data, but by transcribing the audio, the responses of the participants are detached from their voices, and the result is a text that contains no personal information. It is difficult to identify the participant or any other person from this data alone, thus anonymising the data.

Lastly, since the participants worked with children with special needs, they were informed to not talk about people in an identifiable way, and any traces of names were removed when transcribing the recordings. In addition, no specific questions about the children or their conditions were asked, to avoid being able to identify anyone through the text or gain any personal information about them without consent.

4.2.6 Findings From the Background Interviews

In this section, the relevant findings from the interviews will be presented. These include some context around the children and the robot, the interaction between them, and some specific details about the movement of the different robots. This text will contain a mix of the answers from the interviews with all the participants, as they made similar points in some areas, while they made some separate points in some other areas as well.

The Robot in the Lessons

When the robot was tested out in school with the children, the first important step was for the children to become familiar with the robot, especially to observe their initial reactions and for them to become comfortable with it. The robot was also introduced in different kinds of activities; morning meetings, games, and working on tasks with the robot. During the morning meetings, the robot was used together with a class, where the robot was introduced as one of the students, playing the role of a peer and a friend. The robot then participated in answering tasks and interacting with the students, where one of the persons familiar with the robot sat in the back of the classroom and used the remote to control the interaction.

When introducing a new element to children to children with autism, it is interesting to observe their reactions. This is especially because repetition and fixed routines are critical, and there might be significant variation in how much time the children need to become comfortable with the robot. The school personnel observed only positive reactions across all classes where the robot was tested and in general, the children were fascinated and curious. It seemed like they perceived the robot as reliable and trustworthy. The participant mentioned that the robot created a community around itself and the children, where it was one of the students and was able to move, answer questions, and even answer wrong sometimes, on equal footing with every other student. The children were very excited and included the robot in conversations and showed empathy towards the robot, as well as increased focus, motivation, and participation in the lessons.

The participation of the robot led to some children showing atypical behaviours. For instance, in a class, there is a child who typically shows very egocentric behaviour as they always want to choose the song for the morning assembly first, but when the robot was introduced, the first thought of this child was that the robot should choose, which indicates empathy towards the robot. Another child wrote a letter to the robot, while a third child, who is normally very verbal and dominates the conversation, implicated the robot in the conversation as well. Another example is a child who usually does not enter the classroom and is not willing to participate, but came in and participated once the robot was present. These children's reactions show that the participation of the robot in the lessons has a big and positive impact on the children. However, whether this is a lasting effect and not a consequence of the robot being a new and unknown element in the classroom is hard to determine, so more consistent testing over a longer period is needed.

The Importance of Movement

Despite the novelty of the robot being used in the lessons, other elements seemed to interest the children, one being its movements. The children seemed fascinated by movements, such as its dances, its moving gaze, or the raising of its hand. It made the robot seem like an active participant to the children and the school personnel observed great responses to the robot's motions, which they assumed would not have been as big if the robot was more stationary. The motions can act as a way of capturing the children's attention and have them engage more in the lesson, and act as a motivational factor, especially the dances. In addition, since a lot can be said without words, the robot must be able to convey something without verbal language like humans can. Communication is a combination of gestures, movement, verbal language, and facial expressions, and it is important that the robot can embody several of these methods as it can be a motivational factor for children. So, the movements of the robot seem to play a crucial role in the children's engagement. However, it is important to note that for some children, the movements can be distracting so they are not able to focus on anything else.

Moreover, one school personnel assumes that it is not substantial that the robot's movements are humanlike because the robot is different from a human so it is natural that it moves differently. However, based on the children's responses, it seems like the robot having recognisable movements is important. That is because the robot works as a model when it moves, as the children are mirroring its movements. The children are raising their hands, waving, and dancing like the robot, and the robot becomes more attractive to them because it can do the same movements as them and it looks like them so it is easier to look at the robot as a peer. Imitation of the robot was very important to the children, and the fact that they were able to mirror it because of the recognisable movements and humanlike body, it simpler for the children to connect to it.

Misty vs. NAO

Furthermore, the staff were asked about the impact of integrating a new robot with another look and functionalities can have on children with autism. The idea is that the two robots, NAO and Misty, have different functionalities and morphological features, and they will therefore not be able to do movements, such as waving in the same way an important question to consider is how will this impact the children's relationship to the robot and their interaction. This will be useful to take action when implementing the same movements on Misty, to know how to create the transition between robots as smoothly as possible as well as what to look out for when adding a new robot into an existing system that will work with a vulnerable group.

Firstly, humans communicate in different ways, as one interviewee pointed out. For example, the school personnel and students at Frydenhaug have different accents when they speak, they use various versions of sign language according to their abilities, they have diverse mother tongues, and their body language differs. Nonetheless, the children are still able to understand the school personnel and each other despite the differences. The children can learn the differences and they get used to it, so they understand when you communicate, even though we do it in unique ways. This interviewee pointed out that it is the same with robots; they are different and communicate differently, but it can still be understandable despite that. The children will then develop their way of communicating with the different robots like they are used to doing with humans.

However, another important point to consider is that some children with autism have problems with handling variation and change. When children with autism communicate with humans, there are many variables at stake, such as body language and facial expressions, and it can be energy-consuming and hard to focus when these can change so often. These are the benefits of using a robot: its movements and facial expressions are the same between each interaction and it is more static than a human. Thus, the children do not have to use energy trying to interpret the meaning behind the way of communication or the changes. Changing between different robots can pose a difficulty when it involves children sensitive to change, especially since they have grown comfortable with NAO already. Involving new robots might require adaptation time, extra energy spent trying to understand and interpret another robot's way of communicating, and other extra considerations.

In this regard, NAO was chosen for this project because it has a static face and no ability to show facial expressions. This is beneficial for children who cannot focus on other things while trying to interpret facial expressions simultaneously. However, Misty has a screen, which allows for showing various facial expressions. This can be beneficial for example for children who can tolerate it or who have trouble understanding meaning without facial expressions. The same goes for the amount of movement and gestures the children are comfortable with. So, the benefit of one robot over the other depends on the children's needs and abilities. In this context, we assume that the different robots will be used in the same context, but it is possible to leverage the strengths of the robots and use them in different contexts. For example, one can use Misty to teach the children and practice emotions with the children, while working on tasks that require movement with NAO.

Lastly, the NAO robot is proportioned like a human, with comparable limbs and degrees of freedom. This leads to the robot having quite clear movements and its motions are more easily recognisable because of their similarity to human movements. Misty, however, is built very differently and it might be hard for the children to understand its movements as they vary significantly from what they are used to. It is also quite limited in how it can move and it might not be as recognisable as the movements of a humanoid robot. Thus, some of the participants argue that the Misty robot might need more verbal support to accompany the movements to make the meaning of the motions clearer. This is not an unreasonable idea as many of the children at Frydenhaug talk about themselves from the third person perspective. Therefore, it might be beneficial to compensate for the limited movement functionality of Misty with the use of descriptive verbal language. Although it is not grammatically correct to use the third-person narrative in this manner, it is a frequent way and understandable way of communicating at Frydenhaug. Thus, this might increase the children's understanding of Misty.

Chapter 5

Implementation

According to the user-centred design process for system development in section 3.2, the next phase is the design and implementation of the system. At this step, the users' requirements and expectations are established and can be used to drive the implementation forward. The implementation in this context requires the integration of a new robot in a pre-existing remote control system. This task involves several aspects, including a description of the initial remote, communication challenges and solutions, collection of motion data, and movement translation methods. These considerations will be addressed in greater detail in this section.

The discussion will start with an overview of the initial remote control system, where the challenges of integrating a new robot are identified. Some of the issues involve communication and robot-dependability. Based on this, the ZTL framework is presented as the solution for the communication problems with the initial implementation. Lastly, several motion translation methods are explored, to reduce the impact of the robot-dependability of the remote.

5.1 Relevant Robots

The robot models used in this thesis are NAO and Misty, shown in figures 4.1 and 5.1 respectively. The NAO robot is currently employed in the ROSA project, and thus the initial implementation is tailored to its software and hardware. In this thesis, Misty was the new robot introduced into the system. This section will provide a short hardware and software description of the two robots.

Firstly, both robots are social robots that have been engaged in educational settings and therapy with children, where NAO has a humanoid form and mobility as advantages, while Misty is highly customisable and expressive. While there have been multiple robots developed for research involving children with autism, NAO is most commonly used [86], and has been used in tasks including imitation [98] or social engagement [30], among many others. Conversely, Misty is a relatively new platform and has thus not been extensively involved in research, but has been employed in some educational settings to practice communication and social skills with children with autism [41][80]. Because of their extensive functionalities that can aid in working with children with autism, these robots have been chosen for the ROSA project.

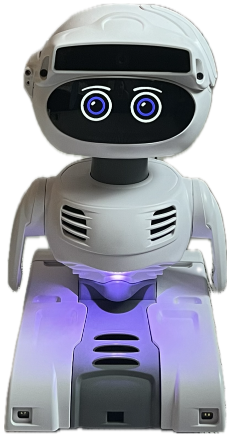


Figure 5.1: Misty

5.1.1 An Overview of NAO's Hardware and Software

NAO is a humanoid robot from Softbank Robotics that was created mainly for research and educational purposes. It offers a wide range of capabilities, such as walking and moving closely resembling human motion and it can interact and talk with its users [99]. With its many capabilities, it is thus possible to create countless interactions with NAO for a wide range of users and scenarios, making it a great companion for education and research.

Several versions of NAO exist, and the one used in this thesis was NAO v5. The robot runs the NAOqi 2.1 operating system (OS), which is built on a Linux kernel. This makes the OS straightforward to work with and makes the robot highly customisable. The NAOqi OS offers a variety of different Software Development Kits (SDKs), such as Python, C++, and even ROS, in addition to Choregraphe, a desktop application that allows for simpler programming of the robot [75]. The flexibility of the OS allows the developer to choose their path for developing applications for the robot. For instance, in the implementation of the remote, a combination of the JavaScript SDK, Python SDK, and Choregraphe was used to program the robot behaviours.

Despite the flexibility of the OS, NAOqi 2.1 still presents some issues. NAOqi 2.1 only supports Python2, an older version of Python, which requires all code interacting with the NAOqi framework to be written in Python2. This is problematic for several reasons, some being that as of 2020 there is no official support for Python2, it is not possible to leverage the new features of Python3, and that compatibility issues might arise. Additionally, as previously mentioned, the NAOqi OS provides ROS bindings which provides a bridge between the NAOqi API and ROS. However, this approach is quite challenging to work with as it is prone to compatibility issues between newer ROS versions and older robots. Most of the documentation is also based on ROS1, a version of ROS that reaches its end-of-life in 2025, but effort has recently been put into creating a ROS2 stack for all NAOqi versions [8].

Furthermore, NAO's body is built up out of 25 motors controlling each of its joints, giving the robot 25 Degrees of Freedom (DOF) in total. The head has 2 DOFs, and the arms and legs have both 6 DOFs each (except the pelvis joint which is only one motor in practice). Some of the actuators are controlling single a revolute joint, that allow movement around an axis, such as the actuators at the wrists or knees. Other actuators control double revolute joints which can rotate around two axes, such as at the shoulders or head. Figure 5.2 shows the actuator placement on the robot. From the picture, it can be observed that NAO has quite similar joints as a human body and mobility. This offers the possibility of programming a large variety of realistic motions on NAO.

In addition, each joint is equipped with sensors, such as position sensor, temperature and current [67]. The position sensor, which is a position encoder, is particularly interesting, as it keeps track of the position of the joint in radians. It is possible to access the the output of the position encoders for all joints through the *ALMotion* API which is part of the NAOqi OS. The position sensors are used to record the joint angles of relevant joints during a motion. Moreover, it is worth noting that NAO has three frames of reference that are either fixed or attached to the robot. Its world frame is fixed at the start position of the robot and the x-axis points in front of the robot, while the y-axis points to its left. The torso- and robot frames have corresponding orientations initially, but they are attached to the robot's body as it moves. When measuring the joint angles of the NAO robot, it is crucial to specify the reference frame from which the data is gathered.

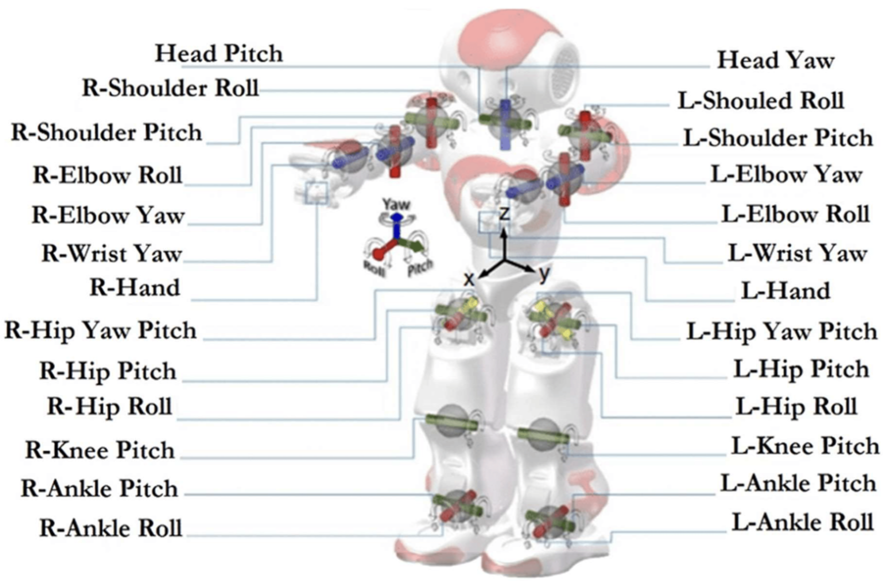


Figure 5.2: Motor placement on the NAO robot [77], which is inspired by the original documentation [67].

5.1.2 An Overview of Misty's Hardware and Software

The Misty robot, developed by Misty Robotics, is designed as a social robot primarily for education, engaging children with and without special needs. Misty is equipped with a range of attractive features, including a variety of sensors, a screen, and driving bands, that make it possible to create interesting and dynamic child-robot interactions. The robot is also highly customisable and easy to program, and can therefore be used for a multitude of purposes, such as teaching and practising coding, social, and communication skills [62].

Misty is equipped with 2 processors, one running Windows IoT Core and one Android 8.1. The Misty platform also has several available SDKs, such as Python and C#, and a block programming software [62]. Misty, however, does not provide official direct support for ROS, which means that a ROS bridge is needed for the communication between the robot API and ROS. Nonetheless, there are numerous options available for creating applications and interactions, offering developers considerable freedom in choosing how to work with Misty.

Furthermore, the Misty robot is more limited in its movements compared to NAO, as it has only 6 degrees of freedom: 3 DOFs for the head, 2 for the arms, and the last for its ability to drive [62], as shown in figure 5.3. As a result, Misty's range of motion is limited, and while it is still possible to create some interesting motions, it is not designed to imitate human movement. On the other hand, Misty has a screen where different facial expressions or images can be displayed. Instead of body language, Misty can therefore use its mobile head and screen to communicate and interact. This enables the creation of different interactions than with NAO, as it uses other methods of communicating and interacting with its users.

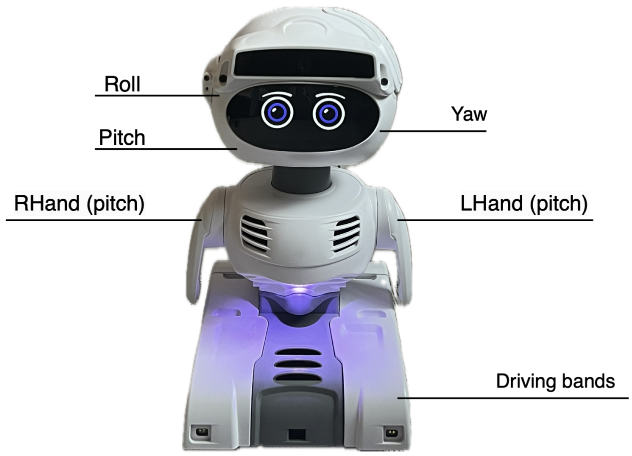


Figure 5.3: Degrees of freedom of Misty's joints

5.2 Initial Remote Control Implementation on NAO

As previously mentioned, the NAO robot is actively used in the ROSA project and, a specialised remote control has been developed to operate the robot, based on its hardware and software abilities. The remote is implemented as a webpage written in Python3, as shown in figure 5.4, featuring multiple buttons for convenient control of the most important behaviours of the robot. Using the remote, it is possible to send text-to-speech, other miscellaneous, and motion commands, including gestures and dances. Since the NAO platform allows us to easily run scripts on the robot itself, the webpage server is hosted on the robot itself. This allows the remote to launch and be available as soon as the robot boots, making it simpler to gain access to the robot for non-technical users.

Figure 5.4: A part of NAO's remote control, in Norwegian. The image shows the buttons for different behaviours, such as gestures or dances. The remote also has a text-to-speech box for giving the robot speech prompts.

In addition to the webpage, a task server is also initiated on the robot. The task server is a script that performs the behaviours defined by the buttons in the remote control. It is created using a Python jumpstarter framework [34] and handles all aspects of the initialisation and execution of the application. This allows for a simple creation of an NAO application, leaving the developer to only implement the desired behaviours.

Whenever a button is pressed on the webpage, the webpage server receives a string message from the javascript file through a web socket. Further, the webpage and the task servers communicate through ZMQ sockets. The webpage creates a publisher socket on a certain binding address and passes the message on the socket. The task server creates a subscriber socket connected to the same address as the publisher. It will receive the string messages from the webpage and handle the requests. The message contains the name of a behaviour to be executed on the robot. The task server contains methods to handle all possible requests using the NAOqi APIs in the execution.

This implementation of the remote control is based on NAO's hardware and software specifications. Firstly, the task server uses the NAOqi APIs for the execution of behaviours, which can only run on NAO. The gestures and dances are all also developed specifically for NAO. In addition, the remote application is designed to operate directly on NAO. These aspects make it challenging to extend the current implementation with other robot platforms, as it would require several considerations. One is that it would entail setting up and managing all aspects of the communication between the remote webpage and several robots running their task servers, either locally on or a development computer. Another element to consider is crucial to handling requests, execution of behaviours, and errors so that the behaviours are executed seamlessly on any robot. For larger systems involving multiple robot platforms, this might become messy and would require a lot of effort on the developer side.

Moreover, this approach would entail that the task servers for all robots receive the same behaviour command, and it is up to the task servers how to handle those commands separately for each robot. This would entail designing the same behaviours for each robot, leveraging their separate capabilities and APIs in the process. In a system with many behaviours and several robots, this becomes a tedious, repetitive and long task.

In light of these points, it would be beneficial to have a framework that handles some of these aspects, such as handling of behaviour executions, errors, and communication within the system. A framework would relieve the developer from multiple necessary tasks when adding a new robot into a remote control system, and would thus make this process simpler and quicker. In this thesis, the ZTL framework [44] will be used for this purpose, and a description of how the ZTL framework works and is used in this remote system follows.

5.3 Remote Control Implementation using ZTL

ZTL [43] provides a structured and simple way of adding new robots to this system. Its greatest advantage includes a backend communication system between the robot task servers, that can be located anywhere, and the remote control that allows for easy integration of different robot platforms. Another benefit is that the framework includes methods for outlining a generic task definition in a YAML file that can be used to dispatch tasks to different robots. The task definition outlines the behaviours that the robots are expected to perform, which the robots can use to tailor to their specific abilities.

These advantages make the ZTL framework suitable for use in this thesis, where it will play two important roles. Firstly, it will handle the distribution of tasks from the remote webpage to the robot servers, as well as all errors that might occur. Secondly, the framework provides a way of defining behaviours, or tasks, to different robots, which will be leveraged in this implementation. Figure 5.6 shows the flow of the dispatching and handling of tasks from the button press of the user to the execution on the robot. The implementation of ZTL in this prototype, along with a description of the framework will be explained in greater detail in this section.

5.3.1 Description of ZTL

The ZTL framework is a remote task execution system, designed to operate across a diverse range of robot platforms. Its necessity arises from the requirements of the Robot House at the University of Hertfordshire, for which the ZTL framework was developed. The Robot House is specifically created for human-robot interaction research in a home environment and houses a variety of robots, such as Pepper and Care-O-bot 4, and a variety of sensors [84]. Researchers can use this space to research a multitude of aspects of the use of robots for care with older people, as well as it allows for creating realistic and interesting scenarios between participants and robots. The use of various robots led to the need for a framework to easily control them all.

The researchers explain that controlling the various robots within the Robot House became a challenge, considering that they run different operating systems and middleware, which entails programming for each robot separately to be compatible with their platform [44]. This is a substantial difficulty, especially as the field of robotics is rapidly changing. Holthaus et al. argue that due to software updates, incompatibility with newer technology, or end-of-life of software, among other factors, may render many older technologies obsolete. The ZTL framework was created with this problem in mind, as a way of separating robots from their platform and offering the possibility of benefitting from modern technology while still operating the robots within their platform. This allows for exploiting the abilities of a robot fully, despite updates in technology.

Multiple solutions to this challenge have been developed, both higher-level solutions such as ROS [78] and lower-level solutions like the framework ZMQ [9]. Holthaus et al. argue that these solutions have some drawbacks that ZTL seeks to address. The disadvantages of using sockets and frameworks like ZMQ involve the additional effort required for managing the communication within the system to various degrees. ROS, however, provides a publish/subscribe or request/response scheme to easily communicate between nodes in the system, but the problem arises when providing support for older robots as ROS is upgraded.

On the other hand, ZTL introduces a user-friendly solution that hides the complexity of the communication. The framework provides tools for setting up a server-client system, where the client is responsible for dispatching tasks and the server is responsible for the execution of a robot. The communication between the different components within the framework is based on ZMQ sockets and it is established within the framework itself, and any error handling is also managed internally. The developer is then freed from the responsibility of establishing the communication and can focus on using the core functions and classes to set up a tailored server-client system. The framework is designed to allow different servers to run either locally or hosted directly on the robots. A client file can trigger tasks, which are defined in a YAML file, on a specified server. This offers easy integration of new robots, as the framework is not dependent on the robot's software and allows for running task servers where it is most convenient. It also allows support dispatching a general task to a robot without needing to handle its specifics at this stage.

Structure

ZTL is a Python-based library that leverages ZMQ sockets for client-server communication. It consists of core components that together define a framework for triggering, managing, and monitoring tasks. At its most basic level, the client will send a task to the server by specifying a scope and a payload. When the server receives a request it will decode the message, and based on its scope it will delegate the task to the correct handler. The task handler will then manage the task execution and the lifecycle of the task. The sections below describe the components in greater detail.

Handler The handler is the robot that will execute a task. The task is the specific job that the robot should execute. The framework dispatches tasks to a specified handler, and this robot will execute them. A TaskHandler object is created for each handler, which is responsible for the execution of the tasks that are assigned to a specific handler.

YAML Files There are two main YAML files used in ZTL. One is the configuration file (config), which holds information about the different handlers (robots) in the system. The information contains the IP address where the task server is located, which can either be on a development computer or on the robot itself, and the port through which the communication will happen. In addition, it defines a scope for identifying the handler. The other YAML file is a task file that defines the jobs the robots can do. It is defined hierarchically, and contains detailed, robot-independent information about the tasks that can be completed This file is user-defined and can be structured in various ways, depending on the project requirements.

Client The client defines a RemoteTask object for each robot in our system based on a configuration file. When the client is initiated, it establishes communication with the server using the host and port information from the same configuration file. The client is responsible for triggering a task, specified in the task YAML file, on the correct handler. When a task is triggered, it is sent together with the scope and payload to the server to be managed further.

Protocol The protocol script defines rules for communication between the client and the server. It has 4 classes; Request, State, Message, and Task. The Request describes the possible request types that can be asked of the server, such as initialising, aborting, or checking the status. The State describes the types of states a task can be in, for instance, accepted or failed. The Message handles the encoding and decoding of messages between the server and the client. The Task handles encoding and decoding of task-related information.

Server The server creates its own ZMQ server socket when initiated, listens for tasks and waits until a client sends a request to act. It is responsible for registering handlers and it can register multiple handlers (of the TaskHandler class) for multiple scopes. When receiving a request from a client, the server will route the task to its specified TaskHandler, which will take care of the execution of the task. The server will handle the life cycle of the task and handle all the possible states the task can be in.

Task The task script defines the task execution and handles the logic. It defines the basic structure of ExecutableTask objects and defines the structure of a TaskHandler, meaning that it provides the basic structure and functions that should have to be defined in a more detailed manner later. In addition, it defines a TaskExecutor object that manages the execution of tasks and handles its whole life cycle, from initialisation to completion. This script sets the State of the task, which the server uses to send back to the client.

Figure 5.5 shows how the main ZTL components can be assembled to create a remote task execution system. In the figure, there is a server listening for requests and a client script that sends task commands to the server to execute. The client reads communication information for each handler (robot) from a configuration (config) file, which is used to connect to the server. The client also reads the task file (task.yaml), where the tasks and their handlers are defined. The client uses the protocol Task class to encode the task payload and triggers the task using the handler for the task that is being processed. When the server receives a request, it is decoded using the protocol Message class to get the task information, the task is initiated, and a response is sent back to the client based on the task status.

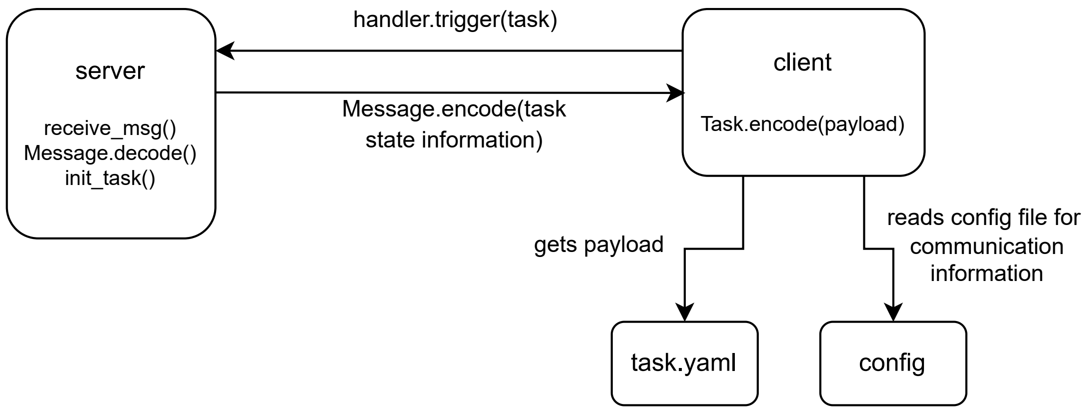


Figure 5.5: Structure of the server-client communication in ZTL

The developer will be able to use the presented components to create their own server and client scripts based on their requirements, where the complexity of the communication and task handling between the components remains hidden. Furthermore, the server will define a TaskHandler for the specified robots, a TaskExecutor and an ExecutableTask to manage the execution of incoming tasks, while the client RemoteTask is used to trigger tasks on the server with a desired scope and payload. Together this enables assignment of tasks to servers regardless of whether they run on the robots or a computer, and is independent of the operating system and software. The precise way in which the tasks will be executed by the robot will be handled by the TaskExecutor for each robot. Thus, this facilitates platform-independent task distribution, in addition to being able to use a robot's API within the TaskExecutor while still benefitting from modern components.

5.3.2 Application of ZTL in a Remote Control Implementation

Triggering Tasks

As shown in figure 5.6, when a user clicks a button on the remote control, a corresponding message is forwarded to the server webpage through a web socket. The webpage server and the client are connected after a publisher-subscriber model so that the server publishes the message on a ZMQ socket to the client for each button press. When the client receives a message, it will read through two YAML files, one for the task description and one configuration file. The latter file, shown in figure 5.7, contains the name of the handlers, which corresponds to the robots, and contains the IP addresses of their task servers. The task servers are not restricted to running locally on a development computer but can be run anywhere, as long as the IP address is specified in the configuration file. The client file uses this information to create a RemoteTask for each scope and to trigger tasks on the given robot.

The task description file is a YAML file containing a description of the task the robot should perform. Originally, the file was intended to contain a detailed description of the tasks of each robot for a given scenario, which will be passed sequentially to the robot server. However, following such an approach in this implementation would entail parsing the YAML file and mapping to the robot's capabilities every time a button is pressed. Thus, the same calculations would need to be done whenever the same button is pressed, which would be a waste of resources. Instead, some of the work is done in advance, during which the general task description is used for mapping the behaviours onto a robot once. Subsequently, the robot-specific details for each robot are collected in a YAML file for each different behaviour. This results in the robot-specific behaviour description being sent to the robot server whenever a button is pressed on the webpage.

A YAML file is created for each task that the robot can perform, which corresponds to one file per button on the webpage. This division was made to keep the tasks ordered and avoid overcrowded YAML files. Each file contains details needed to perform a behaviour on each handler (robot). Furthermore, all YAML files are structured into at least three levels, where the first one is always the behaviour and the second is always the handler. For some behaviours, the third level contains the components of the robot that will execute a part of the task, for example, the head or the screen. For others, the third level will be different mapping methods and the components will be the fourth level. An example of a task description file is shown in figure 5.8. In this example, the behaviour

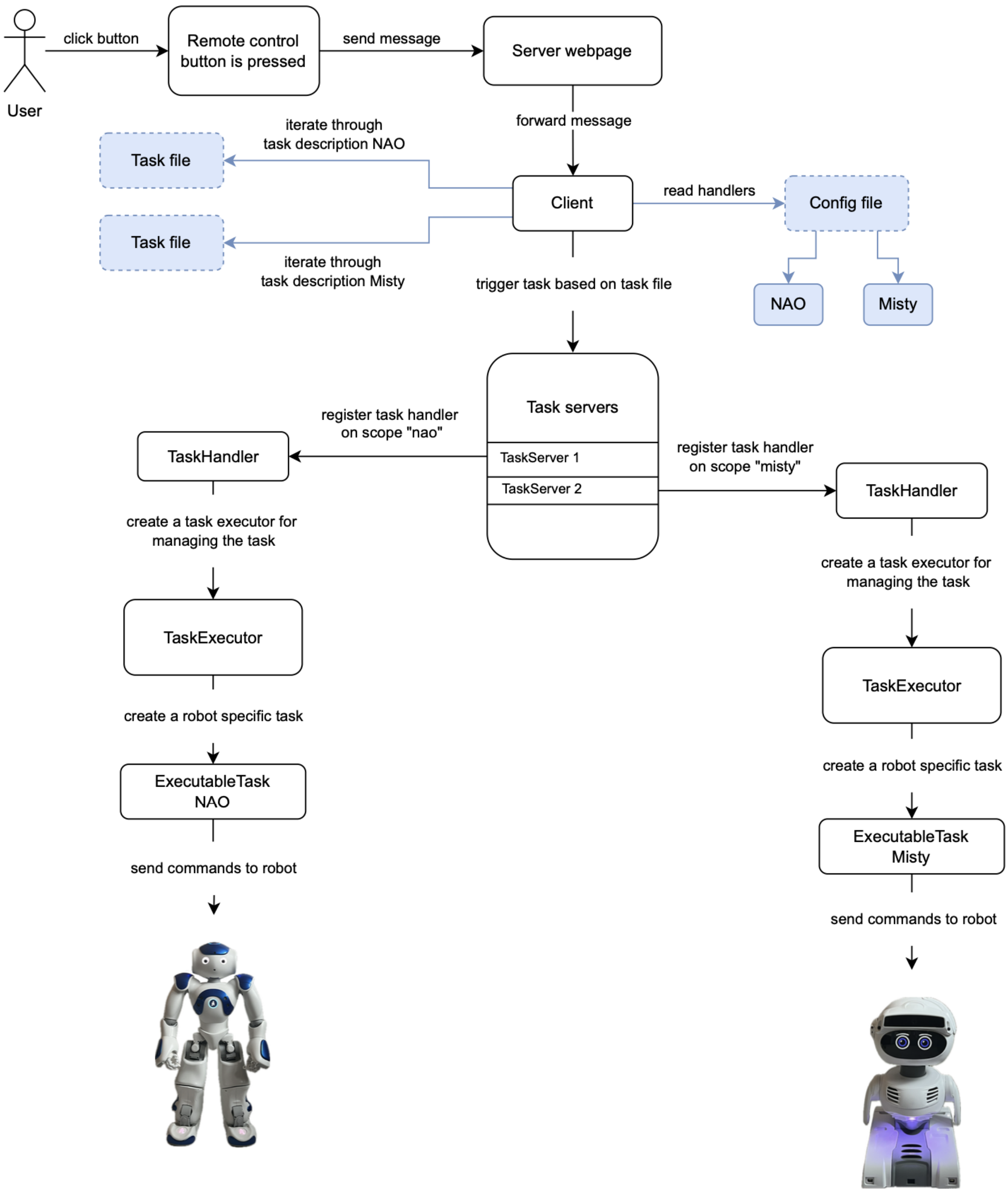


Figure 5.6: System based on ZTL for dispatching and executing behaviours on different robots.

is *dance_robot*. For the NAO robot, the command is only the name of the task, as the behaviour is already implemented and is handled by its task server. For the Misty robot, however, the file contains a description of how Misty should perform the task. This is based on the translation of NAO's motion.

Furthermore, the client will find the correct YAML file based on the pressed button, iterate through the content for each handler, pack the content into a single message, and use this as the payload to trigger a task on the specified server. That is because the YAML file describes how the whole task should be executed and the information is not given in a sequential order of execution.

Task Execution

The top half of figure 5.6 describes how ZTL dispatches tasks to the different robot servers, while the bottom half of the figure presents how the task servers handle and execute requests. The system requires at least one running task server whose task is to pass the received behaviour to a task handler for a specific robot. The task handler is responsible for executing the task on the robot. In this implementation, there are two task servers, one for the NAO robot, which runs locally on NAO, and one for Misty which runs on a development computer. Alternatively, there could have been a common task server and separate task handlers to manage the commands to each robot. However, this would force the task server to run on a development computer, instead of allowing for running task servers locally on the robots. Instead, one server will run on NAO, which provides the advantages of fully using the capabilities of the ZTL library, leveraging the opportunity of running scripts on different locations and handling Python2 and Python3 scripts analogously, which results in a simpler integration with the previous remote system.

Secondly, the Misty robot, among other robots, does not allow for running scripts easily on the robot. To avoid having to deal with different robot operating systems and protocols, a server can run on a development computer. Thus, it is possible to have a common server on a development computer for handling all robots that have this limitation, and separate servers for the robots that are capable of running the server themselves.

When the server is active, it will register a TaskHandler based on a scope. In this implementation, there is only one scope for each handler, so one TaskHandler will be created for each robot that is ready for use. The server will then listen for incoming tasks from the client, which will come whenever a remote control button is pressed. Once a task is triggered, the TaskHandler will create a TaskExecutor object, which handles the life cycle of a task, and this will in turn initialise an ExecutableTask, as presented in figure 5.6. The payload from the client will be passed from the server to the ExecutableTask. In this implementation, an ExecutableTask will be created for each robot and it is responsible for executing the behaviour of the robot by leveraging its API. This part will vary for the different robots.

```yaml
remotes:
  nao:
    host: 10.0.1.17
    port: 5556
    scope: nao
  misty:
    host: 127.0.0.1
    port: 5557
    scope: misty
```

Figure 5.7: ZTL configuration file where the IP addresses and communication ports of relevant robots are specified.

```yaml
dance_robot:
  misty:
    cross:
      arms:
        LArm:
        RArm:
      head:
        Roll:
        Yaw:
        Pitch:
        directions:
      wheels:
    direct:
      -"-
    qom:
      -"-
    eyes:
    leds:
      direct:
        blinking:
        colors:
        rate:
      qom:
        -"-
    motion_length:
    song:
    speed:
  nao: dance_robot
```

Figure 5.8: Example of a task description file showing the commands sent do the different robots. Misty's command consists of the translated behaviour from NAO.

5.4 Collecting Motion Data from NAO

While the ZTL framework takes care of the different aspects of communication between the different components and is the base of the task dispatch system, this is only one part of the whole prototype. The other crucial part is the integration of the new robot in terms of its behaviour. The NAO robot already has the desired behaviour implemented, so any new robot would need to replicate the same behaviour in its manner. This involves several parts, where reading data from NAO's movements is the first step.

5.4.1 Obtaining Angles and Positions Using NAOqi

Firstly, to map the behaviour from NAO to Misty, a way of capturing NAO's motion is needed. There are several ways this can be done, for instance through video analysis or a motion capture system, but the motion can also be obtained by reading sensor output from the robot itself. NAOqi has quite extensive motion API, that provides access to read motion data from the robot, as well as sending motion data to the robot. This API was used to read sensor data from NAO's joints and end-effectors, which provides joint angles for all of NAO's joints, as well as position data of the hands concerning the torso frame and torso concerning the world frame. The data is recorded for each separate motion as a stream of values from the robot from the specified body parts. The figure in appendix D shows an example of the data retrieved from NAO. It is positional data of the left hand, right hand, and torso for a standing-up movement, where each reading contains values for x-, y-, and z-directions, as well as roll, pitch, and yaw rotation for each point.

A script was executed to capture data every half second from NAO while performing each motion. A method was also implemented to save only the segments where the robot is in motion, excluding the parts of stillness at the beginning and end of the motion. The recorded information is written to a YAML file, which will include the joint angles of all of NAO's joints and the position of the hands and torso. In addition, some tags are added for each motion. The *special* tag indicates whether this motion is specific for NAO, such as the standing-up or the sitting-down motions. The *time* tag indicates the duration of the motion, while the *type* tag denotes whether the motion is a dance or a gesture, which are the two categories of motion in the remote control. The structure of the YAML file is shown in figure 5.9. The rest of the labels will be explained later.

This data is read from NAO because it describes the important parts of the movement. The angle data gives us the angles of all the joints and makes it possible to map the joints to another robot directly to do a similar movement. At the same time, the position data can give us an idea of the trajectories of the arms in space, and it can help us recreate a respective movement or trajectory for a new robot. Thus, this data was captured because it plays an important role in the description of the movement and can be used to recreate a similar motion on a new robot.

5.4.2 Using Video Analysis for Measuring Quality of Motion

Retrieving data from NAO directly as explained above gives us a lot of useful and detailed data about the robot's motion in each time step, but this does not capture the whole essence of the movement on a more general level. So, it doesn't provide any

```yaml
dance_robot:
  remote:
    endeffector_positions:
      LArm:
      RArm:
      Torso:
    joint_angles:
      HeadPitch:
      HeadYaw:
      LAnkleRoll:
      ...
    special:
    time:
    type:
    qom:
      extreme_points:
      qom_vals:
      speed:
      threshold:

```

Figure 5.9: YAML file containing data collected from NAO, including joint angles, end-effector positions, and video analysis data.

understanding of the overall movement, only step-by-step angle and position data that we can read. Since the purpose is not necessarily to replicate the motion to the letter as the capabilities of the robot differ, we should also obtain an overall understanding of the motion as well to be able to capture its essence when programming the new robot.

To do this, a tool called VideoAnalysis created by the RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion [50] at the University of Oslo was used. The tool was created for analysing and visualising human motion from videos, but its application can be extended to capture and analyse all types of motion in a video, which is why its use is also applicable here.

The tool's user interface is shown in figure 5.10. The application allows us to upload a video and process it in terms of clipping, colour schemes, and cropping and then it can export the data. The application analyses some interesting aspects of the video and you can get statistics and images as output. The statistics include bounding box coordinates and quantities such as quantity, height, or area of motion, among other parameters. In this thesis, the focus is on exploring the quantity of motion (QoM) of the movement, as this says something about the amount of movement in the video. It is calculated by summarising the amount of shifting pixels in each frame, such that it captures how much movement there is in each frame [23].

This can help us get a sense of how much the robot moves throughout a gesture or dance and can indicate the energy level of the dance. That is because the higher the QoM value, the more movement is there, and if there is more movement, it can be perceived as a higher level of energy in terms of motion [49]. It also shows us how the motion develops over time, so which part of the motion is more energetic or where it slows down. Although QoM gives a great measure of the overall level of movement, it

Figure 5.10: VideoAnalysis application

is not possible to further analyse what motions or body parts led to those values based on only the QoM value [49]. However, this information can still indicate the overall movement and patterns that can help replicate the motion of another robot. This makes it possible to capture and map the energy and essence of a movement, without a human operator having to analyse it.

Also, we can use the QoM values to calculate the cumulative values for the frames, such that you sum up all the previous QoM values up to the current frame, for all frames and for each frame you get the sum of QoM values up to that point. When plotting this information, the evolution of the dance becomes clearer. Where the graph is steeper, it means that more movement is happening over a short amount of time, and when the graph is less steep, there is less movement happening over a longer period. Thus, this can indicate the speed of the movement. Since we are not looking for an accurate mapping of speeds between different robots, this can help us understand how the movement happens and the general speed of it through different parts of the movement and we can use it to capture the same speed level on another robot.

In addition, the QoM value can give us a sense of emotion in the movement. Several studies have explored the relationship between emotions and quantity of motion. One study tried to use different cues such as the velocity of the arms or QoM, among others, as features for a classifier where the scope was to distinguish between emotions [26]. The results showed that the max value of QoM was the most important feature, giving the smallest error and thus indicating that it was able to discriminate between 4 different emotions. However, the researchers discovered that this feature could not successfully discriminate between all 4 emotions, but rather between high and low arousal emotions, so it discriminated between anger and joy and pleasure and sadness. This indicates that QoM plays an important role in discriminating between high and low arousal emotions. Another study also wanted to create an algorithm for discriminating between emotions, where they used a multi-layered approach to analyse different movement inputs to recognise one of these emotions: fear, joy, grief and anger [23]. One of the results was that the QoM measure got higher values for joy and anger than for the other emotions, again indicating that this feature can discriminate between high and low arousal emotions.

These studies suggest that QoM can be used as a measure to find whether a motion can be classified as high arousal, with a lot of movement and high intensity, or low arousal with less movement and low intensity. Thus this can be used to automatically discover whether the movement of the NAO robot is more or less energetic to get an understanding of what category of emotion the motion is in, and this can then help us program the imitator robots such that they capture the same energy. Due to the time restriction, however, there will be limited focus on this use case of QoM.

The processed QoM data is also added to the YAML file and the result is shown in figure 5.9. It is worth noting that QoM was calculated only for NAO's dances, as its gestures are quite consistent and indistinguishable, so the QoM values do not add additional and useful information about the motions.

5.5 Motion Translation Methods

In the previous section, the techniques for recording data through the NAOqi motion API and videos were explained. The result is a YAML file, shown in figure 5.9 including relevant information on NAO's possible motions, such as joint angles, speeds, and duration. This information describes the motion that should be replicated by any new robot added to the system. The developer can use this information from NAO to map the motions of the new robot in a structured manner to adapt them to this robot's capabilities. This method allows for mirroring the actions of a model robot within the range of motion of Misty in an automatic way, such that developers do not have to program all behaviours from scratch. A proposed approach will be presented in this section.

The mapping of behaviour to the new robot includes two important aspects, namely to find a mapping of body parts between the model robot, NAO, and the imitator, Misty, that can both capture the essential part of the movement, while also exploiting the features of the new robot. Because of the possibility that the robots in the system can be very different, the important part of the mapping is not to replicate the movement to the letter, but rather capture its energy and use the features of the new robot to try to convey the same essence so that the behaviours can be recognised on both robots.

Different methods for mapping can be employed, such as direct mapping of angles using interpolation or approximately following a trajectory defined by the end effector, using different mappings between the initial robot and the new one. In addition, the methods using QoM data were explored, where motions were created in three ways: only using direct angles and position from NAO, using only QoM data, and using a combination. The idea is that direct mapping will map the motion of a new robot, such that the new robot will capture the extent of the movement and reflect the direction of the movement of the original robot using its capabilities, but a general overview of the movement will be missing. On the other hand, using only QoM will capture the intensity and essence of the movement, leaving the developer with greater freedom to program the behaviour how they see fit. The combination of the two methods, however, will give a greater overview of the motion, including both a direct mapping of movement for capturing the details, as well as gaining an overview simultaneously.

In the background interviews, as presented in section 4.2.6, the participants reflected on their expectations of the integration of Misty, as well as the relevant factors that can affect the interaction between Misty and children with autism in the classroom. Taking the Interviewees' input into account is a crucial part of user-centred design, to design a system that is best fitted to their needs. The most significant factor that seemed to have a positive influence on the children's attention and motivation was the robot's movements. It made the robot seem like an active participant and one of the students, and the movements acted as a way of capturing the children's attention. Additionally, it was deemed important that the robot could convey meaning with body language only because a lot could be said without verbal language. This indicates that the movement of a robot plays a significant role in the benefit of children with autism. Therefore, care needs to be taken to create translation methods that best encapsulate NAO's motion, as well as reflect the appropriate meaning. One way this can be ensured is to identify and use the parts of NAO that are the most significant to the motion and mirror that within the range of motion of Misty.

5.5.1 Direct Mapping of NAO's Joint Angles

The direct mapping method is based on directly translating the angles and positions of NAO's body parts to fit the capabilities of Misty. This entails creating a mapping of the body parts of NAO to Misty. For some robot pairs, the body configuration of the robots may be similar, making the mapping more straightforward, while in other cases, the mapping might require creative thinking. For instance, NAO's arms have 6 degrees of freedom each, while Misty only has 1 degree of freedom per arm. Misty's arm would therefore only be able to capture the pitch direction of the movement of NAO's shoulders, while the other directions of the arm movement would be lost. Thus, Misty's arms might not be able to ideally capture NAO's arm movement. Conversely, Misty's head has 3 DOFs, which can be used to capture more of NAO's movement.

This can lead to interesting mappings between body parts. One example is to create a mapping between NAO's head pitch to Misty's arms, and NAO's Nao's shoulder pitch to Misty's head pitch, such that when NAO's limb moves a certain amount, Misty's mapped body part will move a corresponding amount based on its limits. The choices of mappings are many, but most importantly, they should reflect the movement of NAO as best as possible. So, the translation of movement does not have to be direct between corresponding body parts, but the developer can leverage the capabilities of the new robot in creative ways to best reflect the motions.

In this implementation, the behaviours in the remote control can be divided between gestures and dances. The gestures complement speech, such as greetings, praise, or encouragement, and are programmed on NAO as human-like gestures. For this reason, the most sensible option is to create a mapping between corresponding limbs. Even though Misty will not be able to fully capture the extent of NAO's gesture, it will create a more natural and recognisable gesture if Misty uses its head and hands, like a human would. The aim is also that this method will lead to understandable gestures for children with autism, given that they were created using some of NAO's significant joints. Therefore, the general mapping for the gestures is as shown in table 5.1, but it is also possible to define other general mappings or even define specific mappings for some gestures.

Dances can also be translated using direct mapping of joint angles, where the resulting motion will reflect some aspect of NAO's joint movement. This will also require a mapping definition, which can either be as defined in table 5.1 or a completely other. Conversely, dances do not require a specific mapping, and the motions do not necessarily have to be structured and logical, nor do they have to replicate NAO's motions precisely, as the gestures should. Thus, this method can be leveraged to define mappings between

NAO's joints	Misty's joints
shoulder pitch left arm (LShoulderPitch)	left arm (LArm)
shoulder pitch right arm (RShoulderPitch)	right arm (RArm)
head yaw (HeadYaw)	head yaw (Yaw)
head pitch (HeadPitch)	head pitch (Pitch)

Table 5.1: Mapping between NAO and Misty for gestures

other body parts that might create more interesting moves, while still mimicking the essence of the motion. This consideration will be addressed in greater detail later. Currently, the same mapping as presented in table 5.1 was chosen to replicate the dances. This mapping was chosen for the dances because it will match the direction of movement of NAO's hands in the forward and backward directions, as well as the head will be able to fully replicate NAO's head. Although this mapping will not necessarily maximise Misty's potential, because several aspects of the movement will be ignored, it is still an adequate way of replicating the motion.

Furthermore, when the mapping is established, the specified joints are used to retrieve data from NAO's behavioural YAML file. These angles are read directly from NAO's joints and are translated to fit within Misty's joint limits. In a study, Pollard et al. aimed to use human motion to animate a humanoid robot [74]. A part of their approach consisted of scaling the human motion to fit the limits of the robot, as the robot has limited mobility compared to the human body. The researchers used a non-uniform scaling method where they calculated scaling values that were applied to segments of the motion, to obtain angles within the limits of the joints and simultaneously following a similar trajectory as the original motion.

A similar idea was employed in this thesis, to fit NAO's angles within the limits of the Misty robot. Instead, a simpler method was employed, using interpolation. The idea of this method is to find the trajectory of NAO's joints within the limits of Misty's joints. The known lower and upper joint limits, in addition to the starting position of NAO's limbs, are used to estimate a function for the corresponding parameters of Misty's limbs. This results in a function that reflects NAO's motion, as it creates an interpolation of the joint limits and start position. Thus, when passing a joint angle from NAO's movement through the interpolation, the outcome is a corresponding angle within Misty's limits. The purpose of this method is to find how large each angle in the motion is about NAO's joint limits, and thus, how large the movement is, and map it to Misty's limits. The result will be angles that move Misty's limb a corresponding amount to the original motion, though within its limits.

Several interpolation methods can be employed to solve this objective, such as linear interpolation or cubic interpolation. Linear interpolation turned out to be an unfit method, as it only allows to interpolate between two values, which would entail ignoring the initial position of the limb. This can result in a shifted motion where only the limits are taken into account, and the issue arises when interpolating for example the values for NAO's shoulder, especially for the gestures. Their initial position has angle zero and the arms are pointing downwards, while this is not the case for the corresponding position for Misty's arms, as their zero position is when the arms are pointing straight forward. To take this into account, linear interpolation is not sufficient. It is therefore beneficial to include the initial position of the limb as it will yield a more accurate result. The interpolated function will also pass through the initial angle for both robots, which means that the result will be a more accurate mapping of the motion in both directions. A cubic interpolator, which makes it possible to interpolate between multiple values, solves this problem. However, it has issues with overshooting values and outputting angles that are outside Misty's range, which results in another issue.

Instead, a Piecewise Cubic Hermite Interpolating Polynomial (PHCIP) interpolator from the Scipy Python library was used. One notable benefit of this interpolator is that the resulting values are limited to the given range and do not overshoot [91]. This is especially significant in this application, as we do not want the resulting angles to be outside of Misty's joint limits. Another benefit is that if the angle data is monotone, it will preserve the monotonicity in the data, which means that the interpolator will not create any oscillations that are not present in the original data. Because of these benefits, the PHCIP interpolator was chosen. It was used using the joint limits and start position of both of the robot's limbs to obtain the interpolated functions. The joint limits were found in the documentation for NAO [52] and for Misty [83]. Then NAO's angles for the motion of the specific limb were run through the interpolated function to obtain Misty's corresponding angles. Figure 5.11 shows the pattern of NAO's left arm (purple) and the corresponding pattern of Misty's left arm (blue) during a motion. The interpolation method captures the pattern of the original motion, as well as keeping the motion within the limits (striped lines), as required.

Furthermore, the angles are recorded from NAO each 0.5 second, meaning that the list of values is rather large and sending each angle as a command to Misty in this interval is unsuitable. Instead, the key angles are identified in the dance, and saved along with a time stamp so that the commands can be sent at the correct time. The key points are equivalent to the extreme points of the angle lists, meaning the points where the angles change direction. The extreme points are checked, because as figure 5.11, the graph is not smooth and it contains some intermediate points which are unnecessary to send as commands. Therefore, the list of angles is cleaned up so that only the angles at the edges, the key poses, remain. Lastly, the commands sent to Misty for each joint come from an angle list, with corresponding indices.

5.5.2 Motion Mapping Using End-effector Positions

As mentioned in section 5.5.1, dances do not necessarily require a specific mapping, because their purpose is to offer encouragement and entertainment. In the background interviews, the staff at Frydenhaug mentioned that dancing to music seems to be a significant factor that contributes to the engagement of the children. Another aspect was that NAO's body is similar to the children's, which makes it easy to imitate. Several interviewees pointed out that the combination of NAO's articulate and dynamic dances and the fact that it is easy to mirror have been the most important factors for the children. Misty, however, is limited in its range of movement, so there is no way of capturing all the aspects of NAO's dynamic movements. And because of its non-articulated body, the resulting dances might not be as intriguing.

Taking this into consideration, the idea behind the use of end-effector positions is to create dances that are exciting and fun, despite limited mobility of Misty. This is a

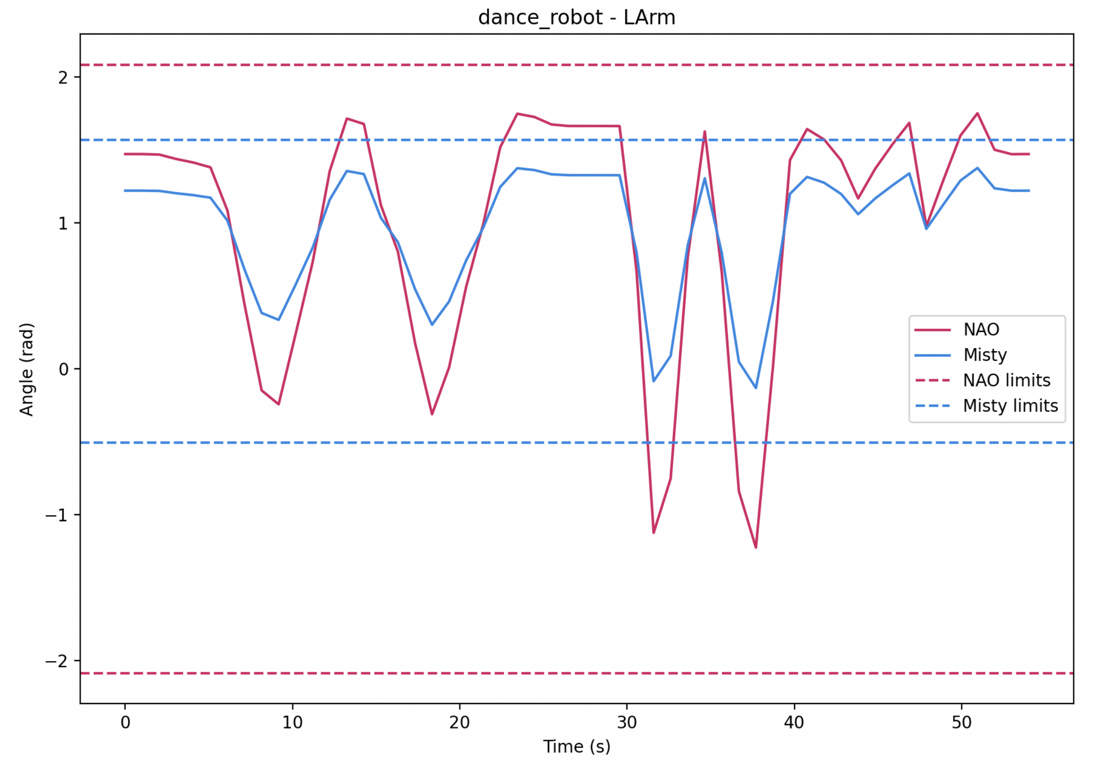


Figure 5.11: Original and interpolated values of the left arm during the robot dance for NAO and Misty respectively.

suitable method for the dances because it allows for capturing a different aspect of the original movement than the direct mapping of angles. This method was devised to leverage the full potential of Misty's head, as it offers great mobility compared to NAO's. A similar approach as the one previously described is employed here, but with some modification.

The approach consists of capturing the trajectory of the left and right hands of NAO in three-dimensional spaces and mapping that movement to head movement on Misty. Thus, the idea is that Misty's head will capture the extent of the motion from NAO. This also entails defining a mapping, which is determined to be according to table 5.2, so that each linear movement along an axis will correspond to a rotation in one direction.

NAO's movement	Misty's joints
x-direction	head roll
y-direction	head yaw
z-direction	head pitch

Table 5.2: Mapping between NAO and Misty for dances

Mapping linear motion to a rotational joint is a challenging task. However, this case does not require an exact mapping of motion, so the interest lies only in representing the general direction of movement. The general method entails finding the directions and magnitudes in each direction and mapping it to its corresponding joint. Figure 5.12 shows the movement of NAO's left arm in x-, y-, and z-directions.

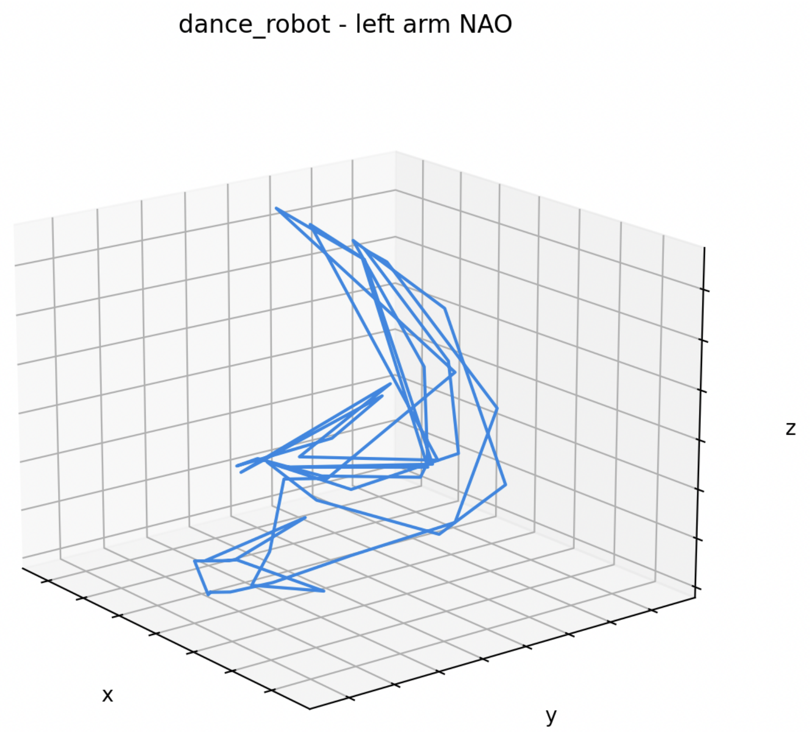


Figure 5.12: Movement of NAO's left arm in 3D space

Similarly to the first method, the turning points in the data are extracted. In this case, it entails finding when NAO's arm changes direction in space. Since it is a three-dimensional space, the turning points are found in the three directions simultaneously, instead of finding the turning points of each direction and having to combine them. The turning points enable the definition of lines between them, which corresponds to a linear motion of the arm in space that should be mapped to a movement of Misty's head. From this line, its magnitude and direction are extracted. The magnitude corresponds to the length of the line, which in turn indicates how far NAO moved its arm in that segment of motion. The direction indicates the motion of the direction and is represented by a vector containing the directions x-, y-, and z-directions by -1s and 1s, where the negative value denotes the arm moving in the negative direction. Thus, the magnitude can be used to decide how much the head should move in a certain direction, while the direction can decide the direction of the head.

Since the aim is not to do a perfect mapping, but to follow the general direction and amount of motion, the magnitudes will not be mapped directly to a certain angle. Instead, the range of magnitudes is transformed into the range of motion of Misty's head. The magnitudes are therefore mapped to the position of the head depending on what range they are in. This means that the smaller magnitudes (smaller motion of the arm) will get a small position value and the head will move a little, while the larger values will lead to a larger movement of the head. This results in a list of angles for each direction of movement of Misty's head that are sent as commands to Misty.

5.5.3 Mapping Using Torso Positions

The NAO robot is a bipedal robot, and thus it is possible to program the NAO to move its lower body to create more dynamic and life-like motions. Misty does not offer that possibility, but it is equipped with driving bands and can drive around, which makes it possible to map the movement of the lower body to Misty's bands. However, this is a challenging task, as the motions of NAO's feet are very complex, so it is simplified by only considering the general direction of the movement of NAO's lower body. For this purpose, the position of the torso with respect to the world frame is used. The idea is that the position of the torso is influenced by the movement of the hips and knees, and thus this single point captures the general direction of movement of the legs. Figure 5.13 shows the movement of NAO's torso in x- and y-direction for a dance. For this dance, the robot is swaying from side to side (in y-direction), which can be identified on the graph.

From figure 5.13 it is clear that this movement is challenging to translate the motion directly to Misty's abilities. Instead, the approach consists of finding the dominant direction of movement, meaning finding whether the robot moves more in the x- or y-direction. For this dance, the robot moves significantly more in the y-direction, as the figure shows. These movements are mapped to Misty's driving, according to table 5.3. Thus, Misty will rotate whenever the dominant direction is along the y-axis, and will drive linearly whenever the direction is along the x-axis.

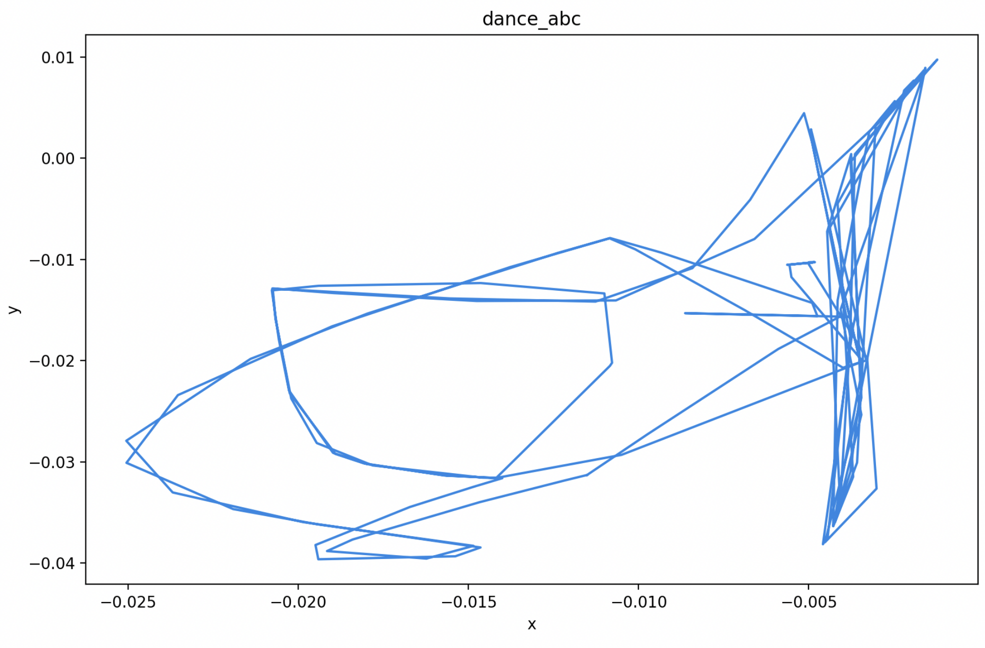


Figure 5.13: Movement of NAO's torso

NAO's torso movement	Misty's driving
x-direction	linear
y-direction	rotating

Table 5.3: Mapping between NAO and Misty for their lower bodies

5.5.4 Implementation using Quantity of Motion

Creating a direct mapping between angle and position data allows for directly replicating the data fitting to the capabilities of a robot, and the focus is fixed on the recorded values from NAO. However, this method itself does not provide a holistic overview of the movement. Thus, it is hard to get a sense of how the motion is performed, its overall speed, and energy level only from a stream of joint or position values. Therefore, another method using Quantity of Motion is devised. QoM is calculated based on a video of a motion and it gives a value for how much movement there is in the video, as explained in section 5.4.2, thus giving a tangible number for the intensity of the motion. This is used to create interesting dances for Misty based on data extracted from the NAO's QoM values during the same dances. Some features from QoM have been extracted and saved in NAO's YAML file, such as QoM values, speed, and segmentation of the movement, which will be of use here.

Firstly, a dance might be made up of different parts and the energy level does not need to be the same throughout the whole dance. Using the QoM graphs for each motion, the dances were manually segmented into meaningful pieces that can be used to understand the energy levels within important parts. Automated techniques were attempted to segment the dance, but it was found that the most accurate method was to manually segment the dances by comparing the graphs and the video of the motions, which led to a better understanding of the dance. This *extreme_points*, as they are called in the YAML file from figure 5.9, denote the frame number of the partitions of the dance.

Using this segmentation of the movement, information is extracted for each part. The two main features that are obtained from each part are the intensity level and the level of fluctuations. The intensity level indicates whether there is a lot of motion within the segment, while the fluctuations indicate if there is a lot of variation in QoM value or a lot of high peaks and low trenches in the segment. These are two dimensions of the intensity, in addition to the speed, that can help to define a new intensity-based motion for Misty. Figure 5.14 shows the QoM graph. The QoM data was smoothed using a moving average technique to remove short-term fluctuations and make it easier to find a pattern in the data.

This approach can be implemented in several ways, and in this thesis, an approach using some randomness was chosen. Here, the range of motion of each Misty's head and arms is divided into three parts. For each segment of the motion, the level of intensity and fluctuations are obtained, and either the upper, middle, or lower range of movement is chosen. Using the intensity measure, if the segment has a high level of energy level, the joint angles for Misty's joint will be chosen from two different segments, or the same segment if the energy level is low. Additionally, if the level of fluctuations is high within a segment, the values will alternate between high and low energy levels. The values are chosen randomly within each range to create more interesting motions. Essentially, the

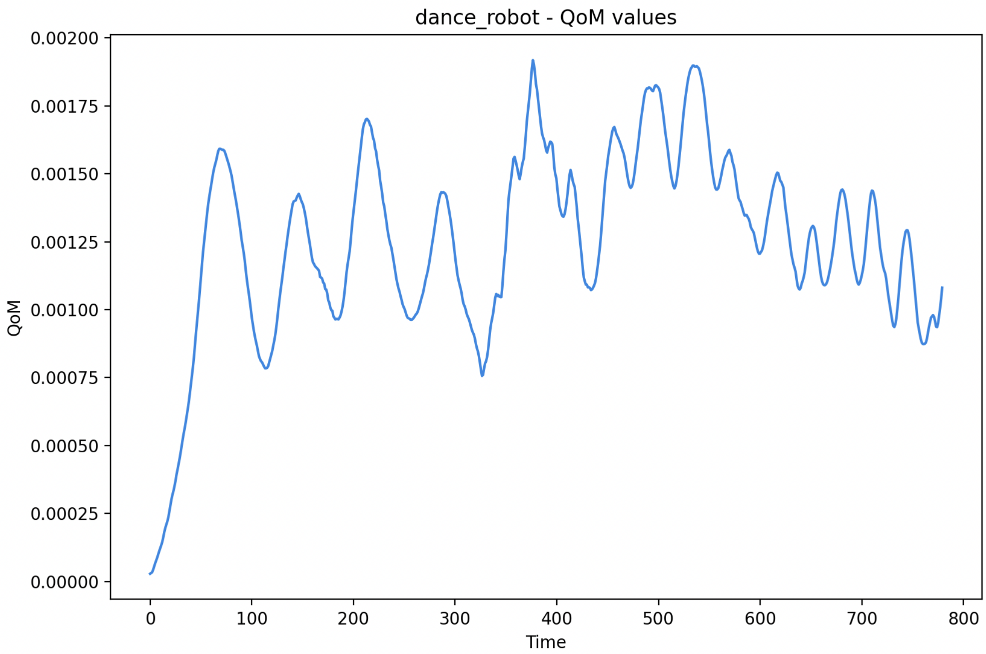


Figure 5.14: QoM values from the robot dance

idea is to match the energy level of NAO throughout the dance.

Moreover, it is possible to use the QoM values to indicate the speed of the movement. For each frame in the video, the QoM values up to that point were summed to create a cumulative sum over the whole sequence, such as the graph shown in figure 5.15. The cumulative sum was used to find the overall gradient of the curve, which entails finding the slope of the cumulative sum by using the start and end of the curve. This will indicate the overall rate of change of the QoM value in each motion, and as explained earlier, it can indicate the speed of the motion. The gradients of all the motions are used to define a threshold used to separate between fast and slow motions. The threshold is found by averaging the thresholds for all motions and the gradient for each motion was compared to the threshold. If the gradient is larger than the threshold, it means that there is in general a higher rate of change of QoM and the average of all dances, which indicates a higher speed of motion. Similarly, if the gradient is less than the threshold, it indicates lower speed because of a lower rate of change of motion throughout the motion. For this thesis, there is less emphasis on directly mapping the speed between the robots, but rather on capturing the general speed at which a motion is performed and recreating that on another robot.

5.5.5 Combination: Direct Mapping and QoM

It is possible to use the previously explained methods separately, however both have their drawbacks. Using direct mapping of angles and positions is missing the holistic overview of the motion, and without using QoM as a feature, it is challenging to determine the speed of the motion and the intensity of the motion in a structured way, in addition to the segmentation into parts. This will lead to a motion, where only the angles and positions are mapped to the capabilities of the new robot without consideration of any

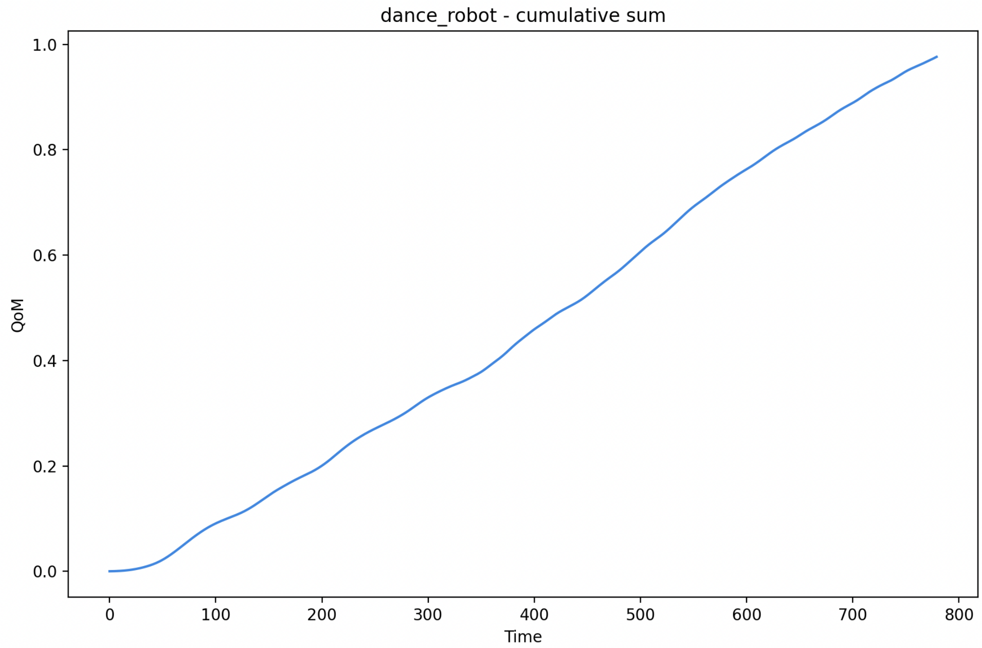


Figure 5.15: Cumulative sum from the robot dance

other parameters. On the other hand, QoM will give us a notion about the speed, intensity, and segmentation, but this information alone is not enough to closely replicate the movement. Without angle or position data, it is not known exactly how the limbs move and where they should be at any time, and thus without this information, the movements of NAO cannot be directly imitated.

Another way of implementing the imitation of the movement is then to combine the two methods, which will provide both a holistic and a detailed overview of the motion. In this implementation, the angles and positions are mapped to Misty to mirror NAO's movement as explained in 5.5.1. In addition, elements from the QoM values are added to the mapping of the behaviour. The speed, for example, is included to decide the speed at which Misty's limbs and driving bands should move, thus making Misty able to move at a speed closer resembling the original motion. In addition, the average intensity value can be used to decide the colours of the LEDs or the facial expressions during the dance.

In addition, the segmentation of the dance can also be used to create a more interesting dance in a way that is up to the developer. For example, in this case, it was found through trial and error that moving Misty's head in all three directions simultaneously leads to a chaotic and incomprehensible movement. Therefore, a method was implemented to find the significant direction in which the head moves the most within a segment of the dance. Thus, the significant directions of the head will be found and the head will only move in those directions throughout the segment. This will allow for using all 3 degrees of freedom of Misty's head without committing to only some directions throughout a motion.

5.5.6 Details on Misty Programming

The sections above explain how the description of NAO's motion is translated for a specific robot, Misty. The translated and robot-specific information is saved to YAML files, as figure 5.8 shows, and is used at runtime when the remote control is used. The idea is therefore that it is up to the developer to use the description of NAO's motion and follow the structure of the aforementioned methods to perform the translation. This leaves the developer to decide the level of sophistication of the programmed movement of the new robot.

In this implementation, the programming of the Misty robot is automated, such that the task-specific YAML file is parsed and the robot performs the task directly based on it. This means that the programmer does use Misty's API, but the angle and position commands that are sent to the robot are included in the YAML file already, for the approach of the direct mapping. Similarly, for the approach using the intensity measure, where the information extracted from QoM is used to map to a certain behaviour directly. This entails that the developer does not have to program each motion separately, but using the YAMl file, the motion is decided already. However, whether to automate the programmed motions or not is a decision left to the developer.

Chapter 6

Evaluation

After implementing a system, the next phase in the user-centred design model from section 3.2 involves testing and evaluating the system. In user-centred design, this entails involving the users and assessing whether the implementation meets the expectations and requirements. In this thesis, the evaluation stage is divided into two parts, one with school staff from Frydenhaug and another with a wider population. The purpose of the evaluation is to gain insight into whether the proposed implementation could work with children with autism within the context of the school and what further improvements are needed for a successful integration of the robot. Thus, that data collection will provide direct insight into the setting where the implemented remote and robot potentially will be used. Another goal is to discover the opinions of a general population on the level of success of the motion translation methods, a method that provided feedback on how the Misty and NAO robots were perceived concerning their movements. This chapter describes how and why the data collections were conducted.

6.1 Closing Interview at Frydenhaug

The closing interview aimed to see how the remote control implementation with both Misty and NAO would fit in within the context of Frydenhaug School. This entails uncovering how children with autism potentially might respond to the new robot and its behaviours, usefulness, and improvement points. This provided the user's input, both from the perspective of the school personnel and the children and aided in identifying both success factors and improvement points for the implementation.

6.1.1 Participants and Recruitment

Similarly to the background interviews, an email was sent to the leader of the ROSA project at Frydenhaug seeking approval for performing an interview with the school staff. The leader recruited relevant personnel who had experience with children with autism and with the remote control system and set up the interview. This resulted in two staff members participating in a common interview. Both of the interviewees had used the original remote control system with NAO, and could thus provide constructive reflections of the applicability of the new remote implementation with Misty with respect to children with autism and their school context.

6.1.2 Interview Design

An interview guide for a 30-minute long interview was created based on the implementation of the prototype. The interview guide, shown in appendix E, included questions about the context in which Misty could be used at Frydenhaug, as well as its functionalities. Examples of questions from the interview guide are:

- How do you think the children would interact with Misty?
- Do you think Misty's motions fit the different buttons on the remote?
- Which other purposes do you think Misty could be used for?

The questions were designed to get an idea of whether Misty can be used as a replacement for NAO or for other tasks, in addition to getting insight into reflections on the mobility and movements of Misty concerning children with autism. The participants also interacted with the remote control and the two robots to test out the functionalities of the system first-hand. The activity aimed to explore the implications of the system on children with autism, to ascertain whether their expectations were met, and what further improvements are needed.

Figure 6.1: Image from the evaluation interview with the two participants.

6.1.3 Data Collection

The closing interview was a semi-structured joint interview with the two participants. As in the previous interview, the semi-structured interview allowed for exploring the interviewees' reasoning and evaluation of the implementation and following the interesting themes that were brought up.

The evaluation interview also took place at Frydenhaug School in Drammen and was conducted in April 2024 and lasted around 30 minutes. The interview process consisted first of an introduction to the interview, this thesis, and a presentation of the implementation. In the next part of the interview, the participants could interact with the remote control and the Misty and NAO robots. The participants were asked the set of questions from Appendix B as they explored the functionalities of the remote and the responses of the robots. Their responses were not recorded, but relevant notes were taken by hand. Figure 6.1 shows an image taken at the interview, where the participants can be seen using the remote control with the Misty robot.

6.1.4 Data Analysis

Only notes of the participants's responses and reactions were taken. Therefore, a simple thematic analysis of the notes was applied to identify interesting themes that arose in the interview. The focus of the analysis was to get an understanding of whether the remote and Misty can be integrated into the context of Frydenhaug, either like NAO or in other settings, as well as get some reflections on Misty's mobility and movements. The idea was merely to get an idea of the first impressions of the users, so an in-depth analysis and evaluation were omitted for the purpose of this thesis.

6.1.5 Ethical Measures During Closing Interview

Since no personal or identifiable information was collected from the participants, there was no need for any specific ethical precautions for this interview. The participant's confidentiality and anonymity were ensured as their responses were independent of their identities, and it would be difficult to use the collected data to trace it back to them. The participants were also informed of what data was collected and for what purpose and were aware of the voluntary participation, as well as their rights. For this data collection, oral consent was deemed appropriate due to the minimal risk involved, the non-sensitive nature of the data collected, and the interviewees' ongoing involvement in the ROSA project.

6.2 Online Questionnaire to Evaluate Robot Movement

In addition to gaining a qualitative insight into the context of the prototype and its evaluation in an educational setting, data collection was performed to gain a general insight into how well the implementation worked. For this purpose, an online questionnaire was created, a method that allows for reaching out to a wider population quickly. The participants were presented with videos of both the original movements of NAO and the translated motions of Misty and were asked to rate their impressions of the robot and the different methods of implementation. This will contribute to seeing the differences and similarities in how the robots are perceived and can indicate the level of success of the motion translation.

6.2.1 Questionnaire Design

The online questionnaire was hosted by Nettskjema, a questionnaire website created by the University of Oslo. The objective of the questionnaire was to gain insight into the general ratings of the created motions, so the questionnaire was divided into two main parts. The first part contained eight short videos of the NAO and Misty robots performing the same motions, where the participant had to match the videos that showed the same motion together. The purpose of this was to observe to what degree people can understand the gestures the robots are performing and thus, the degree of success of the motion translation.

The second part consisted of videos showing NAO dancing, and 3 versions of the same dance performed by Misty. The participants were asked to rate all dances on a scale from 1 to 5, where the objective was to see how the robots' movements are judged compared to each other and to discover the ratings of the different movement translation methods that were tested on Misty. Additionally, the participants were asked to rate their perception of both robots at the start of the questionnaire and at the end, after having watched all the videos, to discover whether the movements affected their perception of the robots.

Appendix F presents the online questionnaire.

Using RoSAS for Measuring Robot Perception

RoSAS, the Robotic Social Attributes Scale, was used for rating the perception of the two robots. RoSAS is a validated scaling framework that is used for rating the perception of robots [25]. It offers a standardised method to measure how humans perceive robots in interactions with them, and it is designed to work independently of the robot's appearance. This scale was developed based on the Godspeed Scale [11], and was reduced to measure three important dimensions of robot perception, namely warmth, discomfort, and competence.

RoSAS measures six different variables for each of these dimensions, where the scores within each category can give indications of the social interaction with a given robot based on how it is perceived [25]. In this thesis, the interesting dimensions were warmth and discomfort. The NAO and Misty robots are developed to interact with children, and thus it is important to minimise the the level of discomfort and maximise the level of warmth in how it is perceived through its appearance and movements. Measuring these dimensions will thus give an insight into how the robot's physical aspects and behaviours influence how they are viewed, and thus can indicate how the interaction with them would go.

Table 6.1 shows the measured variables across the dimensions of interest. Three variables were chosen from the *warmth* and *discomfort* categories based on relevance to this thesis, and to make the questionnaire less overwhelming to the participants. These categories are deemed interesting and relevant for social robots for working with children with autism. The attributes under the *warmth* and *discomfort* dimension, shown in table 6.1, were chosen because these are some traits that a social robot working with children with ASD should embody or not.

Dimension	Variable
Warmth	Happy Social Emotional
Discomfort	Scary Strange Awkward

Table 6.1: RoSAS dimensions and variables of interest in this thesis

Design Choices

The questionnaire was written in English so that it could be distributed internationally and reach a wider audience. It was structured using a within-subject design, which entails that the participants were all presented with the same questions in the questionnaire [28]. The alternative would have been a between-subjects design, where the participants are divided into groups and each group is shown a certain aspect of the questionnaire, instead of having to answer all questions [28]. The within-subjects design was chosen as it is more suitable for a smaller group of respondents, as the between-subjects design requires that there are significantly more participants involved so that they can be randomly assigned to smaller groups.

In this questionnaire, each participant watched three sets of dances done by both robots before rating their final perception of the robots. Thus, the final perception will be influenced by all the videos, which can be advantageous as it gives an overall score to how the movements influenced the score in general. However, it might have been advantageous to use a between-subject inside in this context, so that each participant could have viewed only one set of dances or one method so that the rating would only be influenced by one variable at a time, thus indicating how each implementation method or each dance influences the ratings. In addition, it could also minimise participant fatigue. However, it was not possible to recruit enough participants for this design due to the limited time.

Using within-subject design also leads to having fewer participants, but also great statistical power. Between-subject design research is affected by participant variability, where the personal traits of the participants may affect the results, while in within-subject design, the participants act as their controls for comparison as they are exposed to all questions [39]. The statistical power of the within-subject design also involves the fact that the differences between responses are less likely to be due to interpersonal differences between participants or groups instead of the effect of the independent variable to be tested.

However, when using a within-subject design, randomisation of questions should be considered. Not randomising the order in which participants view the questions can lead to effects such as carryover effect or order effects [28]. The carryover effect implies that the ratings of one set of dances affect the perception of the next ones. The order effect entails that the order of the videos can affect the results, for example, because of fatigue.

In Nettskjema, the questionnaire website used in this thesis, randomisation of the questions was not possible, and thus randomisation was omitted from the questionnaire. This implies that all respondents were presented with the same questions and in the same order. The effect this might have had on the findings will further be discussed in the results in chapter 7.

6.2.2 Recruitment and Respondents

As the purpose of the data collection was to collect a general impression of the implementation, the questionnaire was directed towards the general public who has an interest in robots. The questionnaire was distributed to people within my network, who were encouraged to further share the questionnaire within their network as well. In total, the questionnaire received 37 responses.

The questionnaire was anonymous and no personal data was collected, so it cannot be known exactly who responded and where it circulated. However, based on who the questionnaire was distributed to within my network, it is known that the respondents covered a wide age range and reside in countries such as Norway, Japan, and Romania. Although my network is mostly made up of people living in Norway in the 18 and 30 years age range, it is expected that this group is the most represented in the answers to the questionnaire.

6.2.3 Analysis of Questionnaire Data

The questionnaire included RoSAS scores, matching of gestures between robots, ranking of dances, as well as textual explanations for each of their numerical responses. The mixed-methods nature of the questionnaire called for different analysis methods, so both a statistical method and thematic analysis were employed.

For the RoSAS scores, a Wilcoxon signed-rank test was performed to test the statistical significance of the difference between scores before and after having watched videos of the robots. The Wilcoxon signed-rank test is a distribution-free statistical significance test devised for non-parametric data, which entails that there are no initial assumptions about the distribution of the data to be analysed [101]. Furthermore, this entails that it is not necessary to check whether the data follows the normal distribution, as for some other statistical tests. This is an appropriate method for analysis in this case because there is a high probability that the data is non-parametric due to RoSAS. This is because the distance between the different RoSAS scores is not necessarily perceived as equal between respondents, which might lead to a non-uniform distribution of the data. The Wilcoxon signed-rank test is used in a matched-pair setting here, as the answers of the same participants are obtained and compared at two different times, resulting in two samples of comparable data. The test is then used for identifying whether the distributions of the two samples are the same [102].

The Wilcoxon signed-rank test outputs a p-value that can be compared with the standard value for statistical significance, the α-value. Normally, if a statistical test outputs a p-value such that $p \leq 0.05$, the result is considered statistically significant. However, when multiple tests for one group are done on the same data, as in this case where the Wilcoxon signed-rank test is applied on each measured RoSAS attribute, it is recommended to apply a Bonferroni correction [61]. The Bonferroni correction implies calculating a new

α-value, which the p-values will be compared against, in the cases where multiple tests are performed [61]. This correction method is applied in this thesis, to ensure correct comparison of the statistical comparison case.

The aforementioned statistical methods were applied to the RoSAS score because they offer a way of determining whether or not there was a significant difference in the perception of the robots due to their movements. However, for the matching of gestures and ranking of dances, there are no relationships to be tested, so no statistical analysis is done. For these tasks, however, the textual answers are significant. These responses are analysed with thematic analysis, as explained in section 3.4. The analysis will provide insight into the respondents' reflections on the different motion translation methods in terms of successes and improvements.

6.2.4 Ethical Measures for the Questionnaire

The questionnaire was completely anonymous and no personal and identifiable information was collected. There was no need for an application to the Norwegian Agency for Shared Services in Education and Research (SIKT), as no personal data was collected or handled in this data collection. The questionnaire was also voluntary to answer, and no risks were associated with not being willing to participate or with the participation itself.

Chapter 7

Results from the Implementation and Evaluations

The results of this thesis are two-fold: the resulting motions for Misty from the different motion translation methods presented in chapter 5 and the user evaluations of these methods explained in chapter 6. According to the user-centred design principles, the goal in software development should not be merely to design a system, but it is crucial to ensure that the system is usable and beneficial to its users. Therefore, both an interview and a questionnaire were employed as evaluation methods, the results of which are presented in the remainder of this chapter, together with a presentation of the actual movements created.

7.1 Result of the Motion Translation Methods

The results from the implementation are corresponding motions on Misty, where both robots can be controlled by a remote control to perform the same behaviours. For all the different behaviours on the remote, Misty can mirror NAO's movements. Figures 7.1 and 7.2 show the sequence of movement for a dance performed by NAO, where the different poses can be seen, whereas figure 7.3 shows the corresponding dance by Misty. To show the dances, the method using direct mapping was used, as explained in section 5.5.1, where the angles to all joints were mapped between the robots. This dance has a clear sequence of movement, so it can be seen that for example pose 2, 3, 13, and 16 from figures 7.1 and 7.2 correspond to poses 2, 3, 7, and 9 from figure 7.3.

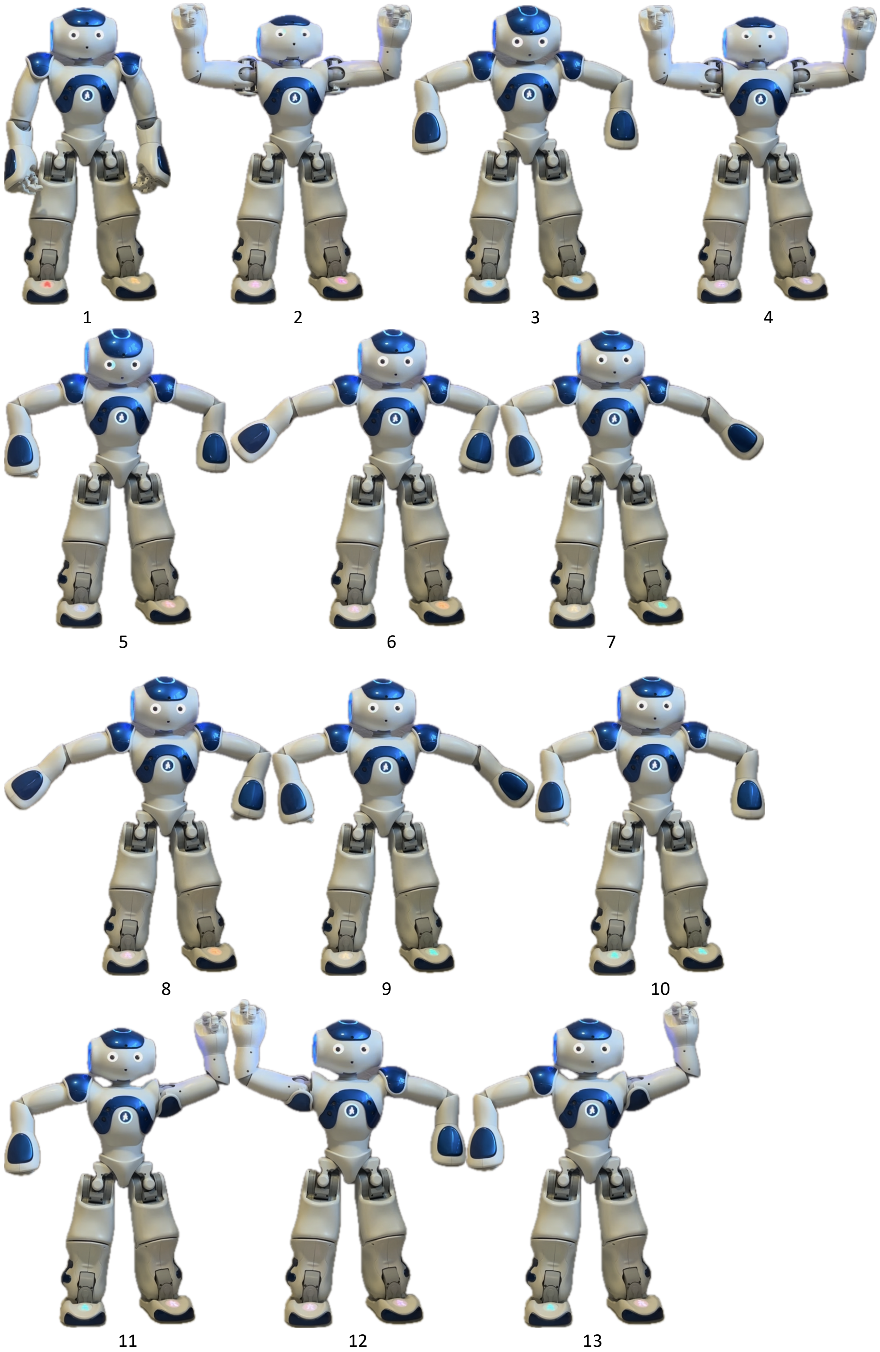


Figure 7.1: Part 1 of the sequence of the robot dance performed by Nao.

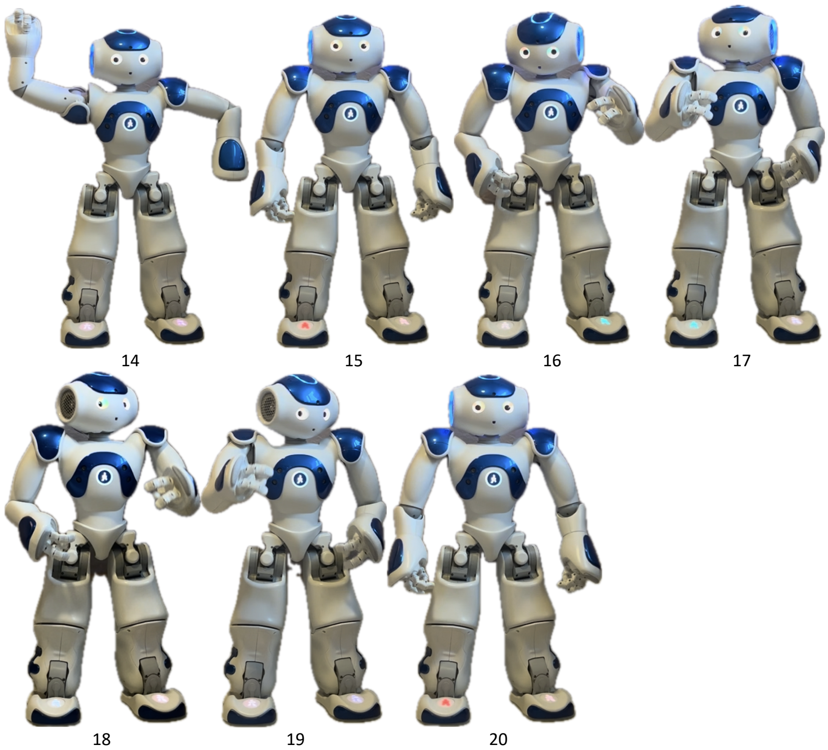


Figure 7.2: Part 2 of the sequence of the robot dance performed by Nao.

7.1.1 Graphs Presenting the Method Using Joint Angles

It is also possible to closely analyse the joint angles for the different motions as graphs. This makes it possible to observe the trend of the original motion in terms of either joint angles for the joints of interest or the position of the end effectors to determine whether the motion mirrored by Misty is performed as expected. Figure 7.4 shows an example of the angles that are input directly into the robot. The pink graphs in the images show the original motion by NAO, and the blue graphs show Misty's motion. As can be seen from appendix 7.1, the movement of the arms is symmetric for this dance, so only the graph for the left arm is included here, as the one for the right arm is similar. These images show that the produced joint angles for the arms, head pitch, and head roll, follow the same pattern as NAO. This indicates that Misty can do the same motion within its range and capabilities by using NAO's joint angles directly.

7.1.2 Graphs Showing the Method Using End-Effector Positions

The method where positions of the end-effectors of NAO are used is more challenging to present graphically, due to the positions in three-dimensional space that are mapped to joint angles. The graphs in figure 7.5 show the mapped angle of Misty's head in yaw-, pitch-, and roll-directions in blue. They are derived from NAO's position of its left arm, shown in pink in the figure. The pink graphs depict the movement of the arm in y-, z-, and, x-directions respectively, where both the magnitude and the direction of the movement (positive or negative) are taken into account. Thus, NAO's graphs do not reflect the actual amount of movement in centimeters or radians, but the general direction and magnitude. It is possible to observe a common pattern between the graphs

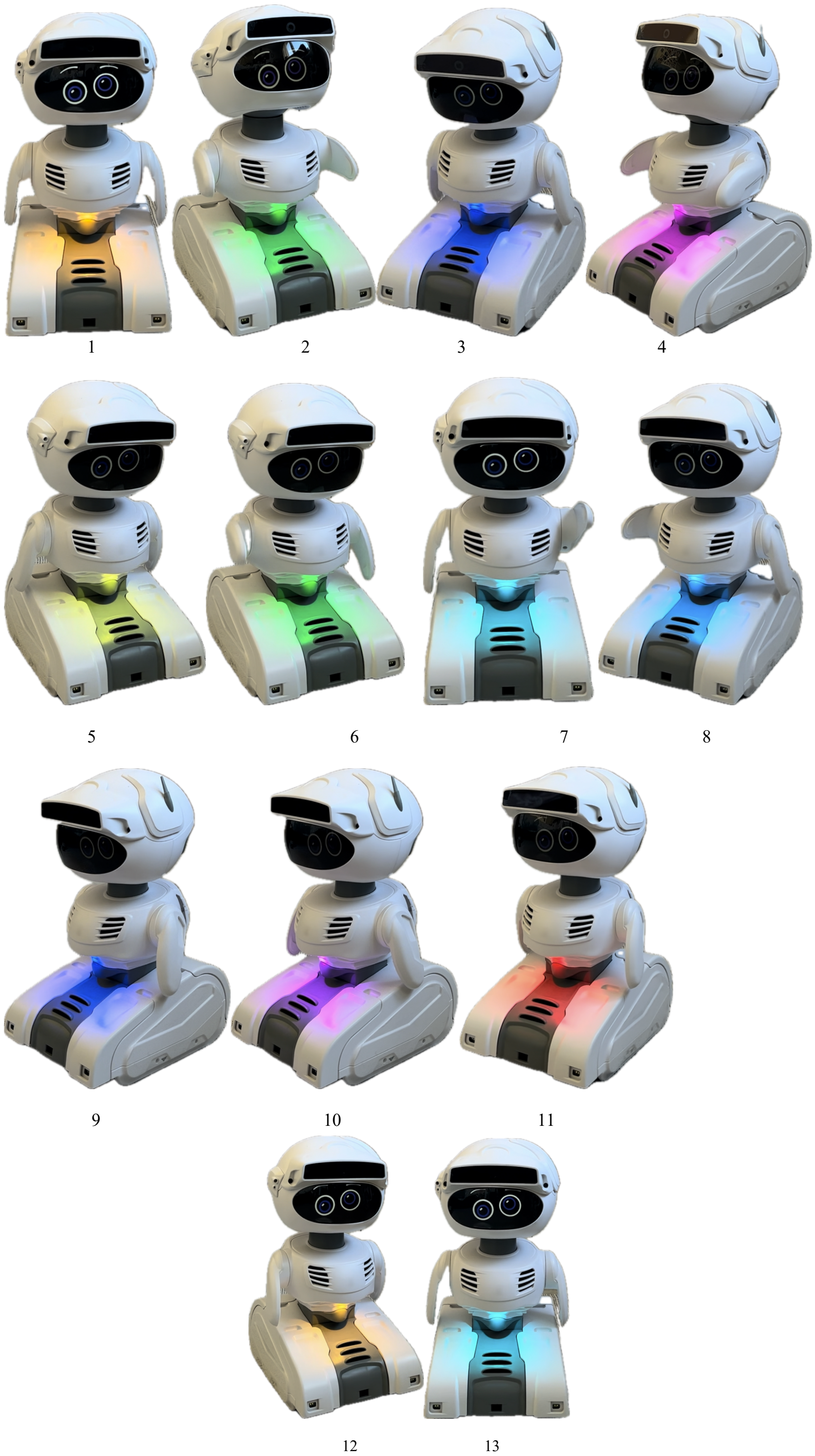


Figure 7.3: Sequence of the robot dance performed by Misty. Direct mapping, as explained in section 5.5.1, was used to mirror NAO's dance.

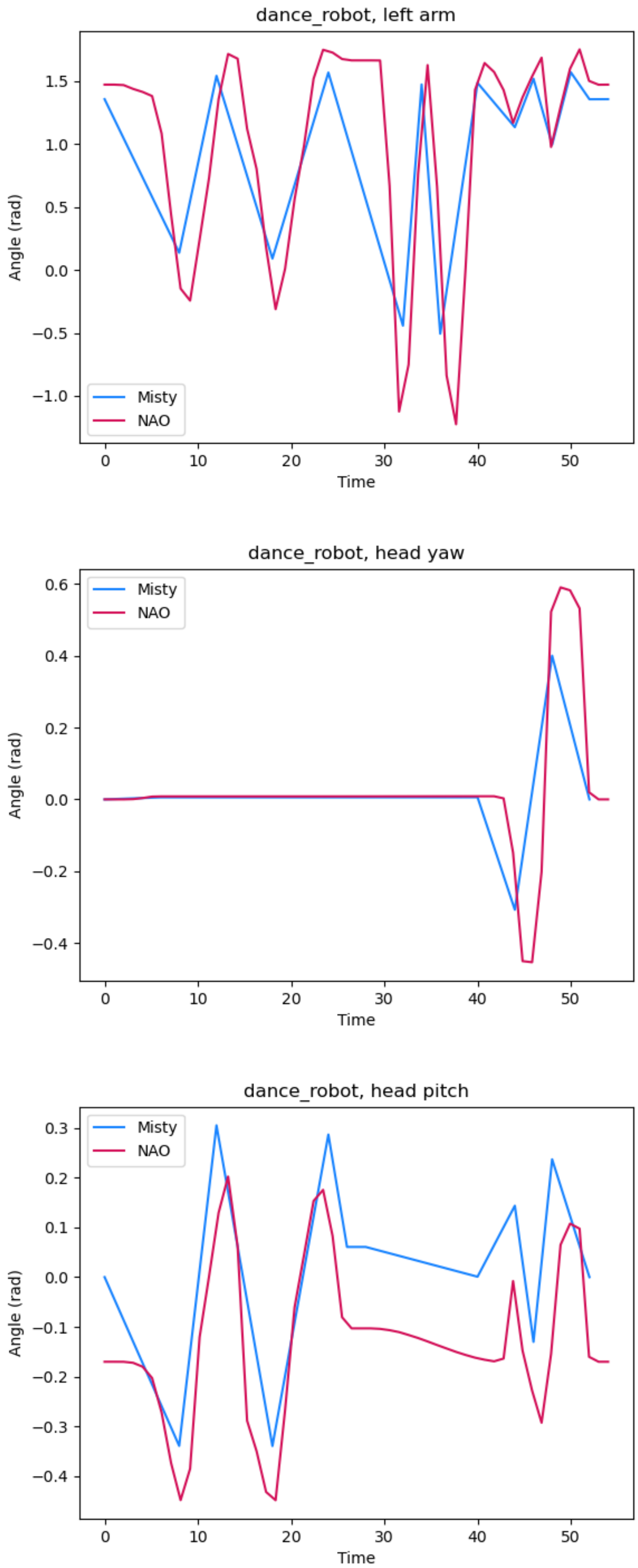


Figure 7.4: Joint angles for NAO and Misty's joints during the robot dance.

so that as NAO's arm for example moves in the negative y-direction, the head will rotate around its yaw-axis in the negative direction a corresponding amount. The graphs in figure 7.5 thus show similar, general patterns by the two robots, which indicates that Misty's head movement can follow the pattern of NAO's hand movements.

However, it is important to note that in the images, NAO's graphs are shifted. This is due to the order within the implementation, where the magnitude and directions are mapped to Misty's head before the significant turning points of the movement are found and saved. Therefore, NAO's graph contains turning points in the movement at this stage in that will later be removed, resulting in Misty's graph at the last step. Nevertheless, the graphs show a similar pattern between the direction in three-dimensional space and the mapped head angles in the form of general direction and magnitudes.

7.1.3 Graphs Presenting the Method Using QoM

Furthermore, the QoM measure is also hard to present graphically because of its implementation. As explained in section 5.5.6, this method entails creating a motion for Misty that resembles NAO's motion in terms of energy. Therefore, the exact motion of NAO is not mirrored, so randomness is incorporated into the method to create an interesting, yet matching motion, in terms of energy. The whole motion is also segmented into important parts, and fluctuations and average intensity are taken into account, things that make it difficult to gain an understanding of the motion and be able to compare the motions between the robots.

Figure 5.14 shows the QoM values for the robot dance for each frame. This dance is divided into four segments, and the intensity and level of intensity fluctuation are calculated for each. From this information, the angles of Misty's joints are calculated, where the angles of the head are shown in figure 7.6. The figure shows that in segments where the intensity is high, there is a lot of movement in the head, which entails both that 2 directions of movement are chosen and that the head uses more of its range of motion. On the other hand, if the intensity is low within a segment, only one direction is chosen. For segments with high fluctuations, the intensity varies between low and high. Thus, this shows the resulting angles for the head that are obtained using information about the intensity of the movement.

7.2 Evaluation of the Motions From the Questionnaire

A questionnaire was performed to evaluate the results of the different methods that were implemented. The purpose of the questionnaire was to get a broad sense of what people, in general, think of the motions that the different methods generated and how the motions might affect people's perception of the robots. The results from the questionnaire include some quantitative data in the form of ratings of motions and attributes, as well as qualitative in the form of text for explanation of choices. The questionnaire contained three sections of questions, one section scores against the RoSAS scale, one matching gesture movements between the two robots, and a last section ranking dance videos. The results of the questionnaire are attached in appendix G and are presented in the remainder of this section

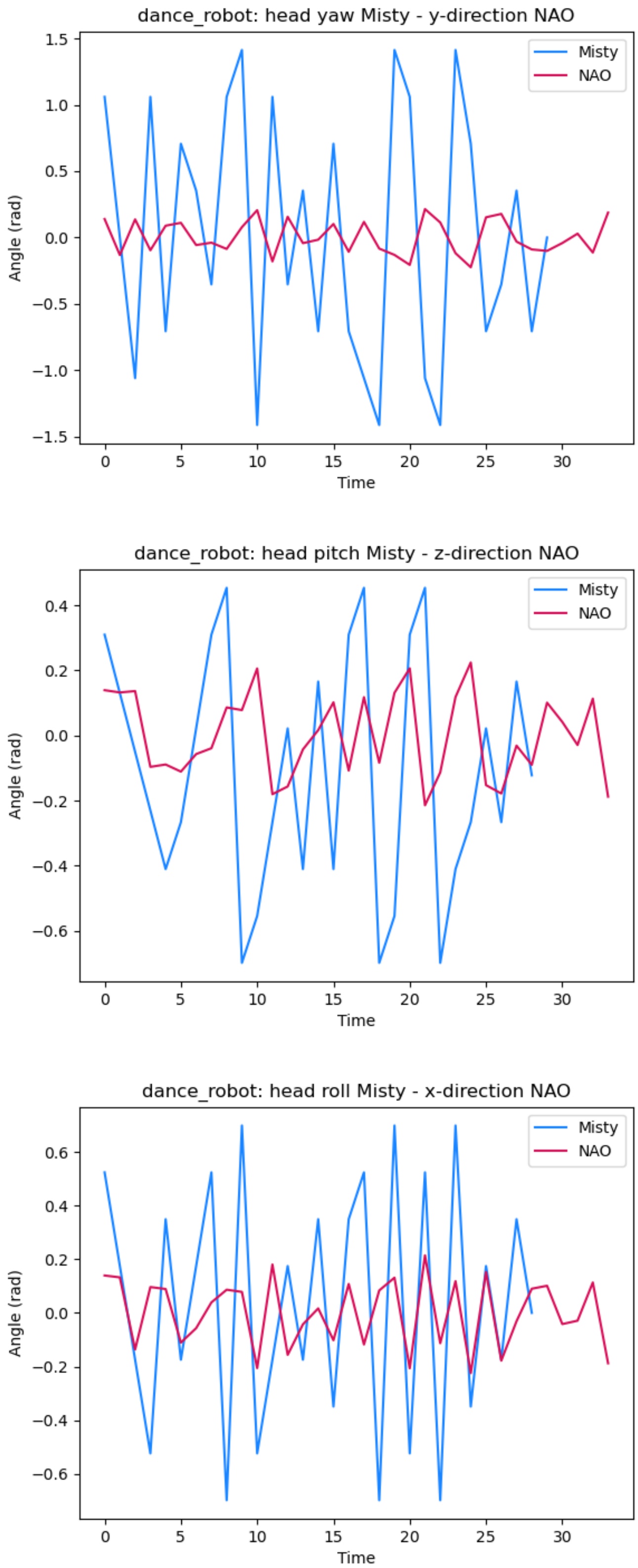


Figure 7.5: General direction and magnitude of movement of NAO's left arm and the mapped angles for Misty's head for the robot dance.

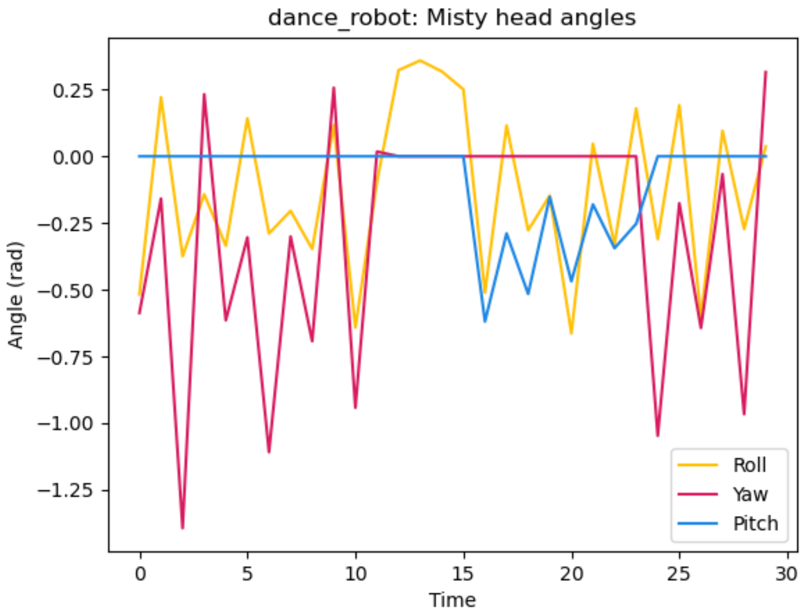


Figure 7.6: Head angles for Misty during the robot dance

7.2.1 RoSAS Scores

In the questionnaire, the participants were asked to rate their perception of the robot in terms of some attributes from the RoSAS scale. The RoSAS attributes that were used were from the categories *warmth* and *discomfort*, where three attributes were rated for each. The null-hypothesis was that the movements would not affect the participants' perception of the robots separately, and thus no effect on the RoSAS attributes.

Tables 7.1 and 7.2 show the means, medians, and standard deviations for each of the attributes before and after having watched the videos of the robots moving. A Wilcoxon signed-rank test was performed to test the statistical significance of the differences between attributes, shown in the tables, as well as a Bonferroni correction of the p-value was also performed, as explained in section 6.2.3. According to the Bonferroni correction, in this context, the difference in RoSAS scores is statistically significant for $p \leq 0.008$.

Figure 7.7 shows a certain trend in the scores for the NAO robot, where the attributes for *warmth* seem to slightly increase and the attributes for *discomfort* seems to slightly decrease after the videos, despite the considerably high standard deviation (STD) for all attributes. The statistical significance for each attribute separately was tested and compared against the Bonferroni corrected value $\alpha = 0.008$. A Wilcoxon signed-rank test indicated that the average *happiness* score after having watched the motion videos, $Mdn = 5$, was statistically significantly higher than before the videos, $Mdn = 4$, $Z = -4.262$, $p = 0.0000228$. Similarly, the test indicated that the average *awkwardness* attribute received a statistically significant lower score before watching the videos, $Mdn = 3$, than after, $Mdn = 2$,$Z = -2.869$, $p = 0.00412$. Conversely, the test indicated no statistical significance for the rest of the attributes for NAO.

These findings suggest that participants in general found the robot to appear happier and less awkward after having watched videos of its gestures and dances. The null hypothesis is thus supported because some attributes seem to show a significant effect after watching the videos, while others did not show any significant effect. This suggests that the videos did not have to significant effect on the perception in terms of all the attributes.

Furthermore, figure 7.8 for Misty shows a similar trend as NAO's data. For the *warmth* attributes, the mean scores seem to increase after having watched the videos, while the scores for the *discomfort* attributes are relatively mixed. The mean score seems to decrease for the *strangeness* attribute but slightly increase for *awkwardness* and *scariness*, in contrast to NAO's trend. However, the scores for Misty have a relatively high standard deviation too, implicating a high variability of scores given between respondents.

A Wilcoxon signed-rank test suggested that the average *happiness* attribute after the videos, $Mdn = 5$, was statistically significantly higher than that before the videos, $Mdn = 3$, $Z = -3.437$, $p = 0.000588$. The test showed no statistical significance for any of the other attributes. The findings suggest therefore that in this context, the motion videos had an effect on the perceived happiness of the Misty robots. These findings do not support the null-hypothesis, because in general, all attributes did not have a significant effect on the perception of Misty.

So, these findings suggest that there is a significant increase in perceived happiness both for the NAO and Misty robots and a decrease in the perceived awkwardness for NAO after watching the motion videos. This indicates that there is little probability that these changes happened due to random chance alone. The perceived sociability, emotionality, strangeness, scariness, and awkwardness in the case of Misty, however, showed no significant changes due to the videos. This suggests that for these attributes, any change in perception before and after watching the videos is likely due to random chance, and thus there is no effect of the videos on the perceived attributes. However, to be able to draw general and definitive conclusions, more research on this topic is needed.

7.2.2 Ranking of Dances

The purpose of the second part of the questionnaire was to get a sense of the participants' perceptions of the dances generated by the different implementations. Three different methods were implemented for the dances and participants were asked to rank each resulting dance. Figure 7.9 shows the results of each dance and method. Method 1 corresponds to the quantity of motion implementation, method 2 to direct mapping using end-effector positions and quantity of motion, and method 3 to direct mapping using joint angles. Moreover, the robots are not referred to by name throughout the questionnaire, so robot 1 is equivalent to NAO and robot 2 is Misty.

As figure 7.9 shows, the median rank given to the dances is around 3 for most dances, which corresponds to around the middle of the rating scale. The rating scale was from 0 to 5, where 0 is the best score and 5 is the worst. The only remarkable score is for the disco dance based on method 1, which had a median rank of 4, which indicates that most participants disliked this dance implementation. However, there is a substantial variance in the ranks given for each dance and method, which suggests a general disagreement of scores across all methods. For these reasons, it is difficult to notice any trend or draw any conclusions from this quantitative data.

Attribute	Phase	Mean	Median	STD	p-value	Z-values
Happiness	Before	4.135	4	1.494	0.0000228	-4.262
	After	5.189	5	1.371		
Sociability	Before	4.865	5	1.398	0.0184	-2.358
	After	5.405	5	1.343		
Emotionality	Before	4.054	4	1.598	0.0210	-2.308
	After	4.622	5	1.722		
Strangeness	Before	2.649	3	1.338	0.197	-1.290
	After	2.378	2	1.361		
Awkwardness	Before	2.811	3	1.561	0.00412	-2.869
	After	2.162	2	1.143		
Scariness	Before	1.486	1	0.870	0.680	-0.412
	After	1.405	1	0.865		

Table 7.1: Mean and standard deviation for RoSAS attributes for NAO before and after watching the motions

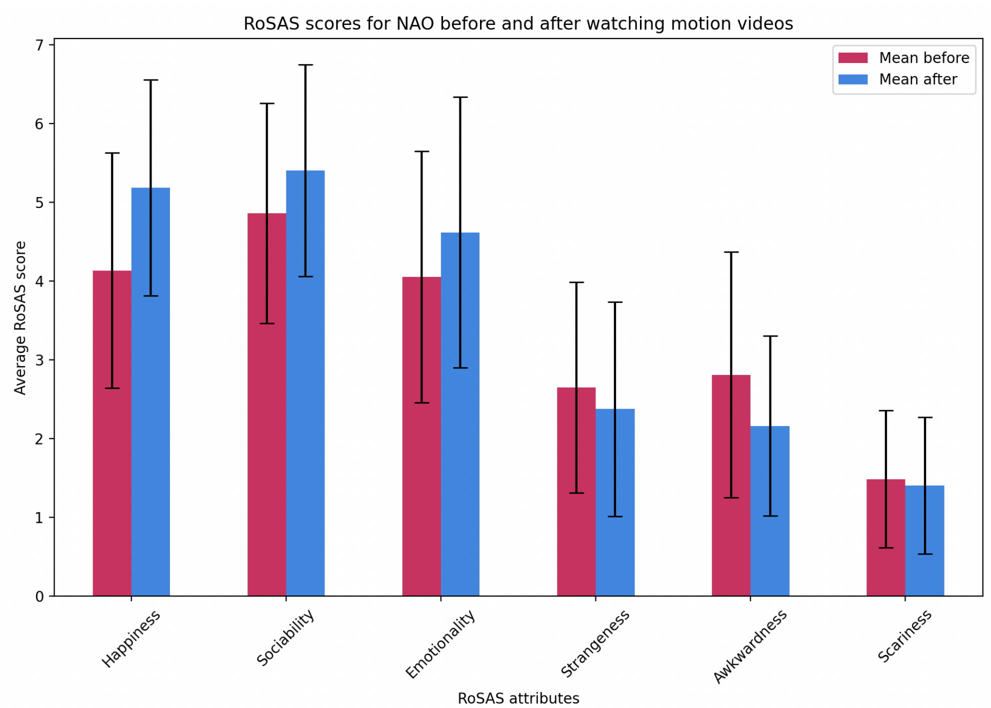


Figure 7.7: Average RoSAS scores for the NAO robot before (pink bars) and after (blue bars) watching gesture and dance videos. The standard deviation is shown through black error lines.

Attribute	Phase	Mean	Median	STD	p-value	Z-value
Happiness	Before	3.459	3	1.643	0.000588	-3.437
	After	4.459	5	1.464		
Sociability	Before	4.270	4	1.677	0.730	-0.346
	After	4.378	4	1.656		
Emotionality	Before	4.270	4	1.790	0.153	-1.428
	After	4.622	5	1.534		
Strangeness	Before	2.892	3	1.646	0.317	-1.001
	After	2.622	2	1.639		
Awkwardness	Before	2.649	2	1.686	0.0990	-1.650
	After	2.973	3	1.833		
Scariness	Before	1.595	1	1.301	0.874	-0.159
	After	1.649	12	1.399		

Table 7.2: Mean and standard deviation for RoSAS attributes for Misty before and after watching the motions

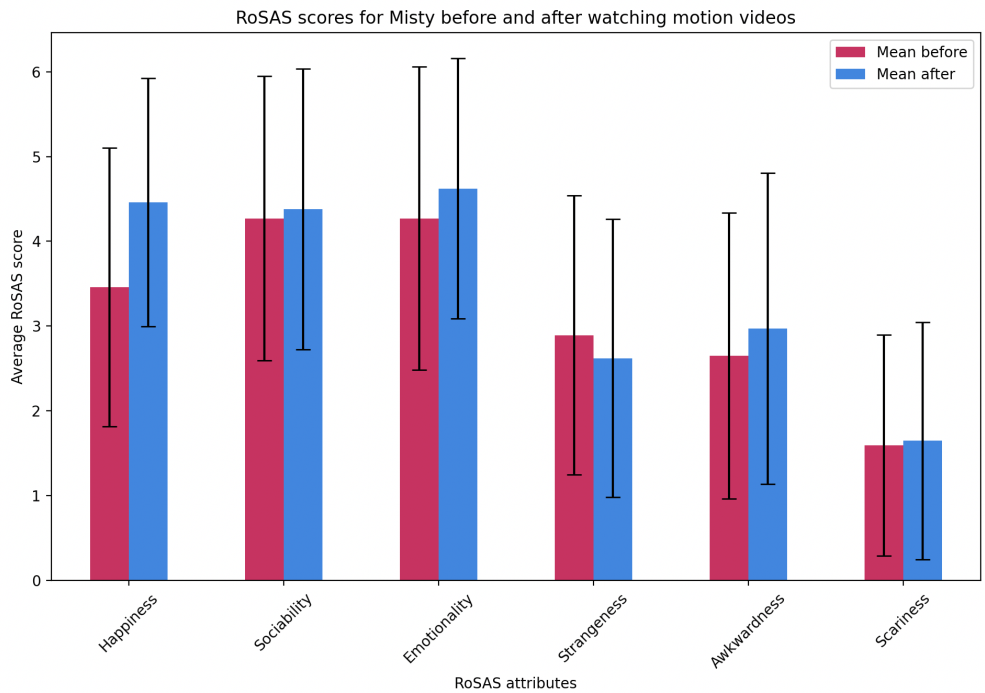


Figure 7.8: Average RoSAS scores for the Misty robot before (pink bars) and after (blue bars) watching gesture and dance videos. The standard deviation is shown through black error lines.

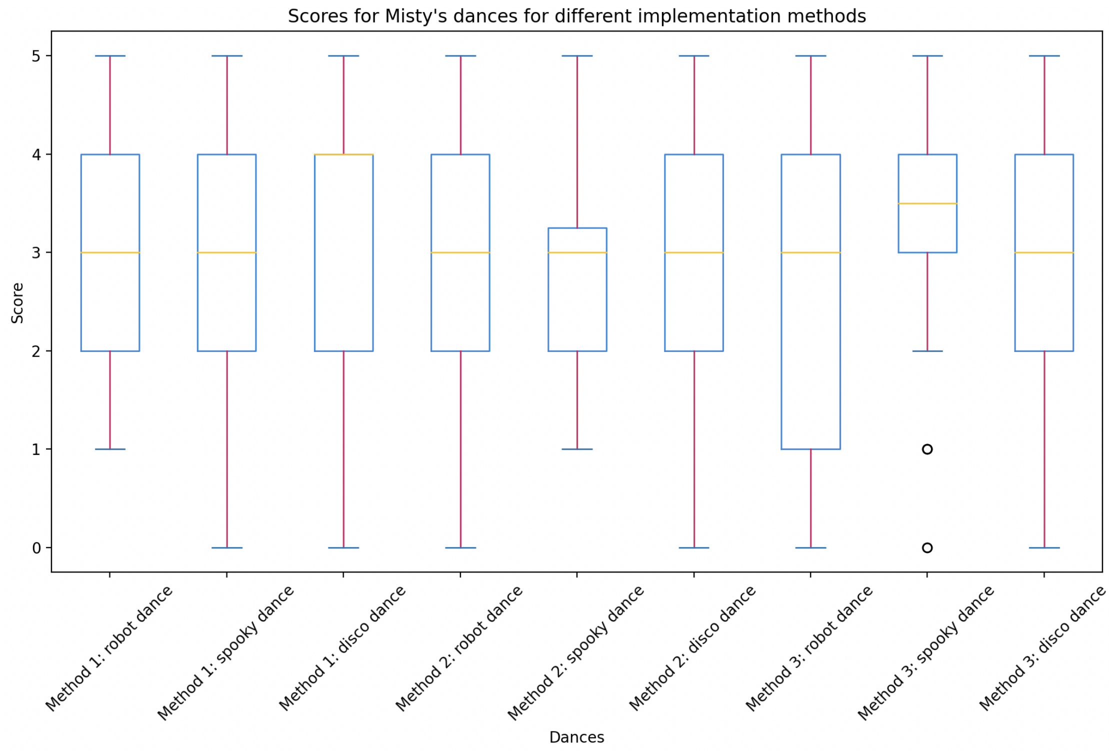


Figure 7.9: Box graph showing the median score and distribution of scores for each dance and method.

However, for each of the sets of dances, the participants were also asked to give an explanation for the ranks given, which provided additional insight into their reasoning and perception of the different methods. By doing a simple thematic analysis of the responses, three recurring themes emerged: the difficulty of recreating the motions on Misty, the factors influencing their rankings, and varying preferences for the dances.

The Difficulty of Mirroring NAO's Dances on Misty

Many participants pointed out that it is difficult to differentiate between the dances and give them a score, a phenomenon that can be observed in figure 7.9 in the form of similar central tendency across all dances and methods. One participant mentioned that "due to the limited mobility of the second robot, it is hard to see if it replicates the movement or does a completely other" and another stated that "absence of joints makes the decision difficult". In general, the responses reflect the challenge of watching the dances and capturing similarities for all implementation methods and dances and evaluating them because the two robots share very few similarities in their bodies and thus are not capable of moving in similar ways.

Additionally, for the spooky and disco dances, several participants remarked that the dances were complicated. The spooky dance has a lot of movement in the hips and legs, while the disco dance has a lot of movement in the arms, both of which are important components of the dance and influence how the dance is perceived. With respect to this, a participant pointed out that the spooky dance was "impossible to convey properly with this robot" and another commented that "the dance is too complicated for Robot

2” about the disco dance.

Some participants drew the conclusion that Misty cannot dance. One participant said that they do not “get the feeling that the robot is dancing”, while another mentioned that “some movements were too stiff to be called a dance”. Numerous participants reflected similar opinions. Another comment was: “It kind of feels like the kid that stands in the corner dancing for him/herself. While Robot 1 is the one winning the dance floor”. This suggests that the respondents in general shared the opinion that Misty does not possess any dance abilities and that Misty is not able to convey a dance in a way that feels like a dance to the observers.

Key Factors Impacting Scores

Many participants also reported the elements that helped them decide the rankings, where many tried to match the movements of either the head, arms, or wheels of Misty to the original motion of NAO. However, the factors that the participants focused more on depended on the dance. For the robot dance, several participants (14) commented that they looked at patterns in the arms, and gave rankings based on whether the arms of NAO and Misty moved in the same direction simultaneously. Another factor that seemed to be in focus was the turning of the wheels, as in the robot dance, the robot moves from side to side throughout the whole dance. This seemed to be a disturbance factor for many, as several respondents reported that the turning of the robot made it less similar. One participant mentioned that if method 3 moved turned less, the dance would have received the highest score. Another participant wrote: “The second and third dance I focused on how the robot rotated its ‘hips’ which was not done by robot 1, so it felt like most of the movements were random”. So, the turning of Misty seemed to influence the scores given to the dance. The head movement was also highlighted as important by some respondents (5), but it seemed to be a considerably less significant factor for this dance.

Furthermore, for the spooky dance, significantly fewer participants (3) mentioned the arms and the turning (2) as important factors for the decision of the scores. Thus, the participants looked for other similarities, and a feature that emerged in these responses was the speed. It seemed like several participants (7) based their scores on how fast or slow Misty was moving and made comparisons to NAO.

Lastly, several respondents (9) replied that the arms are important for the disco dance as well. Few participants mentioned the head movement, speed, and turning as significant factors for this dance, however, some participants also mentioned energy. These participants looked at the energy, so whether the Misty’s dances were energetic or not, to decide the score.

Personal Preferences

The last important theme that occurred in the responses was the preference for the methods, as people seemed to prefer different implementations for each dance based on the similarities or dissimilarities they noticed. This is also evident in the variable scores in figure 7.9. For the robot dance, one participant reported that method 3 (direct mapping using joint angles) was the most similar to the original movement, while another thought that the robot in method 3 moved too much in comparison to the original. The same participant chose method 2 (direct mapping using end-effector positions and quantity of motion) since the head and arm movements were more accurate. A third participant referred to method 1 as the best reflection, because of the timing of the movements.

Another example is for the spooky dance, where one participant mentioned that method 2 “gave a more correct ‘vibe’ since robot 2 is moving its body and hands a lot”, while another participant said that this dance seemed “slower and less enthusiastic”. This participant mentioned that the first method was best as it had “faster movements and closer to the original”. These responses show the difference in focus between participants, and what important factors led them to their decisions.

7.2.3 Matching of Gestures

In the questionnaire, the participants were asked to match videos showing NAO and Misty doing the same set of gestures. The gestures performed were a greeting, farewell, a gesture accompanying the phrase “let me think” and a raising of the hand. Figure 7.10 shows the responses of the participants, where the gestures by NAO are represented by the rows the gestures by Misty are the columns and each square represents a pair of gestures. For example, the third square in the first row (0,2) represents a matching between gesture 1 done by NAO and gesture 3 done by Misty. This figure shows the distribution of the responses for each pairing, and it is evident that the parings that received the most votes, shown in the lighter shades, were: NAO’s gesture 1 with Misty’s gesture 2, NAO’s gesture 2 with Misty’s gesture 3, NAO’s gesture 3 with Misty’s gesture 1, and NAO’s gesture 4 with Misty’s gesture 4. Table 7.3 shows the pairings chosen by most participants and the correct pairings. This shows that gestures 2 and 3, corresponding to the gesture for “let me think” and the farewell, were identified by most participants, while the greeting and the raising of the hand were confused between each other.

The responses seem to show that this was a challenging task for the participants due to the limited joints of Misty. One participant reported: “Hard to compare due to the big difference in articulation points but I took into consideration the amount of ‘hands’ used and their side”. As for the dances, the movements of the arms seemed to be the most important factor that aided the participants in their decisions. Another factor that seemed important based on the responses was the expressions of Misty. Misty can convey meanings and feelings through its screen, which seemed to be a feature that the participants used to understand the gestures.

Lastly, another factor that was mentioned was the sound, although it was not intended that this should be the focus of the participants. Some participants correctly pointed out NAO’s intent for each of the gestures, which is a simpler task as it has an articulated body and the movements were accompanied by phrases such as “goodbye” and “let me think”. However, Misty did not speak during the gestures, which led to confusion and difficulties in identifying the gestures.

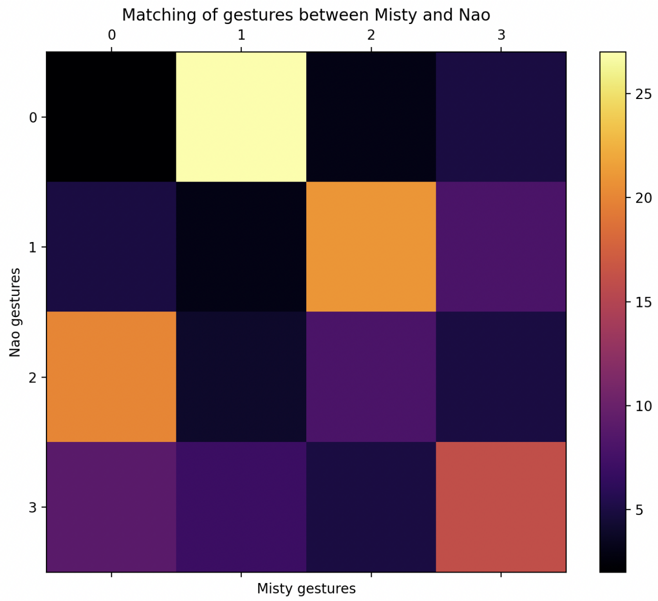


Figure 7.10: Matrix showing the distribution of answers for the matching of gestures task. The numbers represent the gesture number for each of the robots and the colours represent the number of people choosing each pairing. The orange colors represents the pairing chosen by most participants.

NAO gesture number	Misty gesture number	
	Participants' pairing	Correct pairing
1	2	4
2	3	3
3	1	1
4	4	2

Table 7.3: Table showing the matching pairs chosen by the majority of the participants and the correct matching pairs.

7.3 Evaluation Interview at Frydenhaug

This section will provide an overview of the evaluation interview that was described in section 4.2. The participants got to interact with the remote control prototype with the NAO and Misty robots and were asked questions about how the role of Misty and the success of the implementation methods. The responses were analysed using thematic analysis and the analysis is presented here. The themes that were brought up in the discussion were the application of the robot in an educational setting with the children, the interaction of the children with the robot, and its movements.

The remote control prototype, as presented in 5.4, includes several buttons for gesturing and dancing, among other things. The school personnel that participated in the interviews have some experience working with the original remote control with the NAO robot, so they were asked to explore the remote control with the Misty robot too. The initial reaction to the robot's movements was that it is limited in its motion and that "it is not very skilled at dancing", as one of the participants said. It was commented that NAO has greater mobility than Misty and that it is hard for Misty to create interesting and humanlike motions as NAO can. However, they pointed out that the Misty robot will still work as a motivational factor and an attention grabber for the children, especially since it is a "wow-factor" and a new element in the teaching setting on the same level as NAO.

Additionally, it was pointed out that the gestures, such as the one for the *correct*-button, work well. And despite the limited mobility of Misty, the children can learn to understand the motions as children learn and adapt quickly. However, for children with autism consistency and clarity are crucial, and it will therefore be beneficial to combine multiple communication methods for each motion. The teachers suggested having concise verbal support with the gestures, to make them more understandable and make the meaning clear. This can also be underlined using coloured LEDs, like red and green to indicate meanings of the gesture, using a green colour for the *correct*-button on the remote and a red colour for wrong for example. As Misty has a screen, it is also possible to use its expression to communicate meaning. Because children with autism often depend on predictable responses, Misty could display expressions they recognise and understand to lessen the cognitive load. The participant noted that NAO's face is great because it does not show any emotions, allowing the children to focus on other aspects of the communication, while Misty's expressive face might require more focus to understand. Therefore, using recognisable expressions might help the children understand and communicate with the robot more easily.

The teachers also theorised that Misty can be used in a different context because of its functionality, namely using it in working with emotions. Emotions and expressivity are important topics in the education of children with autism, and Misty allows for working with such emotions. One example that was given is that Misty can act out an emotion using its head with greater mobility and its arms in combination with its screen where different emotions can be displaced. This kind of setup and play is difficult to obtain with NAO's expressionless face, making Misty useful in another context than NAO. Simultaneously, NAO has a body with more functionality, making the interactions more exciting and intelligible, which works better for imitation. As was mentioned in the initial interviews, the children are mirroring NAO's actions, such as dancing or raising their hands, and this is a setting where Misty falls short. One of the participants did mention that it would be great if "Misty's head was on NAO's body", thus combining the advantages of both robots in one.

However, the participants mentioned that Misty does move as expected for the different remote control functions and it could be used in the classroom in the same way that NAO is used, provided that adjustments are made. These adjustments such as combining motion and speech, other facial expressions, and LED colours, are not the focus of this thesis. However, Misty and NAO could potentially be used interchangeably in a school setting. One participant said that Misty would be a "common participant just as them", so that Misty could act like a friend and classmate to the children in the same manner as NAO, despite the differences between the robots.

Chapter 8

Discussion

This chapter aims to discuss the results of the remote control implementation and data collections that were presented in chapter 7, in light of the aim of this thesis. As described in section 1.2, the goal was to uncover how a new robot can be integrated into an existing remote control system and what implications arise concerning children with autism. This aim was attempted answered through the following research questions:

> *RQ1:* How can a common interface be used for the control of several robot platforms?
>
> *RQ2:* What strategies can be used to translate movements between robots with varying morphological features?
>
> > *RQ2.1:* How can the motion of a robot effectively be described?
>
> *RQ3:* What factors need to be considered in the integration of a new robot into a system used for children with autism?

The two first research questions address the implementation of the remote control and are answered fully in chapter 5, while their limitations and implications will be discussed in the remainder of this chapter. The last research question was addressed through the data collection and will be discussed in greater detail in this chapter.

There are a multitude of relevant aspects that can be uncovered regarding the results of this thesis. This is why the discussion will be limited to examining the responses from the data collections, limitations of the research and implementation methods, and generalisability. This includes viewing the responses to the interview and questionnaire with regard to the research questions, as well as addressing the biases that might have influenced the data collection. Additionally, the disadvantages of the implemented methods will be discussed, especially the aspect of generalisation and areas that were less successful.

8.1 Advantages and Limitations of Motion Translation Methods

In chapter 5, some methods of translating motions were explored, including the use of mapping joint angles and end-effector positions, using the quantity of motion measure, and a combination of the two methods. The lack of extensive research in the field of motion translation between robots with different morphologies underscores the need for exploring methods in this area, which this thesis has aimed to do. Exploration of methods, however, involves addressing and being aware of different limitations, as well as advantages.

It is interesting to note that few studies have focused on the mapping of motions between robots and the generalisation of movement between robot morphologies. The studies that have addressed this area, have explored quite different methods. These considerations make it difficult to compare results. Nevertheless, the previous studies have shown positive results of their methods, and have in general demonstrated the great possibility of replicating motions on various robots. This is in line with the preliminary results found in this work, where several methods have been explored and have shown some degree of success. It is crucial to acknowledge that the robots used in this thesis have very different morphological features, and directly capturing all notions of NAO's movement on Misty is not possible. Despite the limitations, the results indicate the potential of these methods, with appropriate improvements taken. In this chapter, some limitations and advantages of the methods have been identified and discussed concerning the findings from the data collection.

8.1.1 Personal Differences

The results in figure 7.9 do not show any trend in the preferences of methods, but the qualitative answers indicate the respondent's reasoning behind these scores. In general, it seems like there is a disagreement in which method should receive the highest score, where people have argued for different methods. This indicates that there are personal preferences at play, where some participants prefer some aspect of the motion over others. This is suggested especially for the robot dance, where for the first method (direct mapping of joint angles), the turning of the robot led to less similarity to the original motion for some participants, and thus a lower score. Similar differences in preferences were observed for the other dances as well.

This also suggests that participants focus on different aspects of the movements to conclude while ignoring other contributions. Moreover, another vital aspect could be that the participants were not able to distinguish between the dances. Due to the limited mobility of Misty, it cannot create diverse dance moves, and thus the methods are difficult to differentiate. Several participants mentioned that they were not able to tell some of the methods apart, and this might have led to inconsistent responses.

8.1.2 Discussion of the Direct Mapping Method

The first method that was explored involved using NAO's joint angles or end-effector positions to create mappings to the joints of the Misty robot. This method allows for recreating the motion of a new robot within its range of motion, by taking into account its joints and limits. By choosing appropriate mappings between joints, it is possible to approximate a motion within the limits of another robot in a recognisable way. This mapping does not necessarily create interesting motions, because it is dependent on the joints and joint limits of the robots involved. The significance of this is heavily dependent on the setting. Within the context of this thesis, where the robots will work with children with autism, the method of using direct mapping is important for motions that carry meaning, such as gestures. It is therefore important to ensure that the mapping reflects the original motion in an appropriate manner such that the gesture is understandable. Conversely, dances are meant as encouragement and motivation, and direct mapping is not the only motion translation method. The important aspect is thus to create entertaining and interesting motions, rather than a perfect mirroring of the original movement. For these reasons, using joint angles is deemed more appropriate for gesturing, while using end-effector positions is more suitable for dances.

When it comes to the gestures, the respondents of the questionnaire expressed difficulty in correctly matching gestures between robots, and results revealed only two of four correct matchings for the majority of participants. The qualitative results indicate that the arms were the most important deciding factor for the gesture matching. The reason might be that the arms are one of the key components of non-verbal communication between humans as the arms can convey much of the meaning and intent of a gesture. However, Misty cannot articulate gestures in an easily recognisable way, due to its limited and non-articulated body. This makes it difficult to identify the gesture, compared to NAO, which might for example be why many participants confused the greeting gesture with the raising of the hand. Misty is only able to move its hands up and down, and that makes it hard to discern between the two gestures. This indicates that using a direct mapping of joints helps somewhat increase the understandability, as the new robot would use its arms in a similar way to the original and human motion, but it is also important to realise the physical limitations of the robot that is used.

For the dances, however, it is difficult to draw any conclusion because of the vast difference in the respondents' preference between methods. Some participants seemed to prefer the method using joint angles because of the clear similarities between the motions of the arms. This was pointed out, especially for the robot dance because its arms form recognisable, popular, and clear dance moves. Very few mentioned the end-effector method as a high-scoring method. The reason might have been the non-recognisable and random-looking movements of the head, because respondents generally based their decision-making on finding technical similarities between the dances, instead of focusing on energy.

While this method allows for defining different mappings, it does have some clear disadvantages. Firstly, it focuses on the upper-body motions. This is due to the robots that were used in this thesis, where the absence of legs of Misty made it challenging to create appropriate mappings from a bipedal robot like NAO. The simple implementation of Misty's lower body seemed to be a distraction and a limitation instead of an addition to the motion. Therefore, this method could benefit from a more careful mapping of the lower body. Another point is that for this method, the information from NAO is directly translated and performed by Misty without translation of the speed. This can create difficulties in matching the motions because speed is an important factor for determining the similarities between movements. This method also relies on the identification of key poses, where these key poses are chosen to be the extreme angles or positions of movement of NAO. These are also the poses that are kept and mapped to Misty. However, a more careful capturing of key poses could be beneficial, to create recognisable poses with smooth transitions.

8.1.3 Discussion of the QoM Method

The QoM method seeks to address some of the limitations of the first method. This method involves using QoM, a measure of the amount of movement or energy in a motion, to guide the creation of movements. The idea behind this method is both to be able to create more interesting dances that follow the same energy levels as the original dance, as well as obtaining overall information about a motion. Section 8.1.2 addresses the notion that dances do not necessarily have to be direct mappings of the original movements, which is the reason why this method was devised.

Moreover, this method is in principle robot-independent, as it is based on video capture data of one robot which is mapped to any other robot. The same method, such as a randomised angle creator based on the collected energy level, can be used for all robots, where the only new component would be to tailor the joint limits to the respective robot.

A last advantage is that this method does not require any direct mapping between movements, which leaves the developer free to choose how to incorporate the QoM measure in the creation of dances. It can for example be incorporated by using some degree of randomisation in the creation of the movement based on energy levels within the dance, or through other creative means. This leaves the developer in control of how to implement the dances, while ensuring a similar level of energy and intensity as the original and without having to reprogram the motions for each robot.

However, this can also pose as a disadvantage, because of the effort required to devise an appropriate mapping between energy levels and angles, as well as having to film and analyse QoM values. There is always a trade-off between the method, the effort, and the time spent by the developer. This should be thoroughly assessed when deciding on a method, in addition to its advantages and disadvantages. A second disadvantage is that the method does not create movements that are directly linked to the model robot, and thus does not mirror the direction of movement of the model robot. The QoM measure does not take into account information about which limbs are moving or their directions, so direct mapping is impossible. This might lead to people discarding it as it does not include recognisable motions that can be used to compare movements.

Based on the responses, it is hard to draw any further conclusions because of the respondent's preferences. As explained earlier in this chapter, the respondents focused on different aspects and had different preferences for the motions. This led to some participants preferring the QoM method due to its dynamic and fast movements, while others did not "get the feeling that the robot is dancing". Interestingly, of the people who mentioned a preferred method for the spooky dance, this seemed to receive the most mentions. This might be due to the spooky dance not forming any clearly identifiable motions with the upper body, and it looks to be more of a smooth, fluid, and closer-to-random dance that Misty cannot reflect that well with a direct mapping. But, some responses seem to suggest that the energy was incorporated well, at least for this dance.

Of the participants who mentioned preferences between methods, the QoM method seemed to be the least favourite for the robot and disco dances. This might be because these dances rely heavily on the arms and they form popular dance moves that serve as keys for recognising the dances. Because the arms form distinct moves, it might be natural to look for similar cues in the dance of Misty as well. The random nature of this method is not able to capture those aspects, which probably makes this method less favourable for these dances.

8.1.4 Discussion of Direct Mapping with QoM

The last method consists of using one of the direct mapping methods in combination with the QoM measure. This approach combines the advantages of the aforementioned methods. The direct mapping method produces the mapping on a more detailed level, allowing for a more direct reflection of the original motion. This approach, however, ignores the overarching features of a movement, which the QoM measure provides. The use of video capture can add some insights into the movement that are harder to get a sense of by only using joint angles. One insight is that it gives a general view of the intensity throughout the whole dance, which indicates segments with more or less grand gestures and level of motion. Another indication is the general speed of the movement, as the quantity of motion can indicate segments where there is a lot of movement in a short amount of time and vice versa. Thus, this can be used to divide the dance into meaningful segments that can be used in the implementation, in addition to controlling the speed.

In the questionnaire, the end-effector positions with QoM were used. The findings from the questionnaire do not indicate that the respondents caught the intent of the mapping, and it seems like a common opinion was that the head moved too much. Nevertheless, across all dances, some respondents emphasise this method as one of two that work fairly well. However, due to the chosen mappings and similarities, it is possible that respondents were unable to tell the difference between the two methods using direct mapping. This might have led to inconsistent results and confusion among the participants. However, maybe it would be easier to tell the difference with another robot with an articulated body, that can create a larger variety of motions. Additionally, because only the end-effector method was used together with QoM, and not the joint angle method, it is difficult to draw any general conclusions regarding the success of this method.

Nevertheless, some issues were identified along the way, one of them being that NAO's trajectory involves some rapid or small motions in space that do not translate well to Misty's head. When mapping all directions to Misty's head, the movement becomes choppy and unpleasant. For this reason, the developer should decide which directions to follow at each time, to create a less chaotic movement of the head. This does work to some degree, as presented in the results in section 6.1.2. It seems like Misty's head follows the general direction of the arm in each direction. The findings from the questionnaire do not indicate that the respondents caught the intent of the mapping, and it seems like a very general opinion was that the head moved too much in this method.

As mentioned before, QoM can be used to extract the general speed of the motion, which was used in this method. The intent was to have a sense of the speed of the movement and map that to Misty so that slow movements of NAO lead to slow movements on Misty. However, the programming of Misty's speed through its API behaves unexpectedly. The speed goes from level 0 and level 100, where the head moves fastly from level approximately level 90 to 100, while the rest of the levels are quite slow, and the lower 50 levels lead to an excruciatingly slow movement. The non-parametric levels of speed for the head made it difficult to map the speed correctly, as the slower songs were performed at an excessively slow and unnatural pace, while the faster songs were mapped more accurately.

8.1.5 Key Factors in the Scoring Process

Although many participants thought that the methods were indiscernible and had di"cities with seeing similarities between the methods, a very general trend shows that across dances, the method based on direct mapping of joint angles seems to be preferred by a considerable number of participants. According to their responses, this is especially due to the arms of Misty following the same pattern of movement as NAOs. The arms seemed to be a key determinant for many respondents, especially for the robot and disco dances. One reason for this might be because the dances include upper-body dance moves that are recognisable. The motions are not random and the arms form identifiable shapes, so, naturally, people look for similar patterns in the motion that supposedly mirrors the original. The same factor did not seem that significant, judging by the written responses, which might be because the spooky dance does not form any clearly identifiable motions with the upper body, and it looks to be more of a smooth and fluid dance that Misty cannot reflect that well.

Furthermore, an interesting point that emerged from the qualitative questionnaire data was that most respondents seemed to want to find technical similarities between the original and the different methods, although this was not explicitly specified in the questionnaire text. The question was asked in the form of how well the methods reflect the original dance, but participants, in general, seemed to look for specific movements in the arms, head, timing, speed, and sequence of motion, instead of basing their rankings on vibes and energy of the movement. However, it is natural to find specific anchors of similarity when comparing two motions, instead of basing the perception solely on feeling. These findings might suggest that, in general, people prefer a more direct link between the original and mirrored motion, so that the movement can be recognisable on either body.

Some participants did comment on vibes, speed, energy, and dynamism. It seems like these participants generally favoured the method with the most movement and smoothest movement so that it “looks” and “feels” like the robot is dancing. The movement of all body parts was suggested to be important, and all body parts cooperated to create an interesting motion, to the degree it is possible on Misty. And the replies suggest that more extreme and fast movement, where appropriate in the dances, is better received, than slow and small movements. Repetitive or random motions are also features that were not favoured.

Next, it is important to consider that the participants were presented with nine videos in total, and since Misty has limited mobility, there is a limit to how many varied and interesting dance moves Misty can perform. Therefore, many of the videos were quite similar, and the challenge of finding concrete differences is understandable, especially as it was not expected of the participants to thoroughly analyse the videos. The similarity and limited variety of the motions might be why the participants struggled to see the differences between the methods and why the results of the ranking did not lead to any interesting insights.

8.2 Relevance for Children with ASD

Up to this point, the methods and results of the questionnaire have been discussed with respect to the respondents. As of my knowledge, the respondents were between ages 23 and 55 from several countries in Europe and Japan. Although this group provided some interesting insights into the motion of Misty, these are not the intended users of the remote and robots. In this context, the users of the remote will be teachers and personnel at a school, but the primary beneficiaries of this system will be children with autism. The essential question that remains is whether the same factors that influenced the respondents' perceptions of the robot will extend to children with autism. Another point is whether other factors potentially can influence the reception of the new robot.

Firstly, children with autism often have challenges with change in their environment, and introducing a new robot in their education is a great transition. In this context, the children have already gotten comfortable with NAO, as the initial interviews uncovered, and introducing a new robot into their environment might require an adjustment period. These interviews revealed that they usually make up stories for the children involving the robots, where for example the absence of a robot means that "he has gone on vacation". Similar stories were suggested when integrating Misty, where Misty could be introduced as NAO's sister for example. These stories make it easier to involve new characters in their lives playfully and simply. The roles of the robots were also discussed in both the initial and evaluation interviews and it was concluded that NAO and Misty interchangeably as a friend and peer, but they can also be used in different roles. Misty's expressive face makes it useful for work with emotions and NAO's humanoid body is useful for imitation tasks, both of which are typical areas of difficulty for children with autism. The teachers theorise, however, that the children will adapt to the new robots despite their differences, as any robot will work as a toy, a centre of attention, and a motivational factor.

Furthermore, another concern is Misty's body morphology and its communication with humans. NAO's humanoid body makes gestures and motions clear, while Misty's reduced motion range makes it harder to understand intuitively. This can potentially be an issue because many children with autism also struggle with communication and understanding body language. But when asked, the school personnel believed that the children would become accustomed to Misty's way of communicating, at least the children currently attending this school. It was mentioned that the children are used to the way different adults in the school communicate, because everyone has their means of gesturing and speech, and this is a skill that is generalisable to the robots as well. Since the robots do not look the same, they will have different ways of communicating that the children will adapt to. However, in the questionnaire, some respondents mentioned that sound helped them decide and understand the gestures better, while the school personnel pointed out that gestures should be followed by speech to make them clear and understandable for the children. They said that children with ASD are dependent on clear and short commands which the robot should convey. Combining speech with gestures would make the communication clear, and presumably will work for children with autism.

Moreover, the results of the questionnaire mostly indicate that Misty's dance skills are subliminal, at least judging by the perception of a more general population. The question is, how generalisable is this to children with autism? On one side, NAO performs dynamic dances including lights, music, and funky dance moves, and these behaviours act as motivation and inspiration for the children. The reason for this might be a combination of the novelty of the robot, its mobility and ability to create fun motions, and the fact that the children can imitate it. Misty, on the other hand, is not able to create interesting motions that the children can imitate, but the interviewees believe that it can act as a motivational factor nevertheless because it is a new addition to their everyday life that looks like a toy and that moves in interesting and unexplored ways. For these reasons, the small movements, music, expression, and lights might be enough to serve as motivation and entertainment for the children, despite the lack of movement range.

This might entail that while most participants in the questionnaire seemed to prefer the direct mapping of joint angles and in general, favoured the other methods less, the children might not share the same opinion. The exact dynamics and moves of a dance might not be a focus point for the children, as the movements and the robot itself might compensate for any lack of precision. Thus, the different implementations and the exact way the dances are constructed might be of little importance, as long as the movements are fun, interesting, and captivating enough to watch. In this light, the questionnaire uncovered some attributes that can be important to focus on when creating movements and can serve as a basis for the choice of a method to use with the children. However, more research in this field, as well as testing with children with autism is needed before being able to draw any conclusions. It is difficult to predict how children with autism will react, but based on the evaluation interview with the school personnel, Misty has the potential to serve the same purpose as NAO within the context of Frydenhaug School.

In summary, the evaluation interview at Frydenhaug indicated that there is potential for using the Misty robot in the same context as NAO; in class as a participating student, but also in a different context, where the children can work with emotions. The findings also suggest that Misty can work as a motivational factor for the children with autism on equal footing as NAO, despite its limitations in mobility. Moreover, the communication between the remote control and both Misty and NAO worked well, when controlling both robots simultaneously and separately. This points to the great potential of the ZTL framework that was used for communication and suggests that it can work well in this setting. Lastly, the translation of movement between NAO and Misty seems to work well enough for gestures, but that the dances are less exciting due to their mobility.

It is worth noting that traditionally, for children with autism, the NAO robot has been very popular, as outlined in chapter 2. Few previous studies have researched the use of Misty in an educational setting with children with ASD, although some work has been done in integrating Misty in schools with special needs [41][80]. This thesis has introduced the use of Misty for children with autism at Frydenhaug School and shows its potential to be used equivalently to NAO. However, because of the lack of research involving Misty in this field, it is hard to compare results regarding its integration. The evaluation of Misty from the interviews with the staff at Frydenhaug is in line with the findings of the previous work, which highlights Misty's potential in this setting.

8.3 Generalisability to New Robots

These methods were devised with the Misty robot in mind, a robot with very simple kinematics. A long-term goal would be that a motion translation method should be general enough that it can work on robots with different morphologies. Whether the proposed mapping methods will work well on other robots depends on their kinematics.

Although testing on multiple other robots was outside of the scope of this thesis, it is theorised that the method is generalisable for robots with simple kinematics. Similarly to the approach for Misty, one could define mappings between the joints of the original robot and a new one, and calculate angles based on their constraints.

However, for articulated bodies, this approach would not be as viable. Articulated bodies such as NAO's arm rely on calculations of inverse kinematics to control the trajectory of the arms, because all the joints of the arms contribute to the position of the robot in space. For this reason, it is not enough to define a mapping and calculate an angle for each joint separately. Corresponding joint angles for the model and new robots might result in different positions and orientations in space, due to their kinematic structures. In theory, if the structures of the two robots are similar, direct mapping of joint angles between corresponding joints might work, but not mapping between joints that do not correspond to each other. In addition, it would be crucial to check that the mapped joint angles do not lead to singular configurations, where the joints would require an extreme speed to move by a small degree and the joints can break.

When it comes to the end-effector positions, in the case of Misty, it cannot follow the trajectory in space, and the positions are mapped to angles of the head instead. For similar robots who cannot move in a three-dimensional space, this approach might be viable. For other robots with articulated arms, a similar approach can be used. The end-effector positions can create a trajectory that is transformed into the workspace of a new robot, and inverse kinematics can be used to get the joint angles needed to follow that trajectory. Hypothetically, this should generate a similar trajectory that can be followed by the new robot to replicate the movement. However, this entails using inverse kinematics, which is highly specific for a robot and requires that its joints can move to all positions in a three-dimensional space within its workspace.

Also, the quantity of motion is a method that relies on video capture of a model robot and mapping to a new one according to the specifications of a developer, so this is a method that in principle is robot-independent. Based on the QoM values, the developer is free to implement it in any way on the available robots. Therefore, it might be an interesting method to explore, to see how it can be used to maintain the level of energy and essence of movement across robots.

All these methods are focused on the upper body, both because the dances and gestures both involve significant involvement of the upper body and because Misty does not have a humanoid lower body that requires consideration. Therefore, these methods could work for robots with no lower body or with simple lower bodies, like wheels. However, these methods are unsuitable for robots with humanoid lower bodies. In these cases, it is not enough to map joint angles between their lower body joints, as factors like balance, stability, and coordination need to be taken into consideration. This was not considered for this thesis as the robot integrated into the system did not have a humanoid lower body.

Lastly, due to the lack of extensive research done in the field of generalising motions across robotic platforms, comparisons of results and methods are challenging. As of my knowledge, most studies have focused on the mapping of upper body motions between robots, possibly as a consequence of the complexity of the task in addition to the importance of upper body motions. The difficulty of involving lower body motions is also noted in this work. This entails that the explored methods are only generalisable for a range of robots, especially where the lower body is of little importance, while more work should be done involving the lower body.

8.4 Biases in Data Collection and Analysis Methods

In this thesis, both quantitative and qualitative research methods have been used to gain an understanding of the considerations needed to be taken for the integration of robots in educational settings for children with autism. When conducting research, it is important to identify the different biases that might affect the validity, reliability, and objectivity of research [79], and consider what factors might have influenced the results of your research. Validity is concerned with that the only factor influencing the dependent variable is the manipulated variable (internal validity) and that the results are generalisable (external validity), while reliability addresses the extent to which research is consistent over contexts [79]. Objectivity is based on the researcher being sincere about the methods and results of their research, and not imposing their subjective views on the research. Additionally, it is important to objectively view the advantages and shortcomings of the chosen research methods, and how the chosen methods might affect the results.

8.4.1 Evaluation of Interview Methods

The qualitative interviews have the advantage that they can provide a deep insight into the context of this thesis and the use of this implementation with the actual user group, as well as it can allow for probing respondents to elaborate and [12]. Semi-structured interviews were conducted to allow for the possibility of following new themes that arise during the interviews, something that allows us to explore the context in a wide and thorough manner. As the aim of the interviews was an exploration of the context, there were no definite expectations from the participants' responses, so they could not adjust their answers accordingly. For this reason, it is believed that the risk of social-desirability bias is low for the interviews, which entails that it is not likely that the participants altered their responses to be socially desirable [12]. However, it was noted that across all interviewees, positive examples were pointed out, and negative examples were omitted, although explicitly asked. It is difficult to ascertain whether this is due to a social-desirability bias, recall bias, or the absence of negative events between the children and the robot.

Also, although interviews also leave space for asking questions to the interviewer if the questions are unclear, the possibility of the questions not being worded advantageously remains. The questions might have been phrased too open- or close-ended or were leading, making it hard for the participants to give appropriate answers. Another concern is that the participants were asked questions about the context of the ROSA project, activities they had done, their impressions, and their effect on children with autism. It was not expected of the interviewees to prepare for the interviews, and therefore this entails them recalling past impressions and events. This leads to the possibility of the participants missing relevant details or remembering events in other ways than they happened and filling in gaps with probabilities of what happened [73].

Lastly, a simple thematic analysis was performed to analyse the initial and evaluation interviews. This method can be prone to confirmation bias, a phenomenon that happens when a researcher seeks to confirm an existing belief or expectation in its research [68].

The reason is that the researcher was exposed to the risk of identifying themes focusing on aspects of the interviews that confirm their expectations of what the results should be and failing to identify contrasting beliefs. This affects the objectivity of the data, as the researcher risks imposing their subjective interpretation and views on the result.

8.4.2 Evaluation of Questionnaire Method

A questionnaire was chosen as a data collection due to the advantage of collecting a larger amount of data quickly, and in a convenient manner for the participants [12]. The downsides are, among others, that follow-up questions to the participants' answers cannot be asked, and it is prone to biases such as sample selection bias, participant fatigue, or phrasing of the questions. The questionnaire used a mixed-methods approach, where both qualitative and quantitative data were collected, and the various biases can pose a threat to the validity, reliability, and objectivity of the results.

Firstly, the participants for the questionnaire were sampled by convenience, by recruiting within my social circle. This makes the questionnaire vulnerable to sample selection bias, a phenomenon that entails that the sampled participants do not reflect the intended population to be studied [14]. Since no personal data was collected in the questionnaire, it is not possible to know exactly who answered it, but it is believed that the majority of respondents had an informatics or technical background. As the sampling was not random, it does not necessarily reflect the general population which threatens the validity of the results. Despite the similar backgrounds, it was confirmed that participants from different countries and ages responded, which indicates some spread of participants.

Additionally, because of the personal relation to most of the participants, social-desirability bias might have arisen. In this context, it entails that participants might have given overly positive answers that they believed were beneficial for my research, and ignored less socially desirable points of view [29]. Nonetheless, given the equilibrium of both positive and negative answers in the questionnaire, the probability of social-desirability bias affecting the results is relatively low.

A second important point is that although the respondents of the questionnaire were intended to be a more general population, the intended users of this implementation are children with autism. The participants for this study were not representative of this group, so the question is: to what extent are these results generalisable to children with autism? This problem statement is discussed in greater detail in section 8.2.

Furthermore, issues with the content of the questionnaire itself can involve phrasing of the question, participant fatigue, end aversion, and problems with the scaling system [29], where the risk of these biases will be mentioned here. The phrasing of the questions entails considerations about how unambiguous the questions are framed to avoid differences in interpretation. Based on the qualitative questionnaire responses, the participants might have had slightly different interpretations of the tasks. Another explanation could be that the questions were open-ended and allowed the participants to focus on different aspects of the answers that they believed to be relevant. A second problem could be that the questionnaire was fairly long, with a lot of videos and repeated and similar questions, factors that can lead to participant fatigue. This effect can severely affect the results in a way that answers can become uniform and inaccurate, as participants get tired and bored [29]. A way to combat this effect is to randomise the order in which the participants are presented with the questions. This ensures that across all participants, the questions will get overall an uniform amount of attention, even though participants might experience fatigue. However, the questionnaire website did not allow for easily randomising the order of questions, so participant fatigue might influence the results of the latter questions.

Another factor that must be taken into consideration is how and which scaling system is used. One consideration is that end aversion might occur, which entails that participants tend to avoid the ends of the scale [29]. This phenomenon can lead to participants not expressing their true perception because they wish to be in the safe zone, and thus affect the accuracy of the results. Two types of scales were used in the questionnaire, the RoSAS scale and a standard scale from 1 to 5. The latter scale was used to give a score, while the RoSAS scale was developed specifically as a standardised way of measuring the perception of robots in human-robot interactions [25]. The scale was validated, so that it is consistent across contexts, time, and participants. Although, RoSAS has been tested and validated in human-robot interactions such as hand-overs [70] or perception of robot behaviour [88], it remains to be evaluated and validated in more human-robot interactions. Because of this, and the lack of evaluation in similar contexts as here, it is difficult to draw concrete and generalisable conclusions regarding the applicability of the scale. In addition, RoSAS involve three categories, each with six attributes. In this thesis, both attributes of warmth and discomfort were used, which allows for comparisons between the attributes themselves, but due to the consideration of the length of the questionnaire, not all six attributes were included. However, to draw overarching conclusions regarding warmth and discomfort, all attributes must be considered. Nevertheless, using some attributes can still indicate some trends in the perception of robots.

Lastly, thematic analysis was performed using the qualitative answers to the questionnaire. Similarly, as in the case of the interviews, it is possible that themes in contradictions with the hypothesis and expectations were ignored, and the focus was on favourably interpreting the answers with respect to the expectations. This can affect the validity objectivity and reliability of the research.

Chapter 9

Conclusion

Positive effects have been shown for children with autism when interacting with social robots, such as decreased stereotypical behaviour, increased communication, and motivation, among many others. The effects of robots on children with ASD have received significant attention over the years, but also the development of programs and robots for children with autism. Robots such as NAO, Misty, or QTRobot are examples of robots whose design makes them appropriate for working with children with autism, and they have been used extensively in this field. However, robots tend to sometimes break, especially when used with children, and need to be updated or maintained, which entails that they may for a period be taken out of service, In addition, one robot might not fulfil the necessities of every child, so it might be advantageous to be able to be able to switch between different robots using the same interface. That is a typical problem in robot platform design: each company design their specific robot platform that is incompatible with other platforms.

Therefore, if a school wants multiple robots, the person in charge would need to work with different separate robots with separate interfaces. This adds a barrier to the use of many social robots in school because most educational personnel do not have a technical background, and would therefore need to learn to operate different platforms in fast-paced situations. For these reasons, a robot-independent remote control that allows for easy integration of a new robot would be beneficial and make multiple-robot environments simpler to work with. This is a relevant issue in the Norwegian Computing Centre's ROSA project, and this thesis attempted to address it.

The creation of a robot-independent remote requires two key factors, one being the use of a communication framework that can administer the communication between the remote and different robot platforms and the second a way to animate the added robots. In this thesis, the use of the ZTL framework was used to solve communication issues, which proved to be a useful tool for both presenting robot tasks and dispatching tasks to different robots. For the second part, the goal was to explore ways in which a robot can be animated without the developer having to program each behaviour separately. Three methods were suggested, where joint angles and end-effector positions of a model robot (NAO) were translated to fit the range of motion of a new robot (Misty) for a more direct mapping of motion. Another suggested method was the use of the number of motion values for an energy-based motion translation that can potentially incorporate some randomness into the motions.

To evaluate the created behaviours of Misty in comparison to NAO, both in the context of a general population and the context of children with autism, interviews and a questionnaire were conducted. The questionnaire provided insights into the factors of success for the motions but also revealed aspects that need improvement. Although the respondents of the questionnaire did not represent the actual users of the robot, the children with autism, it did uncover some aspects of the movements that can further be improved for better interaction and perception of the robot. The interview with the school personnel also revealed some improvements that can make the interaction between the children and the robot smoother and more understandable and expressed the potential of the Misty robot being used in their context both similarly and independently of NAO.

The results in general indicate the positive potential of using the remote control system with children with autism with both NAO and Misty. However, further research is needed to explore the effects the integration of multiple robots has on children with autism in the classroom and what additional aspects must be considered. In addition, more work is needed to improve the methods and to expand the system with more robots before being able to draw any concrete conclusions. Nevertheless, this might be an interesting approach that might be worth further exploring for future research.

9.1 Future Work

This thesis has explored some relevant aspects of the integration of a robot in a remote control system for use with children with autism, and through this work, several ideas for future work have arisen. One of the main goals of this thesis was to automate the process of translating motions between robots of various morphologies. Although complex, it would be interesting to explore how machine learning can be leveraged to for instance learn mappings or motion translation between robots, or to teach robots how to imitate corresponding to their limits and abilities. Another intriguing idea is to use ROS to standardise the commands sent to the robot. The current implementation leverages the separate APIs of the robot platforms, but it could be worth further exploring how ROS can be used to distance the implementation from the robot-dependent software. This has the potential of simplifying the workflow of the developer and the integration of new robots in a system, by instead using standardised commands. These components would drive the proposed implementation further in the direction of a truly robot-independent remote control system.

Moreover, the questionnaire revealed the limitations of the implementation methods, and together with the evaluation interview, uncovered important aspects for future consideration. An idea could be to further refine the implementation methods and behaviours, especially the method involving the quantity of motion since these methods might have the potential to yield better results with some additional improvements. The use of the ZTL framework can also be further explored and its use can be improved. Additional features, such as simultaneous control through the same remote, are potentially worth investigating. Also, the methods were only tested on one robot in this thesis, so a future objective might involve repeating the remote control integration of a new robot with a new morphology. This could provide additional insights into how well the method generalises to new robots and what other aspects need to be considered.

Lastly, since the primary users of this system are children with autism, a natural next step would be to conduct experiments and observations involving children with autism. Although persons with experience with children with autism were included in this study, first-hand experience with the primary user group could provide valuable insights into the considerations and adaptations needed. In addition, the remote underwent a simple evaluation with the school personnel, but it would be enlightening to observe how the remote system is used and how children with autism interact with the different robots in a natural setting, where problems and success can be identified and later improved.

Bibliography

[1] 2020. URL: https://www.drammen.kommune.no/tjenester/skole/skolene-i-drammen/frydenhaug-skole/om-frydenhaug-skole/.

[2] ISO 9241-210:2019. *ISO 9241-210:2019 - Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems.* 2nd ed. 2019.

[3] Chadia Abras, Diane Maloney-Krichmar, Jenny Preece et al. 'User-centered design'. In: *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications* 37.4 (2004), pp. 445–456.

[4] Minoo Alemi et al. 'The Effect of Applying Humanoid Robots as Teacher Assistants to Help Iranian Autistic Pupils Learn English as a Foreign Language'. en. In: *Social Robotics.* Ed. by Adriana Tapus et al. Lecture Notes in Computer Science. Cham: Springer International Publishing, 2015, pp. 1–10. ISBN: 978-3-319-25554-5. DOI: 10.1007/978-3-319-25554-5_1.

[5] A. Alissandrakis, C.L. Nehaniv and K. Dautenhahn. 'Imitation with ALICE: learning to imitate corresponding actions across dissimilar embodiments'. In: *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 32.4 (2002), pp. 482–496. ISSN: 1558-2426. DOI: 10.1109/TSMCA.2002.804820.

[6] Aris Alissandrakis, Chrystopher L. Nehaniv and Kerstin Dautenhahn. 'Correspondence Mapping Induced State and Action Metrics for Robotic Imitation'. In: *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 37.2 (2007), pp. 299–307. ISSN: 1941-0492. DOI: 10.1109/TSMCB.2006.886947.

[7] Aris Alissandrakis et al. 'Imitating using JABBERWOCKY to achieve corresponding effects in context'. In: *Univ. Hertfordshire, Hatfield, UK, Computer Science Tech. Rep* 441 (2005).

[8] Surya Ambrose and Maxime Busy. *naoqi_driver2*. URL: https://github.com/ros-naoqi/naoqi_driver2.

[9] The ZeroMQ authors. *ZeroMQ: An open-source universal messaging library*. URL: https://zeromq.org.

[10] A. Bacula and A. LaViers. 'Character Synthesis of Ballet Archetypes on Robots Using Laban Movement Analysis: Comparison Between a Humanoid and an Aerial Robot Platform with Lay and Expert Observation'. en. In: *International Journal of Social Robotics* 13.5 (Aug. 2021), pp. 1047–1062. ISSN: 1875-4805. DOI: 10.1007/s12369-020-00695-0. URL: https://doi.org/10.1007/s12369-020-00695-0 (visited on 01/11/2023).

[11] Christoph Bartneck et al. 'Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots'. In: *International journal of social robotics* 1 (2009), pp. 71–81.

[12] Emma Bell, Alan Bryman and Bill Harley. *Business research methods*. Oxford university press, 2022.

[13] Tony Belpaeme et al. 'Social robots for education: A review'. In: *Science Robotics* 3.21 (2018), eaat5954. DOI: 10.1126/scirobotics.aat5954. eprint: https://www.science.org/doi/pdf/10.1126/scirobotics.aat5954. URL: https://www.science.org/doi/abs/10.1126/scirobotics.aat5954.

[14] Richard A Berk. 'An introduction to sample selection bias in sociological data'. In: *American sociological review* (1983), pp. 386–398.

[15] Karsten Berns and Jochen Hirth. 'Control of facial expressions of the humanoid robot head ROMAN'. In: *2006 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2006, pp. 3119–3124. DOI: 10.1109/IROS.2006.282331.

[16] Virginia Braun and Victoria Clarke. 'Using thematic analysis in psychology'. In: *Qualitative Research in Psychology* 3.2 (2006), pp. 77–101. DOI: 10.1191/1478088706qp063oa. URL: https://www.tandfonline.com/doi/abs/10.1191/1478088706qp063oa.

[17] Cynthia Breazeal. *Designing sociable robots*. 2004.

[18] Cynthia Breazeal, Kerstin Dautenhahn and Takayuki Kanda. 'Social Robotics'. In: *Springer Handbook of Robotics*. Ed. by Bruno Siciliano and Oussama Khatib. Cham: Springer International Publishing, 2016, pp. 1935–1972. ISBN: 978-3-319-

32552-1. DOI: 10.1007/978-3-319-32552-1_72. URL: https://doi.org/10.1007/978-3-319-32552-1_72.

[19] Davide Brugali and Patrizia Scandurra. 'Component-based robotic engineering (Part I) [Tutorial]'. In: *IEEE Robotics & Automation Magazine* 16.4 (2009), pp. 84–96. DOI: 10.1109/MRA.2009.934837.

[20] H. Bruyninckx. 'Open robot control software: the OROCOS project'. In: *Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation (Cat. No.01CH37164).* Vol. 3. 2001, 2523–2528 vol.3. DOI: 10.1109/ROBOT.2001.933002.

[21] Herman Bruyninckx. 'OROCOS: design and implementation of a robot control software framework'. In: *Proceedings of IEEE International Conference on Robotics and Automation*. Citeseer. 2002.

[22] John-John Cabibihan et al. 'Why robots? A survey on the roles and benefits of social robots in the therapy of children with autism'. In: *International journal of social robotics* 5 (2013), pp. 593–618.

[23] Antonio Camurri, Ingrid Lagerlöf and Gualtiero Volpe. 'Recognizing emotion from dance movement: comparison of spectator recognition and automated techniques'. In: *International Journal of Human-Computer Studies* 59.1 (2003). Applications of Affective Computing in Human-Computer Interaction, pp. 213–225. ISSN: 1071-5819. DOI: https://doi.org/10.1016/S1071-5819(03)00050-8. URL: https://www.sciencedirect.com/science/article/pii/S1071581903000508.

[24] Hoang-Long Cao et al. 'A Personalized and Platform-Independent Behavior Control System for Social Robots in Therapy: Development and Applications'. In: *IEEE Transactions on Cognitive and Developmental Systems* 11.3 (2019), pp. 334–346. ISSN: 2379-8939. DOI: 10.1109/TCDS.2018.2795343.

[25] Colleen M Carpinella et al. 'The robotic social attributes scale (rosas) development and validation'. In: *Proceedings of the 2017 ACM/IEEE International Conference on human-robot interaction*. 2017, pp. 254–262.

[26] Ginevra Castellano, Santiago D. Villalba and Antonio Camurri. 'Recognising Human Emotions from Body Movement and Gesture Dynamics'. In: *Affective Computing and Intelligent Interaction*. Ed. by Ana C. R. Paiva, Rui Prada and Rosalind W. Picard. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007, pp. 71–82. ISBN: 978-3-540-74889-2.

[27] Chih-Wei Chang et al. 'Exploring the Possibility of Using Humanoid Robots as Instructional Tools for Teaching a Second Language in Primary School'. In: *Journal of Educational Technology & Society* 13.2 (2010). Publisher: International Forum of Educational Technology & Society, pp. 13–24. ISSN: 1176-3647. URL: https://www.jstor.org/stable/jeductechsoci.13.2.13 (visited on 10/08/2023).

[28] Gary Charness, Uri Gneezy and Michael A Kuhn. 'Experimental methods: Between-subject and within-subject design'. In: *Journal of economic behavior & organization* 81.1 (2012), pp. 1–8.

[29] Bernard CK Choi and Anita WP Pak. 'Peer reviewed: a catalog of biases in questionnaires'. In: *Preventing chronic disease* 2.1 (2005).

[30] Eva Yin-han Chung. 'Robotic intervention program for enhancement of social engagement among children with autism spectrum disorder'. In: *Journal of Developmental and Physical Disabilities* 31.4 (2019), pp. 419–434.

[31] Carlos A Cifuentes et al. 'Social robots in therapy and care'. In: *Current Robotics Reports* 1 (2020), pp. 59–74.

[32] Andreia P. Costa et al. 'More Attention and Less Repetitive and Stereotyped Behaviors using a Robot with Children with Autism'. In: *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. ISSN: 1944-9437. Aug. 2018, pp. 534–539. DOI: 10.1109/ROMAN.2018.8525747.

[33] Audrey Duquette, François Michaud and Henri Mercier. 'Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism'. In: *Autonomous Robots* 24.2 (2008), pp. 147–157.

[34] ekroeger@aldebaran.com. *What is robot-jumpstarter?* 2019. URL: https://github.com/pepperhacking/robot-jumpstarter.

[35] Chelsea Finn et al. 'One-Shot Visual Imitation Learning via Meta-Learning'. In: *Proceedings of the 1st Annual Conference on Robot Learning*. Ed. by Sergey Levine, Vincent Vanhoucke and Ken Goldberg. Vol. 78. Proceedings of Machine Learning Research. PMLR, 2017, pp. 357–368. URL: https://proceedings.mlr.press/v78/finn17a.html.

[36] Kristin S Fuglerud and Ivar Solheim. 'The Use of Social Robots for Supporting Language Training of Children.' eng. In: *Stud Health Technol Inform* 256 (2018), pp. 401–408. ISSN: 1879-8365 (Electronic); 0926-9630 (Linking).

[37] M. Fujita. 'On activating human communications with pet-type robot AIBO'. In: *Proceedings of the IEEE* 92.11 (2004), pp. 1804–1813. DOI: 10.1109/JPROC.2004.835364.

[38] Georgi Gerganov. *whisper.cpp*. URL: https://github.com/ggerganov/whisper.cpp.

[39] Anthony G Greenwald. 'Within-subjects designs: To use or not to use?' In: *Psychological Bulletin* 83.2 (1976), p. 314.

[40] Martin Hägele et al. 'Industrial Robotics'. In: *Springer Handbook of Robotics*. Ed. by Bruno Siciliano and Oussama Khatib. Cham: Springer International Publishing, 2016, pp. 1385–1422. ISBN: 978-3-319-32552-1. DOI: 10.1007/978-3-319-32552-1_54. URL: https://doi.org/10.1007/978-3-319-32552-1_54.

[41] Tyler Brown Herald. *Robotics can help students in special education programs feel more at ease*. 2022. URL: https://www.durangoherald.com/articles/florida-mesa-elementary-school-welcomes-misty-the-robot/.

[42] Todd Hester, Michael Quinlan and Peter Stone. 'Generalized model learning for Reinforcement Learning on a humanoid robot'. In: *2010 IEEE International Conference on Robotics and Automation*. 2010, pp. 2369–2374. DOI: 10.1109/ROBOT.2010.5509181.

[43] Patrick Holthaus and Lewis Riches. *ZTL*. 2023. URL: https://gitlab.com/robothouse/rh-user/ztl.

[44] Patrick Holthaus et al. 'ZTL: Task-based commnunication for multi-robot smart environments'. 2024.

[45] *hub - Top level functions and classes*. URL: https://lego.github.io/MINDSTORMS-Robot-Inventor-hub-API/pkg_hub.html.

[46] Julian Ibarz et al. 'How to train your robot with deep reinforcement learning: lessons we have learned'. In: *The International Journal of Robotics Research* 40.4-5 (2021), pp. 698–721. DOI: 10.1177/0278364920987859. eprint: https://doi.org/10.1177/0278364920987859. URL: https://doi.org/10.1177/0278364920987859.

[47] Katsushi Ikeuchi et al. 'Describing Upper-Body Motions Based on Labanotation for Learning-from-Observation Robots'. en. In: *International Journal of Computer Vision* 126.12 (Dec. 2018), pp. 1415–1429. ISSN: 1573-1405. DOI: 10.1007/s11263-018-1123-1. URL: https://doi.org/10.1007/s11263-018-1123-1 (visited on 01/11/2023).

[48] Luthffi Idzhar Ismail et al. 'Leveraging robotics research for children with autism: a review'. In: *International Journal of Social Robotics* 11 (2019), pp. 389–410.

[49] Alexander Refsum Jensenius. 'Action-sound: Developing methods and tools to study music-related body movement'. In: (2007).

[50] Alexander Refsum Jensenius. 'Developing Tools for Studying Musical Gestures within the Max/MSP/Jitter Environment'. In: *Proceedings of the International Computer Music Conference*. 2005, pp. 282–285.

[51] Chris Plauché Johnson, Scott M. Myers and and the Council on Children With Disabilities. 'Identification and Evaluation of Children With Autism Spectrum Disorders'. In: *Pediatrics* 120.5 (Nov. 2007), pp. 1183–1215. ISSN: 0031-4005. DOI: 10.1542/peds.2007-2361. URL: https://doi.org/10.1542/peds.2007-2361 (visited on 25/03/2023).

[52] *Joints*. URL: http://doc.aldebaran.com/2-5/family/robots/joints_robot.html.

[53] Aidan Jones and Ginevra Castellano. 'Adaptive Robotic Tutors that Support Self-Regulated Learning: A Longer-Term Investigation with Primary School Children'. en. In: *International Journal of Social Robotics* 10.3 (June 2018), pp. 357–370. ISSN: 1875-4805. DOI: 10.1007/s12369-017-0458-z. URL: https://doi.org/10.1007/s12369-017-0458-z (visited on 26/06/2023).

[54] Hanna Kallio et al. 'Systematic methodological review: developing a framework for a qualitative semi-structured interview guide'. In: *Journal of Advanced Nursing* 72.12 (2016), pp. 2954–2965. DOI: https://doi.org/10.1111/jan.13031. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/jan.13031. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/jan.13031.

[55] Junko Kanero et al. 'Social Robots for Early Language Learning: Current Evidence and Future Directions'. en. In: *Child Development Perspectives* 12.3 (2018). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/cdep.12277, pp. 146–151. ISSN: 1750-8606. DOI: 10.1111/cdep.12277. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/cdep.12277 (visited on 10/08/2023).

[56] Elizabeth S Kim et al. 'Social robots as embedded reinforcers of social behavior in children with autism'. In: *Journal of autism and developmental disorders* 43 (2013), pp. 1038–1049.

[57] Kilian Kleeberger et al. 'A survey on learning-based robotic grasping'. In: *Current Robotics Reports* 1 (2020), pp. 239–249.

[58] Geoffrey W Lane et al. 'Effectiveness of a social robot,"Paro," in a VA long-term care setting.' In: *Psychological services* 13.3 (2016), p. 292.

[59] Simon Manschitz et al. 'Learning to sequence movement primitives from demonstrations'. In: *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE. 2014, pp. 4414–4421.

[60] Ian K. McLeod and Patrick C. Melder. 'Da Vinci Robot-Assisted Excision of a Vallecular Cyst: A Case Report'. In: *Ear, Nose & Throat Journal* 84.3 (2005). PMID: 15871586, pp. 170–172. DOI: 10.1177/014556130508400315. eprint: https://doi.org/10.1177/014556130508400315. URL: https://doi.org/10.1177/014556130508400315.

[61] Willem Mertens, Amedeo Pugliese, Jan Recker et al. 'Quantitative data analysis'. In: *A companion* (2017), pp. 1–8.

[62] *Misty II*. URL: https://www.mistyrobotics.com/misty-ii.

[63] Rebecca Muhle, Stephanie V Trentacoste and Isabelle Rapin. 'The genetics of autism'. In: *Pediatrics* 113.5 (2004), e472–e486.

[64] Robin R. Murphy, Satoshi Tadokoro and Alexander Kleiner. 'Disaster Robotics'. In: *Springer Handbook of Robotics*. Ed. by Bruno Siciliano and Oussama Khatib. Cham: Springer International Publishing, 2016, pp. 1577–1604. ISBN: 978-3-319-32552-1. DOI: 10.1007/978-3-319-32552-1_60. URL: https://doi.org/10.1007/978-3-319-32552-1_60.

[65] Alexandre F. V. Muzio, Marcos R. O. A. Maximo and Takashi Yoneyama. 'Deep Reinforcement Learning for Humanoid Robot Behaviors'. en. In: *Journal of Intelligent & Robotic Systems* 105.1 (May 2022), p. 12. ISSN: 0921-0296, 1573-0409. DOI: 10.1007/s10846-022-01619-y. URL: https://link.springer.com/10.1007/s10846-022-01619-y (visited on 12/04/2023).

[66] S. Nakaoka et al. 'Leg motion primitives for a dancing humanoid robot'. In: *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA '04. 2004*. Vol. 1. 2004, 610–615 Vol.1. DOI: 10.1109/ROBOT.2004.1307216.

[67] *NAO - Actuator & Sensor list*. URL: http://doc.aldebaran.com/2-1/family/nao_dcm/actuator_sensor_names.html.

[68] Raymond S Nickerson. 'Confirmation bias: A ubiquitous phenomenon in many guises'. In: *Review of general psychology* 2.2 (1998), pp. 175–220.

[69] Yu Ogura et al. 'Development of a new humanoid robot WABIAN-2'. In: *Proceedings 2006 IEEE International Conference on Robotics and Automation, 2006. ICRA 2006.* IEEE. 2006, pp. 76–81.

[70] Matthew KXJ Pan, Elizabeth A Croft and Günter Niemeyer. 'Evaluating social perception of human-to-robot handovers using the robot social attributes scale (rosas)'. In: *Proceedings of the 2018 ACM/IEEE international conference on human-robot interaction.* 2018, pp. 443–451.

[71] Paola Pennisi et al. 'Autism and social robotics: A systematic review'. In: *Autism Research* 9.2 (2016), pp. 165–183.

[72] Dirk Lefeber Greet Van de Perre Michaël Van Damme and Bram Vanderborght. 'Development of a generic method to generate upper-body emotional expressions for different social robots'. In: *Advanced Robotics* 29.9 (2015), pp. 597–609. DOI: 10.1080/01691864.2015.1031697. eprint: https://doi.org/10.1080/01691864.2015.1031697. URL: https://doi.org/10.1080/01691864.2015.1031697.

[73] Philip M Podsakoff et al. 'Common method biases in behavioral research: a critical review of the literature and recommended remedies.' In: *Journal of applied psychology* 88.5 (2003), p. 879.

[74] N.S. Pollard et al. 'Adapting human motion for the control of a humanoid robot'. In: *Proceedings 2002 IEEE International Conference on Robotics and Automation (Cat. No.02CH37292).* Vol. 2. 2002, 1390–1397 vol.2. DOI: 10.1109/ROBOT.2002.1014737.

[75] *Programming.* URL: http://doc.aldebaran.com/2-8/dev/programming_index.html.

[76] Fotis Psomopoulos et al. 'RAPP System Architecture'. In: *Assistance and Service Robotics in a Human Environment, IEEE/RSJ International Conference on Intelligent Robots and Systems.* Chicago, United States, Sept. 2014. URL: https://inria.hal.science/hal-01090891.

[77] Alfio Puglisi et al. 'Social Humanoid Robots for Children with Autism Spectrum Disorders: A Review of Modalities, Indications, and Pitfalls'. In: *Children* 9.7 (2022). ISSN: 2227-9067. DOI: 10.3390/children9070953. URL: https://www.mdpi.com/2227-9067/9/7/953.

[78] Morgan Quigley et al. 'ROS: an open-source Robot Operating System'. en. In: *ICRA workshop on open source software* 3.3.2 (2009), p. 5.

[79] Adil Abdul Rehman and Khalid Alharthi. 'An introduction to research paradigms'. In: *International journal of educational investigations* 3.8 (2016), pp. 51–59.

[80] Axel Reitzig. *Innovate to Elevate*. 2021. URL: https://innovation.svvsd.org/2021/06/23/innovate-to-elevate/.

[81] Ben Robins, Kerstin Dautenhahn and Paul Dickerson. 'From Isolation to Communication: A Case Study Evaluation of Robot Assisted Play for Children with Autism with a Minimally Expressive Humanoid Robot'. In: *2009 Second International Conferences on Advances in Computer-Human Interactions*. 2009, pp. 205–211. DOI: 10.1109/ACHI.2009.32.

[82] Ben Robins et al. 'Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills?' In: *Universal access in the information society* 4 (2005), pp. 105–120.

[83] *ROBOT COORDINATES AND ORIENTATION*. URL: https://misty-releases.s3.amazonaws.com/resources/Misty+II+Coordinate+System+%26+Movement+Ranges+-+Misty+Robotics.pdf.

[84] *ROBOT HOUSE Home to Human-Robot Interaction*. URL: https://robothouse.herts.ac.uk/facility/.

[85] Y. Sakagami et al. 'The intelligent ASIMO: system overview and integration'. In: *IEEE/RSJ International Conference on Intelligent Robots and Systems*. Vol. 3. 2002, 2478–2483 vol.3. DOI: 10.1109/IRDS.2002.1041641.

[86] Mohammed A. Saleh, Fazah Akhtar Hanapiah and Habibah Hashim. 'Robot applications for autism: a comprehensive review'. In: *Disability and Rehabilitation: Assistive Technology* 16.6 (2021). PMID: 32706602, pp. 580–602. DOI: 10.1080/17483107.2019.1685016. eprint: https://doi.org/10.1080/17483107.2019.1685016. URL: https://doi.org/10.1080/17483107.2019.1685016.

[87] Brian Scassellati. 'Robots for Use in Autism Research'. In: vol. 14. 2012, pp. 275–294. DOI: 10.1146/annurev-bioeng-071811-150036. URL: https://www.annualreviews.org/doi/abs/10.1146/annurev-bioeng-071811-150036.

[88] Marcus M Scheunemann, Raymond H Cuijpers and Christoph Salge. 'Warmth and competence to predict human preference of robot behavior in physical human-robot interaction'. In: *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE. 2020, pp. 1340–1347.

[89] Trenton Schulz and Kristin Skeide Fuglerud. 'Creating a Robot-Supported Education Solution for Children with Autism Spectrum Disorder'. In: *Computers Helping People with Special Needs*. Ed. by Klaus Miesenberger et al. Cham: Springer International Publishing, 2022, pp. 211–218. ISBN: 978-3-031-08645-8.

[90] Trenton Schulz et al. 'A case study for universal design in the internet of things'. In: *Universal design 2014: Three days of creativity and diversity*. IOS Press, 2014, pp. 45–54.

[91] *scipy.interpolate.PchipInterpolator*. URL: https://docs.scipy.org/doc/scipy/reference/generated/scipy.interpolate.PchipInterpolator.html.

[92] Michelle Sintov. *vector-python-sdk*. URL: https://github.com/anki/vector-python-sdk?tab=readme-ov-file.

[93] Christopher Stanton, Anton Bogdanovych and Edward Ratanasena. 'Teleoperation of a humanoid robot using full-body motion capture, example movements, and machine learning'. In: *Proc. Australasian Conference on Robotics and Automation*. Vol. 8. 2012, p. 51.

[94] Brian Still and Kate Crane. *Fundamentals of user-centered design: A practical approach*. CRC press, 2017.

[95] E. Burton Swanson. 'Management Information Systems: Appreciation and Involvement'. In: *Management Science* 21.2 (1974), pp. 178–188. ISSN: 00251909, 15265501. URL: http://www.jstor.org/stable/2629678 (visited on 20/04/2024).

[96] A. Taheri et al. 'Teaching music to children with autism: A social robotics challenge'. In: *Scientia Iranica* 26.Special Issue on: Socio-Cognitive Engineering (Feb. 2019). Publisher: Sharif University of Technology, pp. 40–58. ISSN: 1026-3098. DOI: 10.24200/sci.2017.4608. URL: https://scientiairanica.sharif.edu/article_4608.html (visited on 12/08/2023).

[97] Jie Tan et al. 'Sim-to-real: Learning agile locomotion for quadruped robots'. In: *arXiv preprint arXiv:1804.10332* (2018).

[98] Adriana Tapus et al. 'Children with autism social engagement in interaction with Nao, an imitative robot: A series of single case experiments'. In: *Interaction studies* 13.3 (2012), pp. 315–347.

[99] *The future of education is NAO*. URL: https://us.softbankrobotics.com/nao.

[100] *WEB API Overview*. URL: https://docs.mistyrobotics.com/misty-ii/web-api/overview/.

[101] DOUGLAS WOLFE. *Nonparametric Methods*. eng. Chichester, UK, 2005.

[102] R WOOLSON. *Wilcoxon Signed-Rank Test*. eng. Chichester, UK, 2005.

Appendices

A Interview Guide for Background Interviews

Intervjuguide

Introduksjon

Hensikten med dette intervjuet er å bli kjent med lærernes erfaringer i forhold til roboten og barna med autisme, i tillegg til å få en forståelse for hvordan roboten brukes i undervisningen. Det viktigste målet med dette intervjuet er å få en oversikt over konteksten roboten brukes i og få innsyn punkter som er viktige å ta hensyn til når man utvikler robotbevegelser.

Dette intervjuet skal være semistrukturert slik at vi nødvendigvis ikke går i dybden på alle temaer, og det er mulig at andre temaer kan oppstå underveis. Det er også mulig at rekkefølgen på spørsmålene blir annerledes enn intervjuguiden under intervjuet. Intervjuet er strukturert slik at vi først går gjennom alle punktene i agendaen også går vi gjennom spørsmålene.

Agenda

De følgende punktene skal bli tatt med på starten av intervjuet. Intervjuet vil vare i omtrent en time.

1. Orienter om ROSA prosjektet og min master:
   «Hovedmålet i ROSA prosjektet er å utvikle et robotverktøy som skal brukes i undervisning med barn med autisme som et hjelpemiddel for å lære barna språk- og kommunikasjonsferdigheter, i tillegg til sosiale ferdigheter. Jeg skriver min master i sammenheng med dette prosjektet. Mitt fokus vil være på hvordan man kan generalisere bevegelser mellom ulike roboter som har ulike kropper, for eksempel utføre den samme dansen på roboter med eller uten ben, der robotene skal brukes i undervisning med barn med autisme. I denne sammenhengen ønsker jeg å bli kjent med lærernes erfaringer med roboten og få bakgrunnsinformasjon om hvordan roboten brukes i undervisningen.»

2. Forsikre at deltakeren har lest informasjonsskrivet og la dem stille spørsmål.

3. Be deltakeren lese og fylle inn samtykkeskjemaet.

4. Minn deltakeren på å ikke snakke om andre personer på en måte som kan identifisere dem.

5. Start lydopptak dersom deltakeren har gitt samtykke til det.

6. Vi går gjennom spørsmålene til temaet har blitt diskutert nok. Det blir tatt notater av det som blir sagt underveis med penn og papir. Bilder vil også bli tatt underveis i intervjuet, men ingen identifiserende bilder skal bli tatt.

7. Takk deltakeren for intervjuet.

Spørsmål

Spørsmålene i denne delen er strukturert slik at spørsmålene er nokså åpne og står i form av stikkord under hver seksjon. For hvert spørsmål er det også et/flere eksempelspørsmål som kan bli stilt, men det er ikke nødvendigvis slik spørsmålene vil bli formulert under intervjuet.

Bakgrunnsinformasjon

1) rolle, lengde, utdanning
   - Kan du dele litt om din rolle på skolen og hvordan du kom til å ha denne rollen?

2) erfaring, barn, autisme
   - Kan du fortelle litt om hvilken erfaring du har med barn med autisme?

Lærerne og roboten

3) teknologi, roboter, undervisning
   - Har du tidligere hatt erfaring med spesifikke digitale verktøy eller roboter i undervisning?

4) erfaring med Robbie/Emil, bruk, periode, økter, opplevelser
   - Kan du gi en beskrivelse av din bruk av roboten og din erfaring med roboten og barna?

5) opplevelser, roboter, undervisning
   - Er det noen merkverdige og sterke opplevelser med roboten du kan fortelle om?

6) utseende, oppfatning, bruksområder, kroppstype, skjerm, bilde av roboter
   - Hvordan oppfatter du Robbie/Emil og Mistys utseende med tanke på barna og bruksområdene til disse to robotene?
   - Eksempelbilder som kan vises under intervjuet:



7) kommunikasjon, kommunikasjonstype
   - Hvordan bør roboten kommunisere, og hva har det å si for barna med autisme?

Bruk av robotene i undervisning

8) kontekst, Robbie/Emil og Misty, bruk, kjørende program
   - I hvilken kontekst kan du tenke deg at dere kan bruke hver av de to robotene i undervisningen?

9) typisk økt, roller, fjernkontroll
   - Kan du beskrive en typisk økt der roboten blir brukt?

10) interaksjon, spill, dans, ros
   - Kan du fortelle litt om barnas reaksjoner når de interagerer og spiller med roboten?

11) motivasjon, barn, robotens egenskaper
   - Hvilke av robotens egenskaper kan du tenke deg stimulerer barnas motivasjon mest?

12) reaksjoner, barn, robotbevegelser, preferanser
   - Kan du fortelle litt om barnas reaksjoner til robotens bevegelser?

13) robotbevegelser, effektivitet i undervisning, begrensninger
   - Hvordan tror du robotens bevegelser bidrar til undervisningen og påvirker barna med autisme?

14) flere roboter, samme program
   - Hvordan tror du barna blir påvirket av å interagere med ulike roboter med ulike kropper gjennom samme program og spill?

Oppsummering

15) tilføying, spørsmål
   - Har du noe mer du har lyst å tilføye?
   - Har du noen spørsmål?

B Information Sheet and Consent Form

Vil du delta i forskningsprosjektet «generalisering av robotbevegelser for ulike robot plattformer»?

Dette er et spørsmål til deg om du vil delta i forskningsprosjektet hvor formålet er å utforske hvordan vi kan generalisere bevegelser mellom ulike roboter, slik at samme bevegelse lett kan gjøres på roboter med ulike kropper. I dette informasjonsskrivet gir vi deg informasjon om målet med prosjektet og hva deltakelse vil innebære for deg.

Formålet med prosjektet

Dette prosjektet er i forbindelse med min masteroppgave for Institutt for Informatikk ved Universitetet i Oslo. Prosjektet er en del av ROSA-prosjektet ved Norsk Regnesentral. I en skolekontekst kan det i framtiden være ønskelig å kunne bytte ut den nåværende roboten, med andre roboter, på grunn av hensyn som kostnad, vedlikehold, eller tilgjengelighet av roboten. Derfor er det viktig å kunne kjøre samme program på ulike roboter. For øyeblikket brukes roboten NAO i ROSa-prosjektet, men det kan være relevant å bruke for eksempel roboten Misty også. Som en del av dette vil målet med dette prosjektet være å utforske hvordan man kan generalisere bevegelser mellom ulike roboter med forskjellige kropsskonfigurasjoner. Dette betyr at roboter med ulike kropper skal kunne utføre samme bevegelse, uten å måtte tilpasse bevegelsene for enhver robotplatform som kan brukes. Forskningsspørsmålene handler dermed om hvordan man generalisere bevegelser for roboter med ulike kropsskonfigurasjoner for roboter som brukes med barn med autisme?

Til dette formålet ønsker jeg å involvere ansatte som er en del av ROSA-prosjektet for å få en innsikt i hvordan roboten blir brukt sammen med barna og de ansattes erfaringer med roboten. Dette vil være med å belyse hvilke aspekter som er viktige å ta hensyn til under utviklingen av robotbevegelsene, i tillegg til å gi en oversikt over konteksten roboten skal brukes i.

Hvorfor får du spørsmål om å delta?

Denne invitasjonen gis til ansatte ved Frydenhaug skole som allerede er en del av ROSA-prosjektet, og dermed har erfaring med å bruke roboten i undervisning sammen med barn med autisme.

Hvem er ansvarlig for forskningsprosjektet?

Norsk Regnesentral og Institutt for Informatikk ved Universitetet i Oslo er ansvarlige for forskningsprosjektet. Norsk Regnesentral er ansvarlig for personopplysningene som behandles i dette prosjektet.

Hva innebærer det for deg å delta?

Deltakelse i dette prosjektet innebærer å delta på et intervju, der du blir invitert til å dele dine erfaringer med roboten og barna med autisme i undervisningssammenheng. Temaene på intervjuet vil hovedsakelig handle om din erfaring med barn med autisme og roboten, hvordan roboten brukes i undervisning, og hvordan barna interagerer med roboten. Robotene som det vil bli spurt om på intervjuet er NAO (med navn Emil og Robbie) og Misty, slik som bildene viser.

Emil

Robbie

Misty

Intervjuet vil vare i omtrent en time.

Om du tillater det vil det bli tatt lydopptak av intervjuet, og eventuelt noen bilder, om du tillater det. Vi også registrere navn i forbindelse med samtykkeskjema, i tillegg til generell informasjon om erfaring med barn med autisme, roboter, stilling, og faglig bakgrunn.

Det er frivillig å delta

Det er helt frivillig å delta i dette prosjektet. Det vil ikke ha noen negative konsekvenser for deg dersom du ikke vil delta, i ettertid ønsker å trekke din deltakelse, eller velger å be om å få dine opplysninger slettet.

Personvern – hvordan vi oppbevarer og bruker dine opplysninger

Vi vil bare bruke opplysningene om deg til de formålene vi har fortalt om i dette skrivet. Vi behandler personopplysningene konfidensielt og i samsvar med personvernregelverket.

- Det er bare jeg og mine veiledere for masteroppgaven som kommer til å ha tilgang til dataene.
- Lydopptaket og bildene vil lagres på en sikker skytjeneste (Microsoft Online Services) som er egnet for lagring av fortrolige data med begrenset tilgang og multifaktor autentisering for å sikre at kun utvalgte prosjektmedarbeidere har tilgang til dataene.
- Navnet på samtykkeskjemaet vil lagres på papir på et trygt sted, og holdes adskilt fra lydopptaket.

Kun anonymisert data som vil bli publisert i masteroppgaven, slik at det ikke skal være mulig å identifisere deltakerne.

Hva gir oss rettighet til å behandle personopplysninger om deg?

Dine personopplysninger blir behandlet om deg basert på ditt samtykke. På oppdrag fra Norsk Regnesentral har personverntjenestene ved SIKT – Kunnskapssektorens tjenesteleverandør, vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hva skjer med personopplysningene dine når forskningsprosjektet avsluttes?

Prosjektslutt vil være slutten av 2024. Dataen vil da anonymiseres, slik at det ikke vil bli mulig å identifisere deltakerne ut ifra rådataene (lydopptak og bilder) og samtykkeskjemaene vil kastes/slettes.

Dine rettigheter

Så lenge du kan identifiseres i dataene, har du rett til å:

- be om innsyn i opplysningene som lagres om deg
- be om retting eller sletting av dataen
- sende inn klage til Datatilsynet om behandlingen av dine personopplysninger

Spørsmål

Hvis du har spørsmål, eller ønsker å benytte deg av dine rettigheter kan du ta kontakt med:

- Student: Claudia Badescu på e-post (claudaba@ifi.uio.no) eller på telefon (48224768).
- Veileder: Trenton Schulz på epost (trenton@nr.no) eller på telefon (22852670).
- Norsk Regnesentrals personvernombud: Kari Åse Homme på e-post (personvernombud@nr.no) eller på telefon (22852627).

Hvis du har spørsmål knyttet til vurderingen av prosjektet som er gjort av Sikts personverns-tjenester, kan du ta kontakt med:

- Personvernstjenester på e-post (personverntjenester@sikt.no) eller på telefon: (73984040).

Med vennlig hilsen,
Claudia Badescu

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om dette prosjektet, og fått anledning til å stille spørsmål. Jeg samtykker til:

- ○ å delta i et personlig intervju
- ○ at det tas lydopptak
- ○ at det tas bilder

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er ferdig og innen utgangen av 2024. Etter prosjektslutt vil dataen være anonymisert.

Navn: ____

____

(Sted og dato) (Signatur)

C SIKT's Ethical Assessment of the Project

Sikt

Vurdering av behandling av personopplysninger

Referansenummer	Vurderingstype	Dato
440697	Standard	13.10.2023

Tittel
Generalisering av robotbevegelser på tvers av ulike robotplattformer

Behandlingsansvarlig institusjon
Norsk Regnesentral

Prosjektansvarlig
Trenton W. Schulz

Student
Claudia-Andreea Badescu

Prosjektperiode
09.10.2023 - 31.12.2024

Kategorier personopplysninger
Alminnelige
Særlige

Lovlig grunnlag
Samtykke (Personvernforordningen art. 6 nr. 1 bokstav a)
Uttrykkelig samtykke (Personvernforordningen art. 9 nr. 2 bokstav a)

Behandlingen av personopplysningene er lovlig så fremt den gjennomføres som oppgitt i meldeskjemaet. Det lovlige grunnlaget gjelder til 31.12.2024.

Meldeskjema

Kommentar
OM VURDERINGEN
Sikt har en avtale med institusjonen du forsker eller studerer ved. Denne avtalen innebærer at vi skal gi deg råd slik at behandlingen av personopplysninger i prosjektet ditt er lovlig etter personvernregelverket.

TYPE PERSONOPPLYSNINGER
Prosjektet vil behandle særlige kategorier av personopplysninger om helseforhold for utvalg 2.

LOVLIG GRUNNLAG
Lovlig grunnlag for behandlingen av personopplysninger for utvalg 1 vil være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 a).

FORELDRE SAMTYKKER FOR BARN
Prosjektet vil innhente samtykke fra foresatte til behandlingen av personopplysninger om barna i utvalg 2.

FØLG DIN INSTITUSJONS RETNINGSLINJER
Vi har vurdert at du har lovlig grunnlag til å behandle personopplysningene, men husk at det er institusjonen du er ansatt/student ved som avgjør hvilke databehandlere du kan bruke og hvordan du må lagre og sikre data i ditt prosjekt. Husk å bruke leverandører som din institusjon har avtale med (f.eks. ved skylagring, nettspørreskjema, videosamtale el.) .

Personverntjenester legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til oss ved å oppdatere meldeskjemaet. Se våre nettsider om hvilke endringer du må melde: https://sikt.no/melde-endringar-i-meldeskjema

OPPFØLGING AV PROSJEKTET
Vi vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!

D Example data retrieved from NAO

Figure 1: Data retrieved from NAO for the standing-up motion

E Interview Guide for Closing Interview

Intervjuguide

Agenda

De følgende punktene skal bli tatt med på starten av intervjuet. Intervjuet vil vare i omtrent en halv time. Agendaen for intervjuet er følgende:

1. Fortelle om agendaen for intervjuet i dag.

2. Fortelle kort om oppgaven og implementasjonen min: Følgende punkter skal inkluderes:

    - En av fokuspunktene i masteren min var å lage en fjernkontroll som kan styre flere ulike roboter. Denne er basert på den nåværende fjernkontrollen som blir brukt i dette prosjektet og den fungerer på samme måte.
    - Dette inkluderer å oversette bevegelser fra NAO til den nye roboten, Misty. Implementasjonen er basert på at utvikleren ikke skal programmere hver og en bevegelse separat, men at bevegelsene til NAO kan direkte oversettes til en annen robot.

3. Vise fjernkontrollen med robotene Misty og NAO og demonstrere noen av funksjonene (knappene man kan trykke på).

4. La deltakerne prøve ut fjernkontrollen for å styre Misty.

5. Vi går gjennom spørsmålene til temaet har blitt diskutert nok. Det blir tatt notater av det som blir sagt underveis med iPad. Bilder vil også bli tatt underveis i intervjuet, men ingen identifiserende bilder skal bli tatt.

6. Takk deltakeren for intervjuet.

Spørsmål

Følgende er veiledende spørsmål til intervjuet som viser temaene som vil bli diskutert. Dette er bare eksempler på hvordan spørsmålene kan bli stilt, og det er ikke nødvendig at spørsmålene vil bli formulert slik under intervjuet.

1. Hva synes dere om funksjonaliteten/bevegeligheten til Misty og hvordan tror dere det vil påvirke barna?
2. Er det noe ved roboten som dere tror kan stimulere barnas motivasjon og interesse?
3. Hvor passende er det Misty gjør for de ulike knappene i fjernkontrollen?
4. Hvordan tror dere at barna hadde kommet overens med Misty?
5. Kunne Misty ha blitt brukt som et alternativ for NAO?
6. Hvilke andre formål kunne dere brukt Misty til?
7. Har dere noen andre generelle kommentarer?

F Online Questionnaire

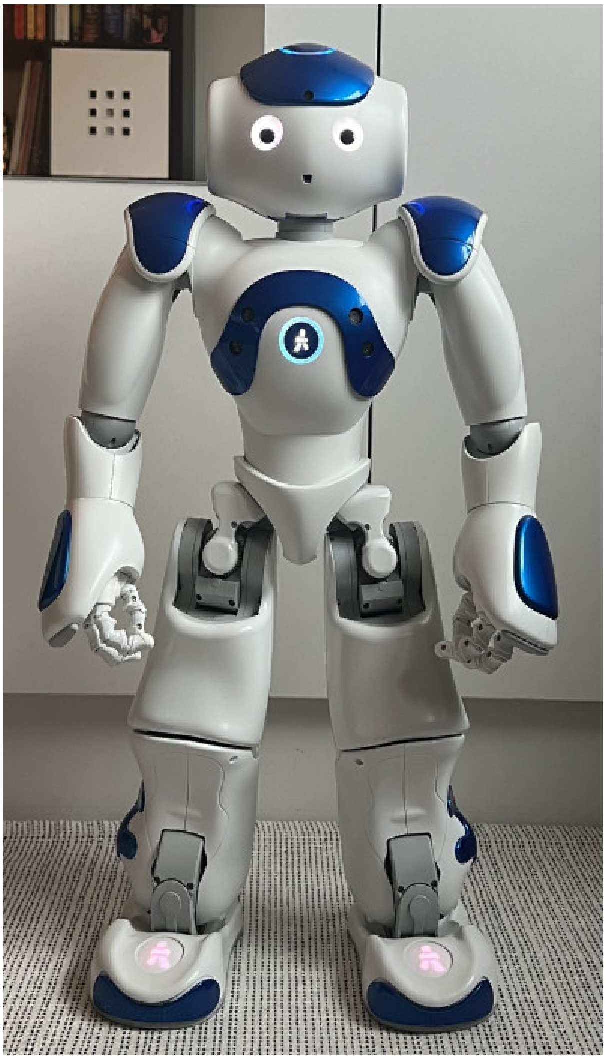
Master

Programming of robot motions

Hi!
Thank you so much for wanting to answer this questionnaire for my master's thesis! :D
My project focuses on creating a remote control system that can control various robots. A remote control for robot 1 (NAO) already exists and it has a library of a lot of pre-programmed movements. A part of this thesis was to explore ways in which the motions can be transferred to a new robot, robot 2 (Misty), without a developer having to program each motion separately. I have implemented 3 different ways of transferring the motion between robot 1 and robot 2. With this survey, I'm looking to find out two main things:
1) How closely the motions of robot 2 mirrors those of robot 1.
2) Your impressions of the robots.
So, in this survey, you will see an original motion done by robot 1 and 3 corresponding motions done by robot 2. You will be asked to rate your impression of the robots based on various attributes, and decide whether robot 2's movements matches robot 1's.

Again, thank you for your participation and good luck! :)

Please rate your impression of ROBOT 1 with respect to the following attributes.



Happiness
1= not happy at all
7 = very happy

Sociability
1= not social at all
7 = very social

Emotionality
1= not emotional at all
7 = very emotional

Strangeness
1= not strange at all
7 = very strange

Awkwardness
1= not awkward at all
7 = very awkward

Scariness

1= not scary at all
7 = very scary

Please rate your impression of ROBOT 2 with respect to the following attributes.

Please rate your impression of ROBOT 2 with respect to the following attributes.

Happiness
1= not happy at all
7 = very happy

Sociability
1= not social at all
7 = very social

Emotionality
1= not emotional at all
7 = very emotional

Strangeness
1= not strange at all
7 = very strange

Awkwardness
1= not awkward at all
7 = very awkward

Nettskjema

Scariness

1= not scary at all
7 = very scary

Matching and ratings of robot motions

These videos show 4 motions done by robot 1 and the corresponding motions done by robot 2. Please watch these videos to answer the following questions below:
1) Which 2 motions done by the two robots belong together?
2) What is your general impression of the two robots based on the 2 sets of videos?

Ps: all the videos contain sound, so turn up the volume!

Please mark the checkboxes for the pairs of motions you believe are correct.

Robot 1 motion 1

- Robot 2 motion 1
- Robot 2 motion 2
- Robot 2 motion 3
- Robot 2 motion 4

Robot 1 motion 2

- Robot 2 motion 1
- Robot 2 motion 2
- Robot 2 motion 3
- Robot 2 motion 4

Robot 1 motion 3

- Robot 2 motion 1
- Robot 2 motion 2
- Robot 2 motion 3
- Robot 2 motion 4

Robot 1 motion 4

- Robot 2 motion 1
- Robot 2 motion 2
- Robot 2 motion 3
- Robot 2 motion 4

Can you give a short explanation for your choices?

Ranking of robot dances 1

The videos show one dance performed by robot 1 and 3 different versions of the same dance performed by robot 2. Please rate the three versions from 1 to 5 based on how closely you think each reflects the original dance by robot 1, with 1 being the best representation and 5 being the worst.
Ps: all the videos contain sound, so turn up the volume (if you want)!

Here is the original motion done by robot 1:

Based on the next videos, please rate how accurately you think the motion of Robot 2 represents the motion of Robot 1

Video 1 (1=best, 5=worst):

Video 2 (1=best, 5=worst):

Video 3 (1=best, 5=worst):

Please give a short and general explanation for your ratings of the motions:

Ranking of robot dances 2

The videos show one dance performed by robot 1 and 3 different versions of the same dance performed by robot 2. Please rank the three versions from 1 to 5 based on how closely you think each reflects the original dance by robot 1, with 1 being the best representation and 5 being the worst. In addition, you will be asked to rate your impression of the different versions of the dances.
Ps: all the videos contain sound, so turn up the volume (if you want):

Here is the original motion done by robot 1:

Based on the next videos, please rate how accurately you think the motion of Robot 2 represents the motion of Robot 1

Video 1 (1=best, 5=worst):

Video 2 (1=best, 5=worst):

Video 3 (1=best, 5=worst):

Please give a short and general explanation for your ratings of the motions:

Ranking of robot dances 3

The videos show one dance performed by robot 1 and 3 different versions of the same dance performed by robot 2. Please rank the three versions from 1 to 5 based on how closely you think each reflects the original dance by robot 1, with 1 being the best representation and 5 being the worst. In addition, you will be asked to rate your impression of the different versions of the dances.

Here is the original motion done by robot 1:

Based on the next videos, please rate how accurately you think the motion of Robot 2 represents the motion of Robot 1

Video 1 (1=best, 5=worst):

Video 2 (1=best, 5=worst):

Video 3(1=best, 5=worst):

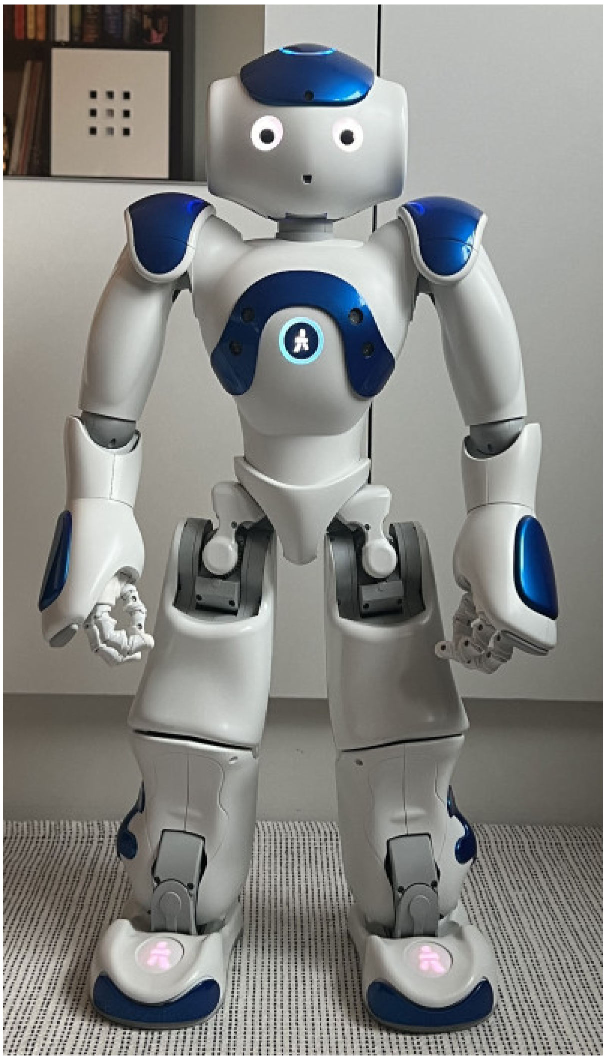
Please give a short and general explanation for your ratings of the motions:

Please rate your impression of ROBOT 1 with respect to the following attributes.

Now that you have watched the videos demonstrating different movements by Robot 1, could you

Nettskjema

please rate your current impression of the robot based on what you observed?



Happiness
1= not happy at all
7 = very happy

Sociability
1= not social at all
7 = very social

Emotionality
1= not emotional at all
7 = very emotional

Strangeness
1= not strange at all
7 = very strange

Awkwardness
1= not awkward at all
7 = very awkward

Scariness
1= not scary at all
7 = very scary

Please rate your impression of ROBOT 2 with respect to the following attributes.

Now that you have watched the videos demonstrating different movements by Robot 1, could you please rate your current impression of the robot based on what you observed?

Please rate your impression of ROBOT 2 with respect to the following attributes.

Happiness
1= not happy at all
7 = very happy

Sociability
1= not social at all
7 = very social

Emotionality
1= not emotional at all
7 = very emotional

Strangeness
1= not strange at all
7 = very strange

Nettskjema

Awkwardness
1= not awkward at all
7 = very awkward

Scariness
1= not scary at all
7 = very scary

G Online Questionnaire Responses

Nettskjema

Master

Oppdatert: 1. mai 2024 kl. 20:41

Programming of robot motions

Hi!
Thank you so much for wanting to answer this questionnaire for my master's thesis! :D
My project focuses on creating a remote control system that can control various robots. A remote control for robot 1 (NAO) already exists and it has a library of a lot of pre-programmed movements. A part of this thesis was to explore ways in which the motions can be transferred to a new robot, robot 2 (Misty), without a developer having to program each motion separately. I have implemented 3 different ways of transferring the motion between robot 1 and robot 2. With this survey, I'm looking to find out two main things:
1) How closely the motions of robot 2 mirrors those of robot 1.
2) Your impressions of the robots.
So, in this survey, you will see an original motion done by robot 1 and 3 corresponding motions done by robot 2. You will be asked to rate your impression of the robots based on various attributes, and decide whether robot 2's movements matches robot 1's.

Again, thank you for your participation and good luck! :)

Please rate your impression of ROBOT 1 with respect to the following attributes.

Happiness

Antall svar: **37** Snitt: **4.14** Median: **4**

Svar	Antall	% av svar	
1	3	8.1%	8.1%
2	2	5.4%	5.4%
3	5	13.5%	13.5%
4	11	29.7%	29.7%
5	11	29.7%	29.7%
6	3	8.1%	8.1%
7	2	5.4%	5.4%

Sociability

Antall svar: **37** Snitt: **4.86** Median: **5**

Svar	Antall	% av svar	
1	1	2.7%	2.7%
2	2	5.4%	5.4%
3	2	5.4%	5.4%
4	8	21.6%	21.6%
5	9	24.3%	24.3%
6	13	35.1%	35.1%
7	2	5.4%	5.4%

Emotionality

Antall svar: **37** Snitt: **4.05** Median: **4**

Svar	Antall	% av svar	
1	2	5.4%	5.4%
2	6	16.2%	16.2%
3	4	10.8%	10.8%
4	10	27%	27%
5	8	21.6%	21.6%
6	5	13.5%	13.5%
7	2	5.4%	5.4%

Strangeness

Antall svar: **37** Snitt: **2.65** Median: **3**

Svar	Antall	% av svar	
1	9	24.3%	24.3%
2	9	24.3%	24.3%
3	9	24.3%	24.3%
4	7	18.9%	18.9%
5	2	5.4%	5.4%
6	1	2.7%	2.7%
7	0	0%	0%

Awkwardness

Antall svar: **37** Snitt: **2.81** Median: **3**

Svar	Antall	% av svar
1	10	27%
2	7	18.9%
3	9	24.3%
4	4	10.8%
5	5	13.5%
6	2	5.4%
7	0	0%

Scariness

Antall svar: **37** Snitt: **1.49** Median: **1**

Svar	Antall	% av svar
1	26	70.3%
2	6	16.2%
3	3	8.1%
4	2	5.4%
5	0	0%
6	0	0%
7	0	0%

Please rate your impression of ROBOT 2 with respect to the following attributes.

Please rate your impression of ROBOT 2 with respect to the following attributes.

Happiness

Antall svar: **37** Snitt: **3.46** Median: **3**

Svar	Antall	% av svar	
1	4	10.8%	10.8%
2	8	21.6%	21.6%
3	9	24.3%	24.3%
4	5	13.5%	13.5%
5	6	16.2%	16.2%
6	4	10.8%	10.8%
7	1	2.7%	2.7%

Sociability

Antall svar: **37** Snitt: **4.27** Median: **4**

Svar	Antall	% av svar	
1	1	2.7%	2.7%
2	5	13.5%	13.5%
3	7	18.9%	18.9%
4	9	24.3%	24.3%
5	4	10.8%	10.8%
6	7	18.9%	18.9%
7	4	10.8%	10.8%

Emotionality

Antall svar: **37** Snitt: **4.27** Median: **4**

Svar	Antall	% av svar	
1	2	5.4%	5.4%
2	4	10.8%	10.8%
3	9	24.3%	24.3%
4	5	13.5%	13.5%
5	6	16.2%	16.2%
6	6	16.2%	16.2%
7	5	13.5%	13.5%

Strangeness

Antall svar: **37** Snitt: **2.89** Median: **3**

Svar	Antall	% av svar	
1	11	29.7%	29.7%
2	7	18.9%	18.9%
3	5	13.5%	13.5%
4	3	8.1%	8.1%
5	11	29.7%	29.7%
6	0	0%	0%
7	0	0%	0%

Awkwardness

Antall svar: **37** Snitt: **2.65** Median: **2**

Svar	Antall	% av svar	
1	14	37.8%	37.8%
2	7	18.9%	18.9%
3	3	8.1%	8.1%
4	6	16.2%	16.2%
5	5	13.5%	13.5%
6	2	5.4%	5.4%
7	0	0%	0%

Scariness

Antall svar: **37** Snitt: **1.59** Median: **1**

Svar	Antall	% av svar
1	27	73%
2	6	16.2%
3	0	0%
4	2	5.4%
5	0	0%
6	2	5.4%
7	0	0%

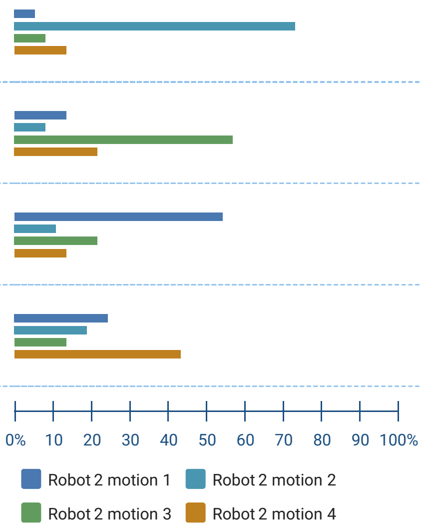
Matching and ratings of robot motions

These videos show 4 motions done by robot 1 and the corresponding motions done by robot 2. Please watch these videos to answer the following questions below:
1) Which 2 motions done by the two robots belong together?
2) What is your general impression of the two robots based on the 2 sets of videos?

Ps: all the videos contain sound, so turn up the volume!

Please mark the checkboxes for the pairs of motions you believe are correct.

Svar	Robot 2 motion 1	Robot 2 motion 2	Robot 2 motion 3	Robot 2 motion 4	Diagram
Robot 1 motion 1	2	27	3	5	
Robot 1 motion 2	5	3	21	8	
Robot 1 motion 3	20	4	8	5	
Robot 1 motion 4	9	7	5	16	



Can you give a short explanation for your choices?

Antall svar: **37**

- I looked at which arms moved and if they were coordinated in similar ways.
- Så mest naturlig ut
- Looking at the facial expressions and similar arm movement to see similarities, but it was hard
- Used a combination of arm movement and sound
- Robot 1 motion 1 and robot 2 motion 2 : looks like it's saying a greeting
  Robot 1 motion 2 and robot 2 motion 1 : seems like it's asking a question
  Robot 1 motion 3 : looks like it's confused
  Robot 1 motion 4 : i don't really know why it raised its hand
  Robot 2 motion 3 : it likes something
  Robot 2 motion 4 : it loves something

  So r1m1&r2m2 greetings, r1m2&r2m4 and r1m3&r2m1questions and answers. I don't really know what to do with r1m4 and r2m3
- Mostly by «facial expressions» and arm movements. Also using the elemination process
- Motion 1: Robot 1's hi could be seen through robot 2 eye gesture and raise of one hand which kept waving a bit.

  Motion 2: Here it looked like robot 2 is giving a hug so it felt appropriate to go with robot 1's bye

  Motion 3: Robot 2's expression looked like a thinking emoji here

  Motion 4: only choice left plus the robot 2's expression gave a bit of peace vibes. Though 2 and 4 could be used alternatively.
- I decided based on expressions and hand movements
- Prøvde å matche det jeg så på videoene, kroppspråk, lyder
- It was hard to determine. Pure guess
- It was hard to pair them up, because the robots are quite different, especially when it comes to facial expressions and hand movements (the first robot has more defined hands than robot 2). In motion 4 robot 1 makes a peace sign with its hand, but this is hard to replicate with robot 2 because of its hands. Another significant difference between the two robots, is that robot 1 can speak, and the other one can't. However, robot 2 can convey emotional expressions with its face. If robot 1 said something i felt robot 2 showed expressions of, i matched them up as pairs. I also looked at arm movements, and paired the motions up if they looked similar in that way.

- It made most sense when comparing them. Robot 2 motion 3 was hard to compare with robot 1 motion, since they had different movements. These combinations mad the most sense for me.
- I think robot 1 shows the movement more clearly and robot 2 showing emotion better.
- Some were chosen because of similar hand movements. Like the first one. And also by how welcoming it felt like (just like when someone says hi). For "la meg tenke" I chose the one that said "hmmm" cause it's the expression I use for thinking. Some i had to guess.. robot 2 Motion 4 was angry but none of the videos for robot 1 felt that way...
- Robot 1 motion 1: Robot 2 is waving its arm in robot 2 motion 2.
  Robot 1 motion 2: Looks like robot 1 is saying "hade" there. It looks like robot 2 is waving its arm to say goodbye in Robot 2 motion 4.
  Robot 1 motion 3: Robot 2 motion 1 makes a facial expression when thinking about something.
  Robot 1 motion 4: Unlike Robot 1, Robot 2 does not have fingers. However, it still looks friendly when it tries to make the peace sign by raising its arm (robot 2 motion 3).
- R1M1 - robot 2 reaches its hand out to say hello
  R1M2 - not sure what robot 1 is doing while saying goodbye but robot 2 had similar movements with its hands.
  R1M3 - robot 2 said «hmmm» as if it was thinking, but this is difficult to guess because robot 2 is not speaking English.
  R1M4 - peace and love. Robot 1 gives peace and robot 2 is falling in love (it seems like)
- it is much more fluent
- I think that two robots make the same gestures, they express the same filings
- More funny!
- I tried to find a correlation between the handgestures of Robot 1 and the mimic of Robot 2.
- Pretty difficult due to absence of joints for Robot 2.
- Hand movements.
- Because the second robot doesn't have joints makes it difficult to say
- Hard to compare due to the big difference in articulation points but I took in consideration the amount of "hands" used and their side.
- Lifting of the same arm and the eyes expresion on Robot 2 matching the words of Robot 1. Not easily to distinguish between movements of Robot 2.
- Observing the eyes of robot 2 as they act as replacement for the voice of robot 1
- hand movements were the most essential part of matching motions, because robot number 2 didn't have as many joints as robot number 1.
- I am not sure if there is an explanation, it was more a feeling they are doing the same motions.
- The robot 2 gave me more "sad/angry" vibes from it. The colors also made a difference on robot 2, in motion 1 it looked ish angry. It looked like robot 2 tried to copy the hand movements of robot 1.
- it made sense? i was highly confused though
- Robot 2 motion 4 seemed the most like a greeting.
  Robot 2 motion 3 resembled Robot 1 motion 2 the most.
  Robot 2 motion 1 has a hmm noise that resembles thinking, making the association with Robot 1 motion 3 easy.
  Robot 2 motion 2 had a similar arm movement to Robot 1 motion 4.
- Robot 2 motion 1 Was very angry.
  Robot 1 was never angry
- Not really. Robot 1 and 2 looked very different and almost all of them did not match.

- Chose the ones that were the best match in my eyes.

- inntrykk jeg får fra robot 1
  Robot1 motion1: Hilse
  Robot1 motion2: Gir beskjed om noe er klar
  Robot1 motion3: Forvirret, uklart
  Robot1 motion4: Farvel

  inntrykk jeg får fra robot 2
  Robot2 motion1: Dette må du gjøre (gir en beskjed til brukeren?)
  Robot2 motion2: Hyggelig å møte deg (Hilse)
  Robot2 motion3: Jeg er glad?
  Robot2 motion4: Lei seg

  Basert på det så er det lett å linke robot1 motion1 til robot2 motion2, og robot1 motion2 til robot2 motion1.

  Robot1 motion4 og Robot2 motion4 er linket sammen bevegelsen farvel er linket sammen med følelsen lei seg.

  Jeg forstår ikke helt Robot2 motion3, men siden robot1 motion3 er eneste valget, derfor ble det det.

- This was not easy.
  Robot 2.1 seems to have suspicions, however this could not be found in the other robot. However 1.3 seems to think, so i guess this fits the best?
  2.2 seems like it is waiting for the other part to leave, while 1.2 says "hade"?
  1.1 says "hei" while 2.3 gives a welcome hug? I guess...
  2.4 and 1.4 i dont really know. give me a small break. both reaches out or something.

- Robot 1 Motion 1 sier hei og vinker, og jeg følte med en gang at robot 2 motion 2 sa hei med øynene og lyden og vinket med en hånd. Robot 1 Motion 2 sier hadet, den var vanskeligere å matche, men tror det er robot 2 Motion 3 fordi den ligner litt på hei, men bruker 2 hender slik som robot 1 gjør. Det er også litt elimineringsprosess fordi jeg føler ikke de to andre sier hadet. Robot 1 Motion 3 var veldig enkel, robot 2 motion 1 viser at den tenker med øynene, mens robot 1 sier «la meg tenke», føler robot 2 er veldig intuitiv med øynene. Robot 1 Motion 4 synes jeg var vanskligst, men tror det er robot 2 Motion 4 fordi den ikke passer med noen av de andre. Og robot 1 viser peace tegn som kan være å pose for et bilde for eksempel å være søt? Litt usikker. Robot 2 Motion 4 virker nærmest forelsket, men kan også se ut som den prøver å være søt.

Ranking of robot dances 1

The videos show one dance performed by robot 1 and 3 different versions of the same dance performed by robot 2. Please rate the three versions from 1 to 5 based on how closely you think each reflects the original dance by robot 1, with 1 being the best representation and 5 being the worst.
Ps: all the videos contain sound, so turn up the volume (if you want)!

Here is the original motion done by robot 1:

Based on the next videos, please rate how accurately you think the motion of Robot 2 represents the motion of Robot 1

Video 1 (1=best, 5=worst):

Antall svar: **37** Snitt: **3.03** Median: **3**

Svar	Antall	% av svar	
1	2	5.4%	5.4%
2	12	32.4%	32.4%
3	9	24.3%	24.3%
4	11	29.7%	29.7%
5	3	8.1%	8.1%

Video 2 (1=best, 5=worst):

Antall svar: **37** Snitt: **2.76** Median: **3**

Svar	Antall	% av svar	
0	1	2.7%	2.7%
1	6	16.2%	16.2%
2	8	21.6%	21.6%
3	11	29.7%	29.7%
4	8	21.6%	21.6%
5	3	8.1%	8.1%

Video 3 (1=best, 5=worst):

Antall svar: **37** Snitt: **2.54** Median: **3**

Svar	Antall	% av svar	
0	3	8.1%	8.1%
1	7	18.9%	18.9%
2	8	21.6%	21.6%
3	9	24.3%	24.3%
4	6	16.2%	16.2%
5	4	10.8%	10.8%

Please give a short and general explanation for your ratings of the motions:

Antall svar: **37**

- I gave ratings based on if the robot could lift both arms at the same time, perform some side to side motion and lift alternating arms
- Ser mest naturlig ut
- Due to the limited mobility of the second robot, it is hard to see if it actually replicates the movement or does a completely other. The turning also made it less similar
- To much head movement in 2 and 3. 1 is a bit too still
- Version 1 : only doing the same thing on repeat
  Version 2 : i can see little similar moves to robot 1
  Version 3: more similar to robot 1
- Doesnt really do any of the same moves, cant call it the same dance
- The first one gave the best "robotic dance" look here
- Choose based on overall movement and tempo
- Robot 1 er mer bevegelig i armer og bein mens nr2 utrykker mer med hodet
- Hand motions(?)
- video 1 - the robot has less face movements than the original
  video 2 - the face and arm movements were pretty accurate
  video 3 - the robot was moving around a lot, which the original didn´t
- Robot 1 is always in the same position, so i know it was not video 3 that fit the most. 2 and 1, were pretty similar but 1 moved its head less. If 3 moved less around, I would Give it 1
- On video 3 robot 2 have more motion and are more like dancing of robot 1
- I tried to match the moves and give the score based on how similar it was to the first one. Robot dance 1 had a good start but it got worse from there. I didn't see any crisscrossed arms. Dance 2 was better at the crisscross but it had added other moves like going side to side.. and the star was off. Dance 3 had great arm movements but added the extra side to side move..
- Video 1: The arm movements are not as precise as in the original video.
  Video 2: The arm movements are mostly precise as in the original video.
  Video 3: The arm movements are precise as in the original video.
- It was really difficult to judge. However, i think the first dance performed by robot 2 was the most similar to robot 1 because of the timing (when robot 2 moves its hands and when it moves its head). The second and third dance I focused on how the robot rotated its «hips» which was not done by robot 1, so it felt like most of the movements were random.
- the movements seem much more real
- Robot 1 is more interesting, more flexible
- Very expressive
- In my evaluation I considered in which order are the hands movments executed.
- Again, absence of joints makes the decision difficult, but the sequence seemed to be the closest in the third video.
- Hand movements. Head movements can not compensate.
- Same as first anwear
- Video no 3 a bit more variation on use of the "hands" closest to the robot 1 moves

- Tried to see matching movements.
- The more movement on robot 2, the better. More lifelike and expressive. Head movement adds a lot to the experience in particular.
- again, the arm motions were the essential. judged based on the vibe and mostly the alternating hand movements
- I took lifting of the arms as reference.
- The hand movements. In video 2 it was almost like only the head was moving.
- the last video had much more åproficient moves
- I was looking at the arms, as that formed the prinicpal motion in Robot 1's dance. As such, video 3 showed the most accurate arm movement by far.
- Missing some movements
- 1. did not do a lot, but moved the head mostly
  2. and 3. moved the whole robot more, and the arms. And got more og the movements in that way
- Did not think it was that great of a match, but it is understandable that it is difficult for robot 2 to replicate the motions of robot 1. So ratings are not based on how great they were, but rather based on the robots compared to each other. I would also add that I think robot 1 is really good with hand motions, while robot 2 is much better at facial expressions. So robot 2 is better for social stuff, while robot 1 is better at doing more labor related stuff. I feel more welcomed by robot 2, but robot 1 seems like the more useful.
- Video3 have both included arm movement correctly (one arm up and one arm down), at the same time the head moves as well as the base.
- The first dance did only move the hands together and did only really mimic the up and down motion in the beginning.
  The other two dances moved to much between the sides and did not preforme the same dance robot 1. In general they all moved their head too much
- Den siste var best fordi den klarte å få med både at begge armene var i synk først, også at de bevegde seg motsatt etterpå. De andre 2 hadde bare ett av de elementene, men den andre var verst fordi den nesten bare repeterte seg selv og nesten ikke bevegde armene

Ranking of robot dances 2

The videos show one dance performed by robot 1 and 3 different versions of the same dance performed by robot 2. Please rank the three versions from 1 to 5 based on how closely you think each reflects the original dance by robot 1, with 1 being the best representation and 5 being the worst. In addition, you will be asked to rate your impression of the different versions of the dances.
Ps: all the videos contain sound, so turn up the volume (if you want):

Here is the original motion done by robot 1:

Based on the next videos, please rate how accurately you think the motion of Robot 2 represents the motion of Robot 1

Video 1 (1=best, 5=worst):

Antall svar: **37** Snitt: **2.89** Median: **3**

Svar	Antall	% av svar
0	1	2.7%
1	7	18.9%
2	8	21.6%
3	6	16.2%
4	9	24.3%
5	6	16.2%

Video 2 (1=best, 5=worst):

Antall svar: **36** Snitt: **2.67** Median: **3**

Svar	Antall	% av svar
0	0	0%
1	7	19.4%
2	10	27.8%
3	10	27.8%
4	6	16.7%
5	3	8.3%

Video 3 (1=best, 5=worst):

Antall svar: **36** Snitt: **3.33** Median: **3.5**

Svar	Antall	% av svar
0	2	5.6%
1	3	8.3%
2	2	5.6%
3	11	30.6%
4	10	27.8%
5	8	22.2%

Please give a short and general explanation for your ratings of the motions:

Antall svar: **37**

- Here everyone gor poor ratings, mostly since it was a complicated dance and robot 2 does not have legs and struggles with more complex movements
- Mest bevegelse
- The second robot kind of just turns from side to side, but not the same sides as the first robot, the arm movements ate not at the same arms ether
- Hard to differentiate. Better head movement in 2
- I think they're all the same
- Some movements look a little similiar such as directions. Other than that some movements were too stiff to be called a dance
- In the best one the motion was more free and matched better
- Based on the music and how fast the movement
- Det at robot har ikke så bevegelige armer gjør at den blir begrenset i bevegelsene
- Better than before
- They all looked very different from the original, but the last one was the worst, because it had the slowest and fewest unique movements
- 3 looked most similar, but very different too
- In video 2 robot 2 have better movement, a little faster and better simultaneous motion which make it more like robot 1-dance.
- This was hard to evaluate because robot two doesn't have the same movement capabilities.. however I judged based on the side movements.. (if they were looking left/right on the same beat)
- Video 1:I don't get the feeling that the robot is dancing. It looks more like it's just moving from left to right and raising its arm.
  Video 2: Making more movements here, but not the same as in the original video.
  Video 3: The robot is moving too slowly and looks a little bit shy or confused.
- I think it will be hard to compare these robots because robot 2 has fewer joints than robot 1. The first dance was not similar to robot 1's dance because it felt as if the robot 2 is moving randomly. The second dance gave a more correct «vibe» since robot 2 is actually moving its body and hands a lot. The third dance was not good at all, where the robot didnt move their hands as much as the original dance.
- much more accurate
- Robot 1 is more approaches human movements
- very accurate
- The handmotions are too little compatible.
- Here robot 2 had head movements closer to robot 1
- Body and hand movements
- Judging on head and members movement
- On video 1 is the most dynamiic.
- The first video shows faster movements and closer to the original. The next and the 3rd were slower and less entusiastics.

- The faster movements of video 1 sold it for me. More expressive and energetic. Hands and head moving together can do a lot when it comes to replicating robot 1.
- rating were given based on the presence core movements of the first robot
- I noticed only that in the last video it wasn't so active.
- Some of the motions felt more smooth, video1 and video2 felt more like "dancing"
- u belive video two had the most gjennomtenkte movements
- This dance was impossible to convey properly with this robot. Video 2 showed the most accurate dynamicity of the dance, while the others did not do so to the same extent.
- It is a whole other dance
- 3 was maybe the best with small movements in the start, and then a bit more afterwards.
- Same reasoning as last time.
- All three video does not express the emotion of the dancing as much as the robot1 which is way all three is rated low. However the video 2 and 3 does seems to be a littel bit better compare to video 1.
- Robot 2 moves way to slow. it kind of feels like the kid that stands in the corner dansing for him/her -self. while Robot 1 is the one winning the dancefloor.
  There is too little motion in robot 2. it just moves from side to side...
- Her klarte jeg ikke skille dansene, føler ingen liknet. Tror det er fordi det er såpass mye bevegelse i hoftene i denne dansen, som robot 2 ikke har.

Ranking of robot dances 3

The videos show one dance performed by robot 1 and 3 different versions of the same dance performed by robot 2. Please rank the three versions from 1 to 5 based on how closely you think each reflects the original dance by robot 1, with 1 being the best representation and 5 being the worst. In addition, you will be asked to rate your impression of the different versions of the dances.

Here is the original motion done by robot 1:

Based on the next videos, please rate how accurately you think the motion of Robot 2 represents the motion of Robot 1

Video 1 (1=best, 5=worst):

Antall svar: **36** Snitt: **3.08** Median: **4**

Svar	Antall	% av svar
0	2	5.6%
1	4	11.1%
2	6	16.7%
3	5	13.9%
4	15	41.7%
5	4	11.1%

Video 2 (1=best, 5=worst):

Antall svar: **36** Snitt: **2.72** Median: **3**

Svar	Antall	% av svar
0	1	2.8%
1	5	13.9%
2	11	30.6%
3	7	19.4%
4	10	27.8%
5	2	5.6%

Video 3(1=best, 5=worst):

Antall svar: **37** Snitt: **3.03** Median: **3**

Svar	Antall	% av svar
0	1	2.7%
1	4	10.8%
2	7	18.9%
3	12	32.4%
4	7	18.9%
5	6	16.2%

Please give a short and general explanation for your ratings of the motions:

Antall svar: **37**

- I gave high ratings to alternating arm movements and lifting both arms at the same time
- Bra lyseffekter
- The robot turns to try to replicate the arm movements, but turns to the wrong side and raises the wrong arm
- Eyes in 2
- Version 1 and 2 are quite similar to each other. Version 3 looks like its low on energy
- Some similarity
- First one seemed to match the best as had similar and “timely” head and arm movements
- Similarity of the movements
- Jo mer man ser på videoene desto større forståelse får man for bevegelsesmønsteret
- Good
- They were all pretty different from the original, because the original made a lot of hand and arm movements I think would be hard for robot 2 to replicate
- The vibe was pretty similar in Motion 2
- More similar movements in videos 2 and 3
- First dance: nothing similar..
  Second dance: I expected the disco move to be performed exactly like this for robot two (one hand moving up and down) this was overall great but still some moves were missing
  Third dance is just got the disco move..
- Video 1: It looks like the robot is walking rather than dancing.
  Video 2: It looks like it's dancing by moving to the left and right.
  Video 3: Same as video 2.
- First of all I dont think robot 2 is able to imitate robot 1’s movement. The first dance being the worst because there were almost no hand movements (which was the most important part of the dance). The second dance was slightly better with more hand movements. The third was the best of the three, but still i cant see that if it actually wants to imitate robot 1. Whats good about the third dance is that the robot is capable of repeating some of the movements, which was done in the original dance.
- much more accurate
- The same answer
- very representative
- The headmovments kan be more correlated.
- Hand movement sequence was closer to original
- Hand and body movement
- Again, lack of joints makes it difficult
- None of them follows the amount and sequence of rising “hands”

- The first dance of robot 2 was more accurate then the other 2. More movements of the arms and more energy in movements.
- Again; faster movements, hands, head as well as moving back and forth
- 2 and 3 had some similarities, but i think the movements of robot 2 overall were the most similar to robot 1
- Only in one video was lifting one arm after each other.
- For the second robot it looks with small movements it seems like it doesn't replicate the first one very good
- the first one had more extreme movements, i feel that the 2nd one was kind of just moving his head. in the third he was a bit slow and not extreme movements
- Once again, the dance is too complicated for Robot 2. The latter videos showed the most dynamicity.
- Robot 2 is not very athletic
- 1 was very much just backwards and forwards. The two other had more moves with both arms and wheels that could resemble robot 1
- Same as last.
- Video1 does not rotate the base, and for me it matches the motion to the robot1 best.
- Dance 1, robot 2: Do the hands really need to move together on robot 2??? robot 1 uses both hands independently, while robot 2 moves them up and down together. no independent movement.
  Dance 2, robot 2: It only moves one hand. then does nothing with the other.

  Dance 3, robot 2: i am still waiting for the robot to use both "arms" independently where they move in oposite directions. Most of the time this robot just goes from one side to the other with the body. nothing more...
- Følte dans en var verst fordi den ikke klarte å bevege en og en arm, mens dans nummer 2 og 3 virket helt like

Please rate your impression of ROBOT 1 with respect to the following attributes.

Now that you have watched the videos demonstrating different movements by Robot 1, could you please rate your current impression of the robot based on what you observed?

Happiness

Antall svar: **37** Snitt: **5.19** Median: **5**

Svar	Antall	% av svar	
1	1	2.7%	2.7%
2	0	0%	0%
3	4	10.8%	10.8%
4	4	10.8%	10.8%
5	10	27%	27%
6	13	35.1%	35.1%
7	5	13.5%	13.5%

Sociability

Antall svar: **37** Snitt: **5.41** Median: **5**

Svar	Antall	% av svar
1	0	0%
2	1	2.7%
3	2	5.4%
4	6	16.2%
5	10	27%
6	8	21.6%
7	10	27%

Emotionality

Antall svar: **37** Snitt: **4.62** Median: **5**

Svar	Antall	% av svar
1	2	5.4%
2	3	8.1%
3	5	13.5%
4	4	10.8%
5	12	32.4%
6	5	13.5%
7	6	16.2%

Strangeness

Antall svar: **37** Snitt: **2.38** Median: **2**

Svar	Antall	% av svar	
1	11	29.7%	29.7%
2	13	35.1%	35.1%
3	6	16.2%	16.2%
4	3	8.1%	8.1%
5	3	8.1%	8.1%
6	1	2.7%	2.7%
7	0	0%	0%

Awkwardness

Antall svar: **37** Snitt: **2.16** Median: **2**

Svar	Antall	% av svar	
1	13	35.1%	35.1%
2	11	29.7%	29.7%
3	9	24.3%	24.3%
4	2	5.4%	5.4%
5	2	5.4%	5.4%
6	0	0%	0%
7	0	0%	0%

Scariness

Antall svar: **37** Snitt: **1.41** Median: **1**

Svar	Antall	% av svar	
1	27	73%	73%
2	8	21.6%	21.6%
3	0	0%	0%
4	1	2.7%	2.7%
5	1	2.7%	2.7%
6	0	0%	0%
7	0	0%	0%

Please rate your impression of ROBOT 2 with respect to the following attributes.

Now that you have watched the videos demonstrating different movements by Robot 1, could you please rate your current impression of the robot based on what you observed?

Please rate your impression of ROBOT 2 with respect to the following attributes.

Happiness

Antall svar: **37** Snitt: **4.46** Median: **5**

Svar	Antall	% av svar	
1	1	2.7%	2.7%
2	3	8.1%	8.1%
3	5	13.5%	13.5%
4	8	21.6%	21.6%
5	12	32.4%	32.4%
6	5	13.5%	13.5%
7	3	8.1%	8.1%

Sociability

Antall svar: **37** Snitt: **4.38** Median: **4**

Svar	Antall	% av svar	
1	1	2.7%	2.7%
2	5	13.5%	13.5%
3	5	13.5%	13.5%
4	8	21.6%	21.6%
5	9	24.3%	24.3%
6	4	10.8%	10.8%
7	5	13.5%	13.5%

Emotionality

Antall svar: **37** Snitt: **4.62** Median: **5**

Svar	Antall	% av svar	
1	1	2.7%	2.7%
2	2	5.4%	5.4%
3	6	16.2%	16.2%
4	9	24.3%	24.3%
5	5	13.5%	13.5%
6	11	29.7%	29.7%
7	3	8.1%	8.1%

Strangeness

Antall svar: **37** Snitt: **2.62** Median: **2**

Svar	Antall	% av svar	
1	12	32.4%	32.4%
2	10	27%	27%
3	4	10.8%	10.8%
4	5	13.5%	13.5%
5	3	8.1%	8.1%
6	3	8.1%	8.1%
7	0	0%	0%

Awkwardness

Antall svar: **37** Snitt: **2.97** Median: **3**

Svar	Antall	% av svar
1	13	35.1%
2	4	10.8%
3	5	13.5%
4	5	13.5%
5	6	16.2%
6	4	10.8%
7	0	0%

Scariness

Antall svar: **37** Snitt: **1.65** Median: **1**

Svar	Antall	% av svar
1	27	73%
2	5	13.5%
3	1	2.7%
4	1	2.7%
5	2	5.4%
6	0	0%
7	1	2.7%