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The Optimal Social Assistive Robot for Autism Spectrum Disorder Interventions

Finding solutions with the use of Artificial Intelligence

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Abstract

People with Autism Spectrum Disorder (ASD) struggle with deficits in social communication and interaction. To help with these deficits, early, intensive and behavioural interventions are recommended. People with ASD have shown a higher degree of engagement through the interaction with robots than through interactions with other humans. Robot interventions for ASD have therefore been one of the first applications explored in the field of Social Assistive Robots (SAR). However, these robots are still semi-autonomous and need to be controlled by professionals at clinics which can be disadvantageous to the learning abilities of the child. The solution proposed in this thesis is to make SARs autonomous with the use of Artificial Intelligence (AI). Making a SAR autonomous to be used for ASD interventions in a home setting influences the current design of a SAR. The current intervention types and designs of SARs will therefore be discussed and what needs to be applied to make a SAR autonomous. Lastly, a SAR will need social intelligence to work during an intervention. The requirements to create social intelligence with the use of AI will be discussed and the differences between general social intelligence and social intelligence specifically for ASD interventions will be highlighted.

Table of context

1. Introduction

Over the years an increasing number of children have been diagnosed with Autism Spectrum Disorder (ASD) (Blaxill, 2004). Children with ASD struggle with persistent deficits in social communication and social interaction across multiple contexts, and have restricted and repetitive patterns of behaviour, interests or activities (Masi et al., 2017). Most observed social behaviours are poor eye contact, failure to initiate social interactions, and the presence of unconventional mannerisms and speech. Without support, this can lead to challenging behaviour like self-injury or aggression, the experience of academic failure, and struggle to create and maintain meaningful social relationships. Furthermore, these deficits have a tendency to increase rather than diminish with age which can lead to adults experiencing difficulty finding employment, starting families, and achieving a desirable quality of life (Lang et al., 2016; Matson et al., 2007). To help increase the level of functioning in daily life, early and individualized interventions are considered to be crucial for children (Huijnen et al., 2016b). These interventions are behavioural mediation that might help reduce the symptom severity and potentially improving long-term outcomes for people with ASD. Because ASD comes in different forms and severities, multiple types of interventions have been created. Support that is beneficial for one person, might harm the other (Scassallati et al., 2012). Many people with ASD have difficulties sustaining high motivation and concentration for interventions led by humans. The dynamic facial features and expressions of humans can induce sensory and emotional overstimulation and distraction. These human expressions can interfere with their learning as they tend to actively avoid the sensory stimulations and instead focus on more predictable elementary features (Kumazaki et al., 2020). A solution to this problem could be the use of robots due to their ability to create controlled environments in which they act in a predictable manner.

The interest in using robots in healthcare settings has been growing rapidly. Robots are found in all different settings in the medical field, they are being used to help with surgeries, drawing blood and help people move around with exoskeletons (The Medical Futurist, 2019). Besides these more physical aspects, robots have also been helping people socially, like Paro the baby seal who keeps elderly company to reduce loneliness. These kinds of robots are called Social Assistive Robots which are defined as robots that recreate social behaviour and help a person socially and/or physically (Feil-Seifer et al., 2005). Hence, research on how Social Assistive Robots could be used for ASD interventions has also increased. Robots might provide tools to address social impairments due to their ability to create situations or environments in which children can practice and learn more safely and pleasantly compared to practicing this with another human. Their ability to create controlled environments allows them to focus on targeting the strengths and weaknesses of the child and could reduce the anxiety that real social situations may cause (Huijnen et al., 2016a). Current robots being researched for ASD interventions are often still heavily dependent on professionals. An example is KASPAR (fig. 1i), KASPAR is a semi-autonomous therapy robot that partially uses pre-programmed expressions controlled by a professional and partially responds to its sensors (Huijnen et al., 2016b). Because professionals are still needed, children need to travel to a clinic to receive their intervention which can be time-consuming for both the child and the caregiver. Furthermore, children with ASD learn better in home- or classroom settings compared to clinics (Waddingon et al., 2016). It would therefore be beneficial if a robot would be autonomous so the intervention could be done at home at any given time. This would save time, energy and would benefit the learning of the child.

So far, a lot of research has been done on *if* robots could be used during ASD interventions and how children with ASD respond to different physical appearances. However, these components get influenced by the setting and type of intervention. What will work for an intervention led by humans might not work for an intervention led by a robot. It is therefore important to understand what research has been done so far and how this gets influenced by the intervention being led by an autonomous robot in a home setting instead of a clinic. The question that will be central in this thesis is therefore the following: How should an autonomous Social Assistive Robot be designed to optimally help children with Autism Spectrum Disorder during intervention?

To answer the main question, components that are needed and unique to Social Assistive Robots used for ASD interventions will be discussed. First of all, there are several intervention types that could be used. These intervention types shape the interactions with the child and state requirement for how the intervention should be led by a robot. A few intervention types will be discussed and will be used throughout the thesis to base design choices on. Secondly, the design will be divided into two sections: the physical appearance and the behaviour of the robot. Like mentioned, a lot of research has been done on how children with ASD respond to different physical appearances. Previous research will be evaluated and used to discuss what would work for autonomous robots. Thereafter, the behaviour of the robot will be discussed. This comprises the design of interaction between the child and the robot. These interactions are shaped by the intervention type, the behaviour goal of the child, and the role of the robot (e.g., plaything, teacher, or friend). These design options (intervention type, physical appearance, and behaviour of the robot) state requirements for what the robot should be able to do so the intervention will be done successfully. Besides these requirements, the robot also needs to have social intelligence to be able to lead an intervention. In the last chapter the stated requirements and need for social intelligence are used to discuss how the robot could be made autonomous by using different AI techniques.

2. Autism Spectrum Disorders Interventions

The development of ASD interventions with the help of robots is still in progress. However, there are existing interventions that help children with ASD improve their functioning. It is important to understand which interventions have been created, how they work, and how they differ from each other to develop new ASD interventions with robots. These interventions will be able to give a frame in which a robot needs to act to help children with ASD.

Even though the underlying cause of ASD has not been found yet, there have been interventions created that have proven to reduce the symptom severity and potentially improve long-term outcomes for people with ASD. These interventions tend to be most effective when they are early, intensive and behavioural (Lang et al., 2016). How early the intervention should start exactly is still a discussion. From a biological perspective, the brain's plasticity is greatest during the first few years of a child's life (Holland et al., 2014). Meaning that this would be the best time to shape the way a child thinks and responds. Another reason to start with interventions at an early age is that learning new skills may allow children to experience more learning opportunities and more complex environmental situations. For example, a child with ASD might be approached more often by other children if they learn to play with toys in the same manner as neurotypical children do. This would create more opportunities for social interaction and learning situations (Lang et al., 2014).

Due to the heterogeneity of ASD, several different interventions have been created. What works for some children will not work for others (Scassallati et al., 20120). Interventions can differ in the degree to which they emphasize natural environments and routines, involve parents as interventionists, focus on specific target behaviours, and follow the child's lead as opposed to being adult-led. Some interventions have been selected which give a broad frame and have been proven to improve the general skills of children with ASD and decrease their deficits.

2.1 Discrete Trial Training

Discrete Trial Training (DTT) helps with reducing social, communication, academic, and self-help difficulties by creating structured learning opportunities. DTT models focus on building learning skills at an early age so that children will be more fluent in acquiring all kinds of skill sets later on. The goal is to systematically teach the child to respond to language and social stimuli in meaningful ways. The discrete trial is a specific interaction consisting out of a few different components. First, there is a discriminative stimulus followed by a structured prompt sequence as needed. The stimulus and prompts should lead to the target behaviour which is then reinforced. Before the next trial starts there is an intentionally short interval. Due to the repeated presentation of the discriminative stimulus with reinforcement for the specific response stimulus control is established. This should lead to a readily response to the stimulus when the child comes across the stimulus under naturally occurring conditions (Lerman et al., 2016).

Lerman et al. (2016) did a meta-analysis on research done on DTT. It suggested that DTT can produce significant increases in intellectual skills, cognitive development, language, adaptive and social skills, and significant decreases in symptoms of autism, problem behaviour, and amount of school support needed. They found that younger children benefit more from DTT. However, even older children can still make substantial gains and ensure they maintain their current level of functioning instead of getting worse over time without intervention.

2.2 Pivotal Response Treatment

The goal of Pivotal Response Treatment (PRT) is to target the key deficit in motivation and therefore it has the potential to produce rapid and widespread improvement in the overall condition of autism. Koegel et al. (2016) explain that low motivation and limited generalizability of treatment gains are problems in ASD interventions which is why PRT has evolved from highly structured and adult-driven sessions to more naturalistic and child-focused interactions. Low motivation is an effect of learned helplessness, this theorizes that exposure to uncontrollable events lead people to believe that behaviours and outcomes are independent, which affects their motivation, cognition, and emotion (Maier et al., 1976). An important factor in treating learned helplessness is increasing the motivation of an individual, this is done by making the connection between the response and reinforcement more salient. Increasing motivation has also shown improvements in children with ASD, namely sociability, communication, behaviour, and academic skill-building.

To assure this increase in motivation, PRT focuses on a few components. First of all, they stimulate child choice by using child-preferred materials, activities, topics, and toys. Child choice can help increase the child’s responsiveness during interactions and can lead to improved generalization outside of the teaching setting. Second, they reinforce attempts regardless of whether these are wrong or right. Because of previous failures children might avoid situations, however, by reinforcing attempts they tend to continue to make further attempts (Koegel et al., 1987). Third, to reinforce the connection between behaviour and outcome natural reinforcements are used instead of arbitrary reinforcers. Fourth, to maintain the knowledge on how to respond to previous tasks, interspersed reinforcement is used. Finally, motivation and responsiveness are improved by varying tasks instead of using constantly the same task (Dunlap et al., 1980). By combining these components an increase in effectiveness was seen. Studies that focused on verbal communication found that about 50% of children with autism became more verbal. However, when PRT was used about 90% of children learned to use verbal expressive language (Koegel et al., 2016).

2.3 Early Start Denver Model

Early Start Denver Model (ESDM) is a comprehensive, developmental, relationship-based behavioural intervention for toddlers with ASD. The focus is on using developmental principles and empirically-based teaching strategies throughout the routines of the children’s daily lives. Applying these strategies in the daily life of a child, instead of only during specific learning moments supports the generalization of their learned skills. Furthermore, the emphasis is on learning via positive, socially engaging, and child-led interactions which should make the learning fun for the children. ESDM differs from more traditional early interventions like DTT. One way it differs is the frame of learning, during DTT children learn by discrete trial while ESDM is more of a joint activity that allows for multiple objectives to be taught. Furthermore, DTT is adult-led with an emphasis on establishing control over the child’s behaviour whereas ESDM is child-led and involves shared control of activities and materials (Talboot et al., 2016).

ESDM conceptualizes ASD as having fundamental differences in children’s motivation for seeking out social interaction. Because children with ASD find social interaction less rewarding, they spend less time seeking out, attending to, and interacting with people and more time interacting with objects. To help with this motivation difference, ESDM uses a few strategies. First of all, increasing the strength and frequency of reinforcement within social interactions. Second, emphasizing pleasurable play with people and social interactions that lead to positive affect. Third, following children’s interests, goals, and initiations in choosing activities and materials. Fourth, using least to most prompting strategies. Fifth, providing new and interesting activities by addressing multiple objectives during an activity and by variation in activities. Lastly, giving children communication strategies that can help them immediately achieve their goals. Children receiving ESDM interventions had significantly improved their cognitive, language, and social skills, adaptive function, and general autism deficits after two years of intervention (Dawson et al., 2010).

These three different interventions all have proven to be successful in helping children with ASD with reducing their difficulties and improving their overall condition. DTT is a structured intervention that provides children with specific learning opportunities. It is mostly adult-led and works best for small children. PRT targets motivation which they claim is the key deficit. They do this in a child-led manner by reinforcing any attempts with natural reinforcements to connect behaviour and the outcome. The tasks are varied to increase motivation and responsiveness. ESDM applies teaching strategies throughout the routines of the child’s daily life instead of having specific learning moments, this supports generalization. They keep these moments fun and child-led and make it a joint activity so multiple objectives can be taught. Even though all three interventions are successful, they are not all equally suitable for interventions with robots. The core of ESDM is the flexibility in learning moments, however, this would not work with a robot because the robot would not always be around to facilitate these learning moments. Both DTT and PRT could work with interventions with robots. A concern for using robots for ASD interventions could be the generalization of learned skills from robots to humans. It is therefore important that the intervention being used pays attention to this potential issue. Child-led interventions should lead to higher generalization which would mean that PRT is preferred over DTT for interventions with the help of robots.

3. Social Assistive Robots for Autism Spectrum Disorder Interventions

Understanding existing interventions can guide the development of robots for ASD interventions. In previous years, a lot of research has been done on *if* robots could be used for ASD interventions. Because of this, different robots have been used for research, resulting in several different physical appearances. Each appearance has their advantages and disadvantages which, combined with the intervention type, need to be considered to conclude what would work best for an autonomous robot used for ASD interventions. Furthermore, the behaviour of current semi-autonomous robots will be discussed to understand what an autonomous robot will be able to do during interventions.

Interventions with the help of robots have the ability to create a controlled environment and the possibility of a more structured and standardized intervention. Robots that operate within predictable and lawful systems provide a highly structured learning environment to people with ASD, which helps them to focus on relevant stimuli. People with ASD often show a higher degree of task engagement through interactions with robots compared to interaction with human therapists (Kumazaki et al., 2020). While neurotypical people often show repulsion towards artificial objects, this is not observed in people with ASD (Diehl et al., 2012). To take it even further, people with ASD often show affinity towards robots which means there are a lot of opportunities for interventions with the help of robots.

There have been some attempts to use robotics for ASD interventions with the following target processes: assisting the diagnostic process, improving eye contact and self-initiated interactions, turn-taking activities, imitation, emotion recognition, joint attention, and triadic interactions (Kumazaki et al., 2020). A variety of robots could be used for these ASD interventions, though the optimal robots must be chosen based on the content of the intervention. Besides the subject matter a considerable amout of different factors play a role in the optimal robot for ASD interventions. For example the appearance of the robot, it is important that the person feels comfortable with the robot and wants to approach the robot and interact with it. In the following section the different appearances of robots will be discussed, followed by how robots behave within ASD interventions.

3.1 Social Assistive Robots Appearance

Robots that have been researched to use in ASD interventions differ considerably in appearance. There is a large range from simplistic nonbiomimetic systems or animal-like robots to very realistic humanoid robots (fig.1). Each design has its advantages and disadvantages in an intervention. A more simplistic design might allow an appearance that exaggerates social cues or helps focus attention on these cues with limited distracting or confusing stimuli. However, a more realistic humanoid robot may be generalized more easily (Kumazaki et al., 2020). The design can be divided into three general categories: nonbiomimetic and animal-like robots, simple android robots, and realistic android robots.

Examples of nonbiomimetic and animal-like robots are Keepon, Pleo, and KiliRo (fig. 1a, 1b & 1c). These robots can be useful for children who have a severe form of ASD because when these children see something with a human form, they are often withdrawn and tend to avoid interactions. However, nonbiomimetic or animal-like robots do not trigger such reactions which allow the children to focus on the robots. The simple design of Keepon and its predictable response gave children with ASD a cheerful and relaxed mood which caused them to play and communicate with it. Eventually, this increased their performance of triadic interpersonal interactions (Kozima et al., 2005). Pleo on the other hand was more used as support and facilitated social interaction with another person which led to more social behaviour during the interaction (Kim et al., 2013). These nonbiomimetic and animal-like robots have advantages in their simplicity and how easy it is for children to have interesting and engaging interactions. However, the disadvantage of these robots is that they may not be generalized because of a significant difference between their design and the appearance of a human. PRT supports child-choice which means it uses child preferred materials and toys, this would increase responsiveness and improve generalization due to higher motivation. So even though the physical appearance would create less generalization, this could be compromised with the higher motivation of the child. A simple design would therefore fit the intervention style well, especially for children with a severe case of ASD.

Simple android robots are often designed in a cartoon-like style, with oversized and exaggerated primary features, such as eyes, and an absence of secondary features like eyelids (Scassellati et al., 2012). Examples of these are CommU, Robota, and KASPAR (fig. 1d, 1g & 1i). The simple designs allow the robots to have a range of simplified expressions that are less complex than those of a real human face. Without this complexity, children with ASD can pay attention to the robot without feeling the anxiety and sensory overload they often experience around humans (Kumazaki et al., 2020). These traits are useful in social-skill training for children to facilitate the understanding of emotional recognition. A study by Wainer et al. (2014) showed that the interaction of children with ASD with KASPAR promoted better collaboration and cooperation with a human partner. An advantage of a robot with more expression possibilities is that it could be used for a longer period when the robot is used autonomously in a home setting. When the child is young it could start with simple tasks without expressions, over time this could increase into more challenging tasks and expressions. This way the robot could be used for several years and develop with the child. This would also be helpful with getting the child more comfortable with the robot so that when the tasks get more difficult the child will not experience anxiety or a sensory overload.

Android robots are either more realistic humanoid robots that show more complex features, for example, Actroid-F (fig. 1e) or, mechanical-looking robots like Infanoid and NAO (fig. 1f & 1h). They often have more degrees of freedom in their movements which allows them to show more complex expressions. Because of this, they could be used to help with more complicated social skills like non-verbal communication (Kumazaki et al., 2019a). The complexity of the robot is both an advantage and a disadvantage. Due to their similarity to humans, they might be generalized more easily. However, people with ASD are often less comfortable with humans which would make android robots less appealing to people with ASD.

Overall Kumazaki et al. (2020) concluded that ‘simple’ is not better but that ‘simpler than humans’ is better which was confirmed by multiple other studies (Kumazaki et al., 2018; Kumazaki et al., 2019b; Robins et al., 2006; Scassellati et al., 2012). They suggested that younger users may prefer a robot with a simple appearance like a nonbiomimetic or animal-like appearance. Furthermore, older individuals with ASD might prefer an android robot due to the advanced technology used to create it. For use during PRT interventions both a nonbiomimetic or animal-like robot and a simple android robot could work well. A nonbiomimetic- or animal-like robot might look more like a toy to a child which supports child-choice. However, a simple android might be able to support the child for a longer period of time and increase the difficulty in tasks over time. A simple humanoid robot still has the advantage that it is simpler than humans which is more appealing to children with ASD.

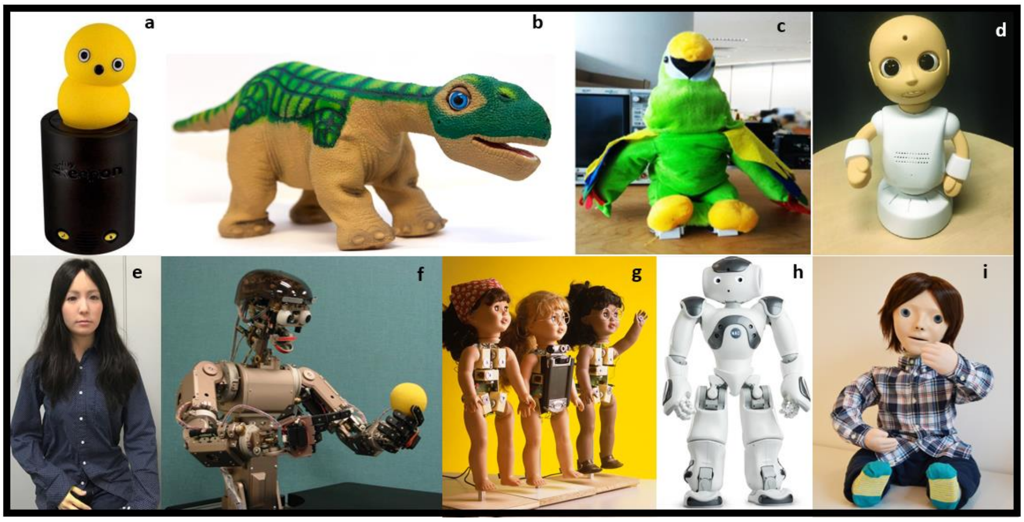

Figure 1 Selection of robots used in ASD interventions
(a) Keepon.
(b) Pleo.
(c) KiliRo.
(d) CommU.
(e) Actroid-F.
(f) Infanoid.
(g) Robota.
(h) NAO.
(i) KASPAR.

3.2 Social Assistive Robot's Behaviour

Together with physical appearance, a robot's behaviour is critical to how it is perceived and how effective the ASD intervention is. The behaviour of the robot is shaped by the goal of the intervention, the type of intervention, and the role of the robot. Generally, the goal of intervention is to help decrease ASD symptoms, however, this can be divided into smaller goals like joint attention, eliciting imitation, or mediating turn-taking. Furthermore, the role of the robot influences how the interaction takes place, the robot can act as a teacher with authority, as a toy intended to mediate behaviour by the user, or as a proxy for the user to allow them to express emotions or goals (Scassellati et al., 2012). Finally, the type of intervention guides the behaviour of the robot, however, it is common to have multiple goals and tasks within an intervention. For example, during PRT it is advised to vary tasks to improve motivation and responsiveness. In the following section, the design of interactions from the perspective of targeted behaviour will be discussed along with examples from different researches on Social Assistive Robots for ASD interventions.

First of all, children with ASD often have difficulties with starting and/or maintaining eye contact, facial expressions, and other social behaviours that regulate engagement (Johnson et al., 2007). This is the basis for the goal to elicit and maintain engagement throughout an intervention. A considerable amount of studies report positive effects of robot presence on attention and engagement in therapy-like scenarios, even though several of different physical appearances were used (Scassellati et al., 2012; Shamsuddin et al., 2012). Attention and engagement are acquired through for example appropriately timed movement, social request, and the display of desirable behaviours. During DTT interventions this would be the discriminative stimulus. When the target behaviour, in this case engagement, is accomplished the child would be reinforced. Shamsuddin et al. (2012) used a NAO robot (fig. 1h) to gauge whether a child with ASD would show less ASD characteristics during robotic exposure compared to their normal environment in class. The robot was placed in front of the child and would go through five pre-programmed modules to engage with the child. It would start with an introductory rapport, followed by NAO talking to the child, moving its arms, playing a song while blinking its eyes, and ending with playing a song while moving with its arms. The results showed that a single session was able to dampen their ASD traits compared to their normal behaviour in the classroom. When the goal is to elicit and maintain engagement, the role of the robot is often that of a plaything because they are novel, toy-like stimuli that easily attract children's attention. This is also seen in the interaction between NAO and the child in the research by Shamsuddin et al. (2012), the child is only expected to pay attention, no further interactions are required.

Secondly, elaborating on the previous goal is joint attention. Children with ASD have difficulties demonstrating shared interest toward objects by pointing or using eye contact. This skill is important for regular human communication and essential for learning and collaborative tasks (Johnson et al., 2007). Depending on the physical appearance of the robot, joint attention can be encouraged in different ways. For instance, Keepon (fig. 1a) is able to pose itself to first initiate eye contact with the user and then shift towards an object of interest to create joint attention. Robots with limbs and more degrees of freedom will be able to create joint attention by pointing towards objects or, if a robot is able to produce sound, talking about the object of interest. To create joint attention, the robot needs to guide the user, so the role is more of a teacher. However, when an intervention is more child-led like during PRT or ESDM, the child can also start the interaction. In this case, the robot will need to follow the child and also pay attention to the object the child is focused on. By doing this the robot is also reinforcing the initiation and interest of the child.

Thirdly, children with ASD often have difficulty imitating other people's behaviour. However, this skill is important for learning appropriate behaviour like learning social constructs such as waving hello and goodbye by imitating others around them (Williams et al., 2004). Thus, interventions that stimulate imitation are useful for the generalization of other learned skills. In previous research, imitation seems to occur naturally in human-robot interactions. This can either be structured by games or encouragement of an adult/robot, or the imitation can happen spontaneously. When it happens spontaneously, the robot can continue by imitating the child again which can lead to it becoming a game (Kozima et al., 2005; Kozima et al., 2007; Scassellati et al., 2012). When this happens during a PRT intervention it is important that these spontaneous interactions are naturally reinforced, so that the child can connect their behaviour to the outcome. This should give them the insight that their behaviour can have good consequences and that social interaction and games are positive experiences. The role of the robot can differ in this case because imitation can be accomplished by minimal communication the robot can be like a plaything to the child. In contrast, when the imitation is accomplished by a structured interaction the role of the robot is more of a teacher and example to the child. The role of the robot is also influenced by the appearance of the robot. When the robot has a nonbiomimetic or animal-like appearance it is more inclined to be perceived as a plaything while a more humanoid robot will be more likely to be perceived as a teacher.

Lastly, imitation often goes together with turn-taking. Children with ASD generally have difficulties with sharing and turn-taking which present challenges for social interactions (Scassellati et al., 2012). Goodrich et al. (2012) designed a robot called Troy which has a computer screen for a face, able to show multiple emotions, and moveable arms. They designed the robot behaviours to promote turn-taking and imitation behaviours. During the intervention they played a game in which the robot would push a truck to the child, followed by a request for the child to push back the truck. The child would be helped by a clinician when needed. The role of the robot is in this case that of a teacher and example to the child, it needs to guide the child through the interaction. For turn-taking tasks, the robot needs to have an appearance that is able to naturally do these tasks. A simple design without limbs with a certain amount of degrees of freedom will not be able to do this successfully. A simple humanoid or android robot would therefore be most suitable for these tasks.

To conclude, the behaviour of a robot in ASD interventions is shaped by a few different factors. The goal of the intervention determines what kind of activities will take place. There are often different smaller goals within an intervention that might be combined, for example with imitation and turn-taking. For some of these goals and tasks the robot needs to be able to have enough degrees of freedom to interact with the child. It is, therefore, more beneficial to have a simple humanoid robot with limbs compared to a nonbiomimetic or animal-like robot. The role of the robot will then determine how the robot will act to reach the set goal. This can be done in passive ways where the robot acts on its own and the child can either engage or not, or it can be done by actively requesting the child to engage and participate in the interaction. This also depends on the type of intervention. During DTT the child will be actively included in the engagement with specific stimuli and prompts, while ESDM will do this passively during the routine of the child. PRT is more in the middle with specific moments to have an intervention, however, it has a more passive child-led approach to reach the goal. Furthermore, the type of intervention shapes the framework in which the interaction will take place. AS mentioned before, PRT is child-led which means the robot needs to be able to adapt its behaviour to the child. So far, robots are semi-autonomous with pre-programmed scenarios and a professional who can control the robot remotely (Bharatharaj et al., 2017; Goodrich et al., 2012; Huijnen et al., 2016; Shamsuddin et al., 2012; Van den Berk-Smeekens et al., 2020). This allows the professional to change the robot’s behaviour when needed, however, it also means that the intervention will take place at a clinic and a professional always has to be present to accommodate.

4. Artificial Intelligence in Social Assistive Robots

Currently, all robots used for ASD interventions are semi-autonomous. Because of this, children will need to go to the location of the intervention accompanied by their caregivers. This can be challenging for the children because children with ASD can be uncomfortable in new or different surroundings which could affect their learning. Furthermore, there are a lot of resources needed, one or multiple professionals are required to lead the intervention and control the robot, in addition the caregivers need to put in a lot of time to be present which can limit the quantity of the interventions. However, interventions work best when they are intensive. The proposed solution in this thesis is to make a robot fully autonomous using AI techniques. In the following chapter the requirements for the implementation of AI in robots for ASD interventions will be discussed.

When creating an AI for robots used during ASD interventions, it is important that the AI is able to perform the tasks which would happen during a regular ASD intervention. As stated in chapter 2, PRT would be a suitable intervention style to use with robots. It is therefore essential that the robot is capable to provide child-choice, meaning that it should work with child preferred materials, activities, and topics. It should be able to provide an intervention that is child-led and be able to adapt quickly given the cues from its environment. It should reinforce any attempts at a task, no matter if the child fails or succeeds. Lastly, it should vary different tasks during an intervention. Furthermore, for a robot to lead an intervention it should be socially intelligent which means it should have a Theory of Mind (ToM). ToM is a competency that comprises both social and cognitive skills that enables people to think about their own and other's mental states and emotions. An AI that is able to have a ToM will understand the users it interacts with which allows it to make better decisions on how to act. To create a ToM, it will need to discern the needs, emotions, beliefs, and thinking of the user (Davies, n.d.). Malerba et al. (2019) defined four fundamental skills that should be implemented to achieve social intelligence: sensing, dialogue management, emotion recognition, and user modelling. These skills should also get the robot closer to having a ToM.

Sensing

There are a few different sensors a robot needs to have to be able to perceive its environment. The two standard sensors are microphones for speech and sound recognition, and cameras to visually perceive its surroundings. For speech recognition, Deep Convolutional Neural Network (CNN) models, designed for processing structured arrays of data, are used to improve the accuracy of voice recognition (Wood, n.d.; Xiong et al., 2017). Advancements in this area have made the development of high-level tasks like semantic recognition and semantic understanding possible. These form the basis for the dialogue management of the robot (Malerba et al., 2019). Computer vision is necessary for the recognition of human facial expressions and movements. A combination of CNN models and a Support Vector Machine (SVM), a deep learning algorithm that performs supervised learning for classification or regression of data groups, can be used for the classification of facial expressions and movements. For PRT intervention it is important that the AI is able to recognize an attempt of the goal behaviour during a task. This should be included in the recognition of movements. For example, when eye contact is one of the tasks during an intervention and the child attempts it by looking in the general direction but not actually at the eyes, the child should still be reinforced for the attempt. This is different from other social assistive robots and therefore comes with its own complications like recognizing when something is an attempt and when it is just general behaviour. Certain parameters have to be set to distinguish between behaviours. During interventions, there are also general challenges with vision. Since the interaction with a child can change abruptly, there might be problems such as occlusions or poor camera viewpoints which would make the classification of facial expressions and movements inaccurate or not possible at all. It is therefore crucial that a robot has a robust multi-view action recognition system (Malerba et al., 2019).

Specifically, for ASD interventions it is important that the robot has touch sensors. Children with ASD have deficits in communication, especially nonverbal communication which includes physical communication. The robot should therefore be able to detect and differentiate between touch gestures, like affection or aggression. Traditional touch sensors have shortcomings like requiring almost direct contact or having a short detection range of just a few centimetres from the sensor itself which means the robot would need several sensors to cover its entire body. A suitable alternative might be acoustic sensing, which uses microphones to detect touch, combined with Logistic Model Trees to classify the touches. This technique requires only one microphone per part of the robot (e.g., the torso) and still provides rich information which allows distinguishing between different touch gestures (Alonso-Martin et al., 2017).

Dialogue management

For a robot to lead an intervention it has to be able to handle dialogues. There are different aspects of handling a dialogue: regulating initiative, handling communication interferences, making deductions from the sentences pronounced by the other person, and plan, organize and maintain the discourse. Initially the robot perceives the user input, continued with extracting the meaning which a dialogue manager then uses to decide and reason how to respond to the user so eventually a dialogue flow can be established.

There are different approaches to dialogue management. The most straightforward way to handle dialogues is with finite-state models which are mostly used in settings where the dialogue flow occurs simultaneously with the task structure. The disadvantage of finite-state models is that they lack flexibility which is required for ASD interventions (Malerba et al., 2019). An alternative would be planning which is a more complex approach, however, it is able to deal with changes in behaviour which is a requirement when working with children during an intervention. Petrick et al. (2013) used knowledge-level planning and the PKS planner to create a bartender that was able to deal with multiple human customers when ordering and delivering drinks. They chose this approach because of its ability to work with incomplete information and sensing actions. These properties are also important for ASD interventions since children with ASD can be unpredictable. The robot will need to work in a setting where it will not know how the child is going to respond. Furthermore, according to PRT, the intervention should be child-led which means interaction might change fast to which the robot should be able to respond and continue the intervention. It is therefore important the system can work with incomplete information and still respond appropriately. Planning would therefore be a good approach to use for dialogue management during ASD interventions.

Emotion recognition

Emotions are a tremendous part of communication which makes them an important topic during ASD interventions. Children need to learn how to read and interpret other people’s emotions and how to show appropriate emotions themselves. Having a system with strong emotion recognition is therefore important for ASD interventions. However, there is a key difference that will need to be implemented in robots used for ASD interventions compared to other social robots that work with children. A robot that works with neurotypical people can use the emotions that it learned to recognize to show emotions for itself. However, the way people with ASD show their emotions might differ from neurotypical people (Winkielman et al., 2009) which means that the robot needs to learn to recognize the emotions of people with ASD rather than those of neurotypical people. Furthermore, children with ASD do need to learn how to read the emotions of neurotypical people during ASD interventions so the robot needs to be able to show emotions in a way neurotypical people would. This means that a robot for ASD interventions will need two different systems for emotions, one for the recognition of emotions shown by children with ASD, and one for showing appropriate emotions during interactions that a neurotypical person would show.

For emotion recognition, facial expressions and speech are the most important communication channels that can be analyzed. A Facial Expression Recognition (FER) system has to be trained on suitable datasets (Ko, 2018), in this case, a set of people with ASD for emotion recognition and a set of neurotypical people for expressing emotions. The system then has to go through steps that are typical for this application domain: preprocessing, face detection and registration, feature extraction and classification (Malerba et al., 2019). A big challenge in FER is the considerable overlap between emotion classes which can make it difficult to classify emotions. Ebrahimi Kahou et al. (2015) used a Recurrent Neural Network (RNN) combined with a CNN in an underlying CNN-RNN architecture to model the spatio-temporal evolution of facial expressions of a person in a video. These deep learning techniques have achieved state-of-the-art results in emotion recognition making them appropriate techniques to use in robots for ASD interventions.

Besides FER, speech also conveys a substantial amount of information through what is actually said and how it is said. For Speech Emotion Recognition (SER) only pure sound processing is used without any linguistic information. There are certain features in the sounds that are considered and contain useful information for emotion recognition. Specifically, Mel-Frequency Cepstral Coefficients (MFCCs), formants, energy, pitch, and temporal features have successfully been used (Schuller, 2018). Either deep neural networks can be used for this or a simple SVM (Ebrahimi Kahou et al., 2015). This information can then be combined with the information collected by the FER to create a more robust emotion recognition system.

User Modeling

To create personalized interaction, a user model is applied which is a structured representation of user characteristics (Fischer, 2001). In general, the user model is designed to use during the decision-making process during an interaction, both for verbal and non-verbal behaviour of the robot. A regular challenge for the use of user models is that the system needs to make a user model for every person it interacts with, which can be challenging if the robot is placed in a more public area (Malerba et al., 2019). However, in the case of robots for ASD interventions, the robot only has one child or one household it interacts with which leads to a limited amount of user models needed. The user model would consist of information about the user’s age, gender, personality, past interactions, the severity of ASD, deficits, and progress.

Whether these four skills will give a robot full ToM is debatable. However, it will be able to discern the needs and emotions of the user. These are the most important components of ToM when applied to

ASD interventions because the needs define what will happen during an intervention and emotions are key to communication. Due to the development and growing field of deep learning techniques, the skills mentioned (sensing, dialogue management, emotion recognition, and user modeling) have improved considerably which creates new opportunities for social assistive robots, including ASD interventions. These skills are general capabilities needed for a social intelligent robot, however, there are some additions required specifically for ASD interventions. It will need to be able to support PRT interventions that have specific requirements. The base for every interaction is sensing, a robot will need visual, auditory, and touch senses. The visual perception must include movement recognition which can differentiate between attempts of a goal behaviour and general behaviours. This is essential for the reinforcement of attempts, a requirement for PRT interventions. Furthermore, cutaneous senses are not always needed for general SAR use, however, they are important for ASD interventions because touch is a form of communication in which the child needs to be able to receive reinforcement as well. The information from these senses will be used for dialog management and emotion recognition. For dialog management, the robot needs to be able to be flexible and follow the child during an intervention. Specifically for PRT, it is important the robot can follow the child because the intervention needs to be child-led. Therefore, planning would be a suitable model due to its ability to work with incomplete information. For emotion recognition, the robot will need a unique system that differs from other emotion recognition systems in SARs. Two systems will be needed, one for the actual recognition of emotions shown by the child with ASD, the other to show emotions that neurotypical people would show during the interaction. Lastly, user modeling will be used to create a personalized intervention and guide the dialog manager. Due to the heterogeneity of ASD, it is crucial that the user model collects the unique information and needs of the child so it can use this information to create an intervention that will work best for the child. These skills should make the robot socially intelligent and capable to lead an ASD intervention independently.

5. Conclusion

Due to the heterogeneity of ASD, it is difficult to state one optimal robot for every child with ASD. There are several factors that influence how well a general intervention works (e.g., age, gender, the severity of ASD, etc.), which also transfers to interventions using robots. However, an improvement for interventions using robots would be to make robots autonomous with the use of AI. When a robot is fully autonomous it is able to lead the intervention from any location, meaning the intervention could be done from home which saves the child and caregivers a lot of time. This means that interventions could be done more frequently, combined with the ability of children with ASD to learn better in home settings means the intervention would be more successful. Current research on using robots for ASD interventions have all used semi-autonomous robots meaning that conclusions about designs for robots used during interventions do not apply to autonomous robots because they are used in different settings and manners. Therefore, current designs of robots needed to be reevaluated to create a new optimal design for autonomous robots.

When designing a robot for ASD interventions it needs an effective intervention style as a basis that focusses on generalization. Generalization is important because the child will need to be able to transfer the learned skills from the robot to real-life situations with other humans. The best intervention type to be used during ASD intervention led by a robot would therefore be PRT. PRT creates generalization by having the intervention be child-led, combined with reinforcing any attempts, natural reinforcements, and varying tasks it increases children's communication skills. An autonomous robot should be able to provide these components during an intervention, however, for an intervention a robot should also be able to detect and understand the needs and feelings of a child. This is crucial because a robot would otherwise not be able to adapt to the child and function as a replacement for an intervention led by professionals. To accomplish this the robot needs to be have social intelligence. To create social intelligence, a robot requires four skills: sensing, dialogue management, emotion recognition, and user modelling. For ASD interventions these components need adjustments to work which will differ from robots used in other settings. The motion-sensing will need to be able to detect attempts at tasks so that these can be reinforced according to PRT. The dialogue management will have to be flexible and able to work with incomplete information so that the intervention can be child-led. The emotion recognition will need two different systems, one for the recognition of emotions shown by children with ASD, and one that is able to show the emotions of neurotypical people. These skills should make the robot able to lead an ASD intervention autonomously, however, for an intervention to work the child also needs to feel comfortable with the robot. It is therefore important that the robot has an appearance that makes the child feel comfortable and is able to execute the intervention tasks. The appearance should therefore be simpler than humans to make the child feel comfortable and enable them to focus on the elementary features of the face for communication. Simultaneously, the appearance should be humanoid enough to have enough degrees of freedom for more complex tasks. This allows the robot to develop with the child when they get older and make the tasks more complicated. Suitable examples of these are KASPAR and NAO (fig. 1h & 1i).

The field of autonomous robots for ASD interventions is a new field with no current examples on how it should be done. The stated design elements are the important alterations to current designs of previous research done on semi-autonomous robots for ASD interventions. When these elements are applied they should form the base for fully autonomous robots for ASD interventions and allow further exploration and improvement in this field.

This thesis has been theoretical research based on previous research done on the topic. Future research could be done on how the different AI systems should be programmed and combined to realize to proposed solution. This could be followed by a study on how children with ASD and their households respond to the new intervention form and how the robot would fit into their daily lives. Future work might be able to give more understanding in this young and growing field and eventually help better the quality of life for people living with ASD.

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