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Trends and Considerations in Robot-Assisted Autism Therapy

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Abstract — **Recent research suggests that children with autism exhibit certain positive social behaviors while interacting with robots that are not observed while interacting with their peers, caregivers, and therapists. This paper explores trends in robot-assisted autism therapy, as well as some of the specific therapies that have been shown to elicit desirable social interactions when working with children with autism. Considerations for the design of robots for use in robot-assisted therapies are also presented. Finally, general conclusions and recommendations are made to help further the work of robot-assisted autism therapy.**

I. INTRODUCTION

There is growing anecdotal evidence that robots provide unique opportunities for assisting children with autism. While interacting with robots, children with autism exhibit social behaviors, such as imitation, eye gaze and joint attention, which may be useful in potential treatments [1], [2]. These social behaviors are typically rare in children with autism, but evidence suggests that robots trigger them more often in such children; sometimes these behaviors can be prompted and sometimes they are spontaneous [3].

Autism is a behavioral disorder characterized by (1) deficient social interaction, (2) poor communication skills, and (3) abnormal play patterns, and affects 0.2-0.4% of the general population [4]. Perhaps the most visible manifestation is the difficulty with which children on the autism spectrum interact with their peers. They often avoid eye contact, remain aloof from others, and fail to follow many social norms. They also often fail to recognize the emotional states of others and do not understand that their own actions affect what others do and how they feel. Nearly all children with autism exhibit some level of language impairment, which can range from a complete lack of verbal communication, to prolific talkers who talk incessantly about favorite topics without allowing communication partners to add to the conversation. Most children with autism engage in stereotypical behaviors and repetitive play, such as constantly repeating the same joke or flapping their hands when they are excited. Many fail to use imagination and creativity during play, but some study a single subject tirelessly and learn all there is to know about it. Children with severe autism may exhibit all of these symptoms and appear to live in their own world, whereas higher-functioning children on the autism spectrum exhibit mild forms of these attributes and can achieve a certain level of sociability [5].

The causes of autism are poorly understood, with only a small minority of cases stemming from a known etiology. The signs of autism, however, may be observed at an early age and remain throughout the person's life.

Myriad treatments have been proposed to ameliorate the effects of autism, some of which have been moderately successful in helping children to manage symptoms, interact with others, and hold jobs as adults [6], [7]. The relatively new field of robot-assisted autism therapy aims to develop novel treatments aimed at improving the quality of life for children with autism and their families. As mentioned previously, the hypothesis behind this work is that robots are able to elicit certain desirable social behaviors in children with autism that are not typically observed in therapies not involving robots. The purpose of this paper is to explore the trends in robot-based autism therapies and to investigate the state of the art and future directions that hold the greatest promise for using robots to help children with autism.

II. ROBOT-ASSISTED AUTISM RESEARCH AND TREATMENT

Researchers have investigated the use of robot technology to achieve specific therapeutic objectives for children with autism. In this section we explore the trends in robot-assisted diagnosis, research, and treatment of children with autism. Specific applications are discussed and observations on their effectiveness and lessons learned are presented.

A. *Diagnosis*

Early intervention has been shown to greatly increase the long-term benefits of clinical therapy in children with autism [2], and consequently, there is a focus on diagnosing autism at earlier stages in development, which could lead to higher functionality later in life. Therapists are generally unable to diagnose autism until children are about three years old and have missed typical developmental milestones [8].

The use of technology in the early diagnosis of autism has received increased attention in recent years. At Yale, researchers are exploring eye-gaze patterns of infants as a potential diagnostic tool. The method is based on the fact that typically developing children exhibit standard ways of focusing on the movements of others, especially on their caregiver's face and eyes [9], [10]. These gaze patterns develop before typical infants learn to speak, and thus may provide a method for early detection of autism. From an

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early age, children with autism show a marked difference in their gaze patterns; it has been observed that they concentrate more on their caregiver's mouth than eyes, if they focus on the face at all.

Researchers in Italy are using three specially designed sensors to detect abnormalities in infants which could lead to early autism detection. The first is an eye-gaze tracking device with audio cues to determine if the children respond appropriately to audio and visual cues. The second is a set of motion-sensing ankle bands and wristbands with motion sensors that can be worn by infants as young as two weeks old. The third is a toy ball with embedded force and tactile sensors that is able to quantify the way in which children handle and play with the ball. These sensors are placed on children in infant centers in order to establish a baseline to which others can be compared [8].

Others have taken a similar approach and have had great success using sensors to distinguish between children that do and do not have autism [26], [27]. In the future, the ideal is to use these devices with infants, and an early diagnosis of autism could be reached if abnormalities are detected. A combination of these devices would likely lead to more reliable diagnosis, and early interventions could begin. The children would then need to be monitored as they develop to ensure they are not misdiagnosed.

Another difficulty associated with autism diagnosis is caused by the lack of repeatability during screenings. Since autism is a behavioral disorder, it is diagnosed through an experienced clinician's evaluation of their interactions with the child. The clinician cannot perfectly repeat the same actions from one evaluation to another, which can cause the children to appear on various levels of the autism spectrum. Although robot repeatability will not help diagnose the children at a younger age, it is believed that, by using a robot as standard stimuli in these autism screenings, a more consistent autism diagnosis can be reached [10]. Together, these efforts will hopefully result in a new method for detecting autism more accurately and at earlier stages in life.

B. *Self-Initiated Interactions*

One component of the impaired social skills of children with autism is a deficit in their ability to initiate social interactions. Many of these children have difficulties requesting things they want or need, and many clinical therapies focus on helping them to be more proactive in their relations with others. For example, when a child is hungry a desirable behavior would be for the child to ask for food, rather than resorting to a tantrum. It is common for a clinician to encourage the child to ask to play with certain toys, and reward them with those toys after the request is made. In an effort to promote this self-initiated interaction, researchers are extending this idea to using robots to encourage the child to engage the robot proactively.

At USC, researchers built a small, mobile robot that is appealing to children with autism. The robot has a large button on its back that the child can push, to which the robot responds by blowing bubbles [11]. This encourages the child to engage the robot proactively (by pushing the button) to receive the desired reward (the bubbles).

The University of Hertfordshire's AuRoRA Project has sought to take advantage of child-initiated behavior. As they have performed studies involving interactions between children with autism and their robots, the clinicians have intentionally played a passive role. Using this approach, there have been limited occurrences during the children's interactions with the robot in which the children have initiated communication with the therapist in much the same way as would be observed with a typical child [12].

C. *Turn-Taking Activities*

Other researchers have focused on using robots to help children with autism participate in turn-taking behaviors. Due to a lack of turn-taking abilities, these children often have difficulties conversing with others, and can regularly be found rambling without allowing their conversation partner to participate. At the University of Hertfordshire and the University of Southern California, researchers have built small mobile robots that react to the children that play with them. The goal is for the children become accustomed to waiting for responses after they say or do something. The Hertfordshire mobile robot, Labo-1, can play games of tag with the children, which forces them to alternate between engaging and avoiding the robot [13].

D. *Imitation*

Another common technique used in clinical sessions is imitation therapy. Therapists have found that, when an adult "imitates the child's behavior, the child displays more social responsiveness, for example, increased eye contact, touching, vocalizing, and toy exploration" [6]. The children often lack the ability to recognize their peers and caregivers as "social others," and imitation activities may help the children to realize that their actions are related to the actions of those around them. Imitation may help them to see that their actions are observed by others who may, of their own accord, repeat those actions, and that the child can also repeat the actions that are initiated by others. Imitation also helps improve hand-eye coordination, and, according to P. Hinerman, "Imitation training is the first step in teaching autistic children to communicate….Children who can be taught to imitate motor responses are more likely to learn to use some form of communication…. Start with large muscle groups, like raising an arm, and then move down to more subtle ones like a smile or frown" [14].

Most researchers that have built robots to help children with autism have attempted some form of imitation therapy. At the University College London, children with autism attempted to imitate another person's hand as well as a simple robotic hand. The children appeared to imitate the human hand only slightly better, which establishes robot-based imitation as a plausible therapy [15].

Researchers at the University of Sherbrook compared the children's ability to imitate their robot Tito against their ability to imitate another child [16]. They found that the children with autism would stand closer to the robot and look at it more during the interaction than they would when imitating another child. They also observed that the child was better able to imitate their peer, but that may have been due to the limited motion capabilities of the robot.

Likewise, researchers in the AuRoRA project at the University of Hertfordshire used a doll-like robot, Robota, in reciprocal imitation activities where the child would imitate the simple movements of the robot and vice versa. Since their robot's automatic imitation software required the child to sit still and use a limited range of motions, they performed their studies by having the robot's imitative motions controlled remotely by a therapist [12]. Therapist-controlled imitation is also used in interactions with robots such as Keepon and FACE [17], and it has been shown to generate novel interactions directly between the child and the therapist. At the University of Pisa, the FACE robot has been used to imitate children's facial expressions instead of general arm and body movements like with Robota and Tito. They observed that the children generally imitate the expressions on FACE better than on other humans [18], and they are working to automate this process so that a therapist will no longer have to control the imitative expressions.

E. Emotion Recognition

Studies have shown that children with autism generally have difficulties reading facial expressions, and so some researchers are attempting to help alleviate this deficiency [19]. The human face is very complex, and facial expressions of emotions carry subtle nuances that are difficult for these children to understand. The amount of information contained in the human face can cause children with autism to feel overwhelmed when looking at someone else's face, and making eye contact can result in sensory overload. There are also slight differences in expressions between people, which are hard for many children with autism to understand. Due to slight differences in the face, a person could smile twice, and to a child on the autism spectrum they could appear to be two entirely different expressions. Robots are more repeatable than humans, and so they may prove to be better able to teach children with autism about facial expressions.

At the University of Hertfordshire the robot KASPAR can represent facial expressions with less complexity than a real human face [20]. This has helped children with autism focus on KASPAR's face without showing the anxiety and sensory overload they often experience around humans.

Researchers at the University of Sherbrook performed a study to evaluate how well children with autism are able to recognize and imitate, among other things, the facial emotions of a human mediator and their robot Tito, which has a mouth made up of small LEDs that can represent a smile or a frown. Four children with low-functioning autism were selected to participate in their study; two were paired with Tito, and the other two were paired with a human mediator. During a series of 22 sessions, the children were each asked to imitate the facial expressions of their mediator, and it was observed that the children paired with the robot were better able to imitate the facial expressions than those children paired with the human mediator [16].

The FACE robot at the University of Pisa is designed to closely approximate a real human face and show the detail of human expressions while still remaining repeatable. In studies with FACE, children were asked to select pictures of people making the same expression as the robot as well as verbally naming each expression made. They also gave the child a scenario and asked them to pick an appropriate emotional expression for FACE to make [21]. These therapies are aimed at helping the children to generalize the information they learn in the therapy session to other situations. After performing these tasks over a series of therapy sessions, the children were tested using the Childhood Autism Rating Scale (CARS), and it was shown that, while working with the robot, all four of the children improved in the categories of Emotional Responses and Relating to People [18].

F. Joint Attention

Another deficiency that children with autism often have is the ability to consciously focus on the same object with another person. Joint attention can range from looking into someone's eyes, to focusing on the teacher in the front of a classroom. It is often hard to remain focused on specific things, and so helping them with joint attention is critical to their success in learning. These children frequently do not acknowledge others around them, and joint attention activities can help them to understand that others are aware of them, that they are aware of others, and that they are both aware of the same object.

Multiple research groups have focused on joint attention in their clinical studies, but they have used it in very different ways. With the robot Keepon, operators remotely direct its gaze toward the child or toward an object to establish joint attention [17]. As it alternated between establishing eye contact and looking at an object, Keepon would emotionally react whenever the child made any significant social interaction. When the child would look or point at the same object that Keepon focused on, Keepon would bounce and rock to show its excitement, thus encouraging the child to interact even more. The Toyota Technological Institute, along with researchers from the Aizu and Aoyama Gakuin Universities, also used a robot to encourage, and then autonomously detect, joint attention with a child on the autism spectrum [28].

Researchers at the University of Hertfordshire and the University of Sherbrook have used joint attention as a metric to see how receptive children are to their robot [16], [22]. They found that children with autism are generally more willing to interact with and pay attention to robots than they are with other people. They also observed children with autism interacting with their robots, showing concern for them, and focusing on them in the same ways that their typically developing peers would. While some of these interactions are merely anecdotal, the consistency of such interactions makes joint attention activities a promising part of robot assisted therapy [1].

G. Triadic Interactions

Since mechanical objects like toys and robots are simple and predictable, they can be very appealing to children with autism. Many novel social interactions have also been observed while the children have been playing with these robots. The goal, however, is not, and should not be, to improve the way that they play with toys or interact with robots. The goal, rather, is to use these objects to improve their interactions with other people. In an effort to help these children generalize what they learn with the robot to interactions with their peers and caretakers, multiple researchers have begun to focus on triadic relationships. A triadic relationship is one that consists of the child, the robot, and another companion, which may be another child, a parent, a teacher, or a clinician. The importance of this form of interaction, known as robot-mediated interaction [23], has been noted by at least four researchers [10], [16], [24], [25].

The various forms of triadic interactions take advantage of the robot as a social "pivot," where the robot helps to elicit interactions between the child and other humans. During clinical sessions with their robot Keepon, Kozima *et al.* observed children with autism using Keepon as a social pivot, resulting in increased interaction with their peers, parents, and therapists. In one case study, a three-year-old child with autism avoided playing with Keepon until after observing another child playing with it. The child with autism then imitated the other child by repeating their actions towards Keepon. That same child later made referential looks at her mother and therapist during the time she played with Keepon [24]. These types of actions are not typical for children with autism, but there was something about the presence of the robot that helped elicit them.

In two independent studies [16], [25], researchers found that as children realized that the therapist was controlling the robot, new excited interactions between the child and experimenter emerged. In a study by Robins and Dautenhahn, a child took the experimenter by the hand and led him to the robot to play with the robot as well. At one point, when the child noticed that the robot leg was broken, the child tried to convey that information to the experimenter. Through this triadic interaction, the child exhibited self-initiated behavior and joint attention with their experimenter. On another occasion, while imitating the robot Robota the child realized that the experimenter was actually controlling the motions of the robot. When the experimenter made mistakes in the imitation game, the child looked at the experimenter, laughed, and corrected him [25]. Since there appears to be a benefit to having the experimenter in the room controlling the robot in real time, at least two researchers have developed tools that allow their clinicians to do so [3], [10]. It has been hypothesized that these triadic interactions are the key to achieving generalization or transfer [3], meaning that the positive social behaviors will occur outside of the clinic or laboratory.

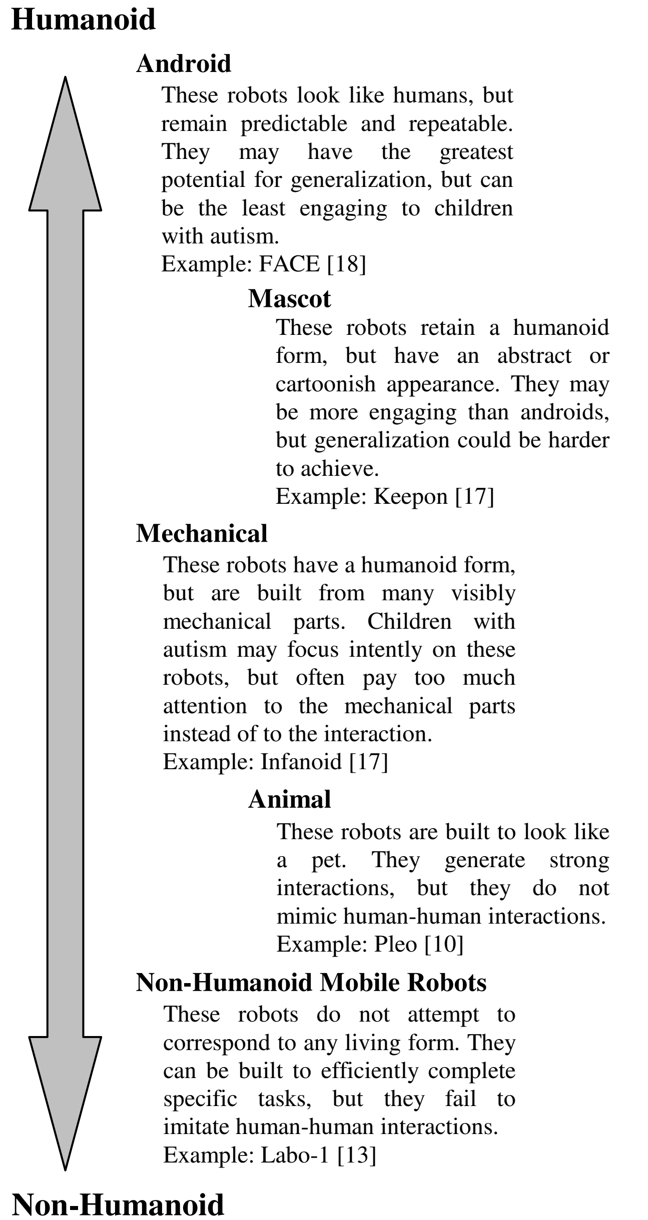

Fig. 1. A comparison of robot types used in autism research, based on their location on the humanoid to non-humanoid spectrum.

III. DESIGN OF ROBOTS FOR AUTISM RESEARCH AND TREATMENT

Much consideration has been given to the type and form of robots used in autism research. Some robots used for this purpose are humanoids, while others are small, mobile, and carlike. Some attempt to achieve a realistic human appearance, while others have created robots with very mechanical forms, and still others have created robots with a cartoonish, or mascot-type form [20]. As illustrated in Fig. 1, each of these types of robots has its benefits and drawbacks in working with children with autism.

A. *Non-Humanoids*

Non-humanoid robots have been used by various researchers because of their simplicity and the ease of creating interesting and engaging interactions. By leaving aside the human form, researchers have been able to create simple robots that are not limited in appearance, but rather are able to have whatever form is best suited for their applications. The bubble-blowing robot at USC, for example, was able to be built much simpler by not forcing it to take on a human form [11]. University of Hertfordshire researchers also used a non-humanoid robot, Labo-1, that can play games of tag with the children [13], and, at Yale, studies are being performed using a mobile, robotic dinosaur named Pleo that can convey desires and emotions through recorded sounds and body language [10]. Pleo's expressiveness, versatility, and pet-like appearance help to engage the children in the clinic. As a child with autism sees something with a human form, they often become withdrawn and avoid interactions. Robots in the forms of animals, cars and toys often do not trigger these same reactions, which can make them more engaging than robots with a humanoid form. In addition to helping the children engage in activities, non-humanoid robots can often be much simpler and affordable.

B. *Humanoids*

The benefit of using humanoid robots in autism therapy research is that there may be a greater potential for generalization. For example, only through a human form can children engage in imitation and emotion recognition activities. Although some general guidelines on robot designs have been proposed, there is no clear consensus as to what a robot used in autism research should look like.

Robins *et al.* performed a study to evaluate the importance of the robot's appearance for children with autism. The children were asked to interact with the doll-like robot Robota when it was dressed as a doll and while it was dressed in plain white clothes with a bag covering its head. Other children were asked to likewise interact with a man disguised as a robot and later with that same man dressed in typical business attire. In both instances, the children appeared to be more interested in interacting with the less-human of the two. From this study, they concluded that robots that interact with children with autism should avoid the details and complexity of a human while still holding to the humanoid form. They subsequently designed the robot KASPAR to fit these design criteria [22].

Researchers at the National Institute of Information and Communications Technology in Japan came to similar conclusions based on their work with the robot Infanoid. They noticed that as children with autism interacted with Infanoid, they tended to pay more attention to the mechanical parts of the robot's body than to the interaction they were trying to achieve. This observation appears to be consistent with the general knowledge regarding children with autism, i.e., that they gravitate toward simple, repeatable, mechanical objects. The small, soft, snowman-shaped robot Keepon was designed to minimize any distractions the children may have, but it still appears roughly humanoid, with a head, body, eyes, and nose. Since it cannot show facial expressions, emotions are effectively conveyed by shaking, rocking, and bobbing up and down [17], [24]. Other researchers have followed a similar approach by building simplistic, mobile, humanoid, robotic platforms that have likewise been successful in interacting with children with autism [11], [16].

Most researchers tend to advocate the notion that simpler is better because it appears to be more engaging to the children. The researchers at the University of Pisa have taken a different approach by creating the robot FACE, which was designed to appear as realistic as possible. FACE utilizes a skin that can accurately display human emotions and complexity while remaining more repeatable than a real person [18], [21].

Simple robots may be more engaging to children with autism, but they arguably have less potential for crossover or generalization due to the large divide between their appearance and the appearance of another person. Consequently, each type of robot design is suited for specific types of interactions, and the robot should be designed with specific therapeutic goals in mind.

IV. CONCLUSIONS

Based on the work of many skilled researchers, it is clear that robot-based therapies have potential to help in the treatment of children with autism. The potential for earlier and more repeatable diagnosis, and the social skills these children demonstrate while interacting with robots are very compelling and warrant further work to investigate the best ways to utilize robots in this field.

Unfortunately, generalization of the skills learned in these therapy sessions has not been observed outside of the clinic or laboratory. Researchers have noted that, after extended exposure to the robots, the children have become more sociable with the robots themselves while little has been said about how well the kids can apply these skills outside the clinic. For this reason, we feel that by making the clinical experience as similar to the outside world as possible, we can focus on the end goal of increased social interaction outside of the clinic. Consequently, we feel that of all the aforementioned therapies, triadic interactions have the greatest potential for success. Robots will never achieve the types of rich social interaction that human-to-human interactions provide, and so using the robot as a tool to increase interaction with the therapist or other humans may prove to be very productive.

A further possibility is to bring the robot out of the clinic as a "cognitive orthotic" [3]. If the mere presence of the robot allows the child to be more social, a portable robot that the child could have on hand may have the potential of helping the child open up to peers and family members. Using a robot in the clinic has opened up communication between the child and the therapist, and this same phenomenon may prove to be beneficial in the home and school as well.

The appearance of the robot may have a great influence on the clinical benefits achievable with a given robot. If simple interaction is the objective of a given treatment, then a non-humanoid may be the best option; however, humanoids may be better for simulating human-to-human interactions. Initially, children with autism tend to be more interested in working with simplified, abstract forms rather than realistic depictions of another person, and these types of robots will help to engage the child especially when they are first introduced to the robot. Realistic robots have the benefit of being similar to humans, and so there is a possibility (unproved at this point) that generalization may be more easily achieved. As a downside, realistic robots may also be less appealing to children with autism. Consequently, multiple researchers have proposed that a series of robots, or a robot with a changeable face, be developed to take advantage of the benefits of each of these types of robots [10], [22]. Children could begin therapy with a simplistic robot, and as they become comfortable with that one, a more realistic robot could be introduced. In this manner, the child could be weaned off the robot-mediated interactions and become more comfortable interacting with others.

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