Toward Therapist-in-the-Loop Assistive Robotics for Children with Autism and Specific Language Impairment

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Abstract. In this paper we summarize some of the current work in the field of robot-based therapy for children with autism, and explore new directions that emphasize the important role of the therapist in achieving clinical benefit for these children and children with specific language impairment (SLI). Our ongoing and future research related to robot-based imitation therapy, design of therapist interfaces, and development of therapy robots is described. The overarching assumption in each of these research thrusts is that clinical benefits to children with autism and SLI are best achieved through triadic interactions between the child, the therapist, and the robot facilitator.

1 INTRODUCTION

There is growing anecdotal evidence that robots provide unique opportunities for assisting children with autism. Children with autism exhibit social behaviors with robots that may be useful in generating potential therapies. Such social behaviors include imitation, eye gaze, and joint attention [12,15]. These social behaviors are often 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.

Unfortunately, there is no evidence that the social behaviors observed in interactions between children with autism and robots will generalize from laboratory or clinical settings to interactions between children with autism and other people. However, it is believed that developing even basic social skills for children with autism will not only allow them to becoming higher functioning, but also enable and reward their caregivers in the challenging task of providing their care.

In addition to children with autism, there is another large population of children that can potentially benefit from using robots to improve social skills. It has been observed that children with specific language impairment (SLI) often lag behind their peers in social development [2,4]. Although there is much debate as to the cause of social deficiencies in children with SLI, there appears to be general agreement that early intervention to promote social skill development will allow these children to have fewer social problems in the near-term and to achieve higher levels in the long-term. Thus, it is desirable to consider how assistive robotics can benefit children on a spectrum of abilities, from low-functioning children with autism to higher-functioning children with SLI.

The purpose of this abstract is to summarize general trends in robot-assisted interactions with children with autism, and outline a research agenda for developing effective therapies for helping not only those children but also children with SLI. We are interested in using robots to help children with SLI, although there appears to be no work on using robots to help this portion of the population even though the number of children with SLI is much larger than the number of children with autism [27].

2 THERAPIST-IN-THE-LOOP INTERACTION

2.1 Brief Overview of Related Literature

Children with SLI tend to exhibit reticence and solitary-passive withdrawal more than typically developing peers, and children with more severe impairments demonstrate fewer prosocial behaviors [1]. Additionally, emotion regulation and language impairment are significant predictors of reticence [2]. Studies considering why some children with SLI can struggle with social competence point to difficulty in identifying and describing emotional state from a story context [3], as well as in inferring emotion from prosody in vocally-presented stories [4]. Complementing these studies is evidence that children with SLI may also display deficiencies in properly displaying emotions, specifically knowing when to display and when to dissemble emotions in social situations [5].

Robotic technologies provide potential therapies for children with SLI and autism, but it is important that we do not lose sight of the goal of helping children just so we can promote a robotic research agenda. However, there are a number of reasons to consider robots as therapeutic tools for children with autism and SLI. Robots have been shown to invoke interest and social interaction from young children [10] and to engage children with autism at various age levels [11-13]. One of the reasons for using robots in therapies for autistic children is because of the toy-like engagement that it offers [14]. Additionally, work has been performed that uses robots as a tool for diagnosing autism [15]. However, it is important to note that using robots to treat children with autism or SLI should avoid introducing new or reinforcing old stereotypical behaviors in such children [16], including providing an object on which the child may fixate, and should consider including the robot not only as a "social other" but also as a mediator/facilitator for a therapist, clinician, parent, or other child [11, 12]. Moreover, attention must be given to the appearance of the robot because it may be that animal-like robots or simple humanoid forms are more useful than realistic humanoid robots [11, 17]. Finally, it should be noted that robots

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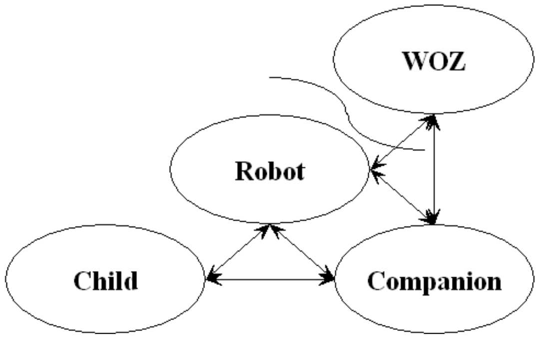

Figure 1. Triadic interactions between child, robot, and companion.

are not the only computer-based technologies that are useful in autism therapy, so technologies that focus on managing or tracking the information requirements associated with therapies should also be considered [18].

2.2 Triadic Interactions

Among the trends emerging from studies of using robots to interact with children with autism, one trend captures our attention because it seems most likely to allow robot-assisted therapies to generalize to other social domains. This trend is the emergence of triadic interactions between child, robot, and therapist. This triad is important because it suggests the possibility of using the robot as a tool in the hands of a skilled therapist to trigger social interactions between the child and the therapist. At least four researchers have noted the potential importance of this triadic interaction [6,9,14,24], and at least two have designed tools for a therapist that allows him or her to modulate robot behavior while interacting with children with autism [24,25].

We believe that interactions with the robot, though interesting, are less likely to produce generalizable social skill development than interactions between a child and the therapist. Indeed, robot social skills are very simple and are likely to remain simple for the near future, a fact that is perhaps the reason that robots trigger social responses in children with autism that are not usually triggered by human-human interactions. To support generalization, it is desirable (a) to use the robot as an engaging object of attention that allows therapist and child to engage in joint attention, (b) to shape social behaviors triggered by a robot by including a therapist "in the loop", or (c) to use the robot as a type of "cognitive orthotic" to facilitate social interactions between a child with autism and his or her caregiver, even if the child is unable to engage in social interactions in the absence of the robot.

We propose that effective therapies can be built on triadic relationships between social agents: robot, child, and another human. This other human can be a therapist, a teacher, a parent, or another child. There are two different triads that seem most promising, as illustrated in Figure 1. The first is between the child, the robot, and the child's Companion. This Companion can be a therapist, parent, teacher, or another child. This triad has been identified as potentially valuable in therapy and is known as robot-mediated interaction [11,12]. The second triad is between the robot, the child's Companion, and a "Wizard of Oz." Although this triad affects the robot's behavior, the presence of the Wizard is hidden from the child, as indicated by the wavy line between the robot and Wizard in Figure 1. The Wizard can extend the robot's perception and behaviors beyond what is possible using existing state-of-the-art algorithms, and can allow the robot to display a wider range of behaviors. The Wizard and the child's Companion can communicate via some means (radio, chat window, etc.) so that they can collectively work toward a therapeutic goal.

With the presence of the Companion and Wizard, it is possible to strongly emphasize robot-mediated interactions between a therapist and the child. The therapist can either play the role of Companion or Wizard, or perhaps both simultaneously [14]. We refer to the presence of a therapist modulating robot behavior as Therapist-in-the-Loop Assistive Robotics (TiLAR). We emphasize again that our objective is to use the robot as a facilitator in creating connections between the child and the therapist or other people, and the triadic therapies that we are exploring are designed to minimize the importance of the robot and emphasize the importance of other people in the triad.

2.3 Requirements for Interface Design

Given the constraints on the role of the robot in the interaction triad, it is desirable to understand the constraints on the user interface for interacting with the robot. Most prior work in this area has emphasized the interactions between robot and child, and there appears to be no prior work that systematically studies how to create a user interface to support the therapist. Since supporting the therapist by making the robot an effective and responsive tool in his or her hands is the goal of this work, we identify several practical constraints for this interface.

First, the user interface should allow interactions for either a Wizard or Companion location in the triad. For a Wizard, the user interface could allow a storyboard or other graphical user interface, but for a Companion the interface should probably be unobtrusive so that it does not distract the child. Indeed, controlling the robot unobtrusively was a key influence on the way the therapist managed robots in both Robins' and Scassellati's work [24,25].

Second, the user interface should be created for someone who is not a roboticist or computer professional. The therapist will be trained to understand and to help children, a task that often requires substantial mental workload on the part of the therapist. If the interface requires the therapist to do some form of "programming" during the therapy, it will likely be unusable.

Third, the user interface should support a specified clinical script, but be flexible enough to allow the therapist to modify behaviour in response to the child's responses. To track progress of a therapy and to measure effectiveness, robot-assisted therapies should have specific therapeutic goals and should exist within a framework specified by the training and schooling of the child. This influence tends to constrain robot behaviours to a fixed set that may be rigid and repeatable. However, the flexibility of having a semi-autonomous, socially responsive robot in a therapeutic loop means that unplanned behaviours may be exhibited by the child, and the therapist should have flexibility to respond to those unscripted interactions.

Fourth, the user interface should allow the set of useful robot behaviours to grow. This could include using interactive learning, wherein the robot's behaviours are modified over time by feedback from the child or the therapist. This could also

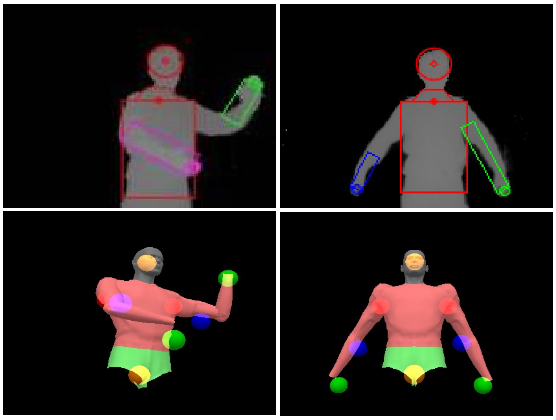

Figure 2. Avatar imitation (bottom) from estimated human pose (top).

include having the human demonstrate behaviours to the robot, which are then added to the robots behaviour repertoire. Finally, this could include the ability to sequence primitive behaviours into a more sophisticated social script. This could be especially beneficial for high functioning children, such as those with SLI.

We are developing a computer interface to provide to clinicians the functionality just described. Specifically, it will allow therapists to design and record robot behaviors that may be played back during therapy sessions, either as sequences of behaviors (storylines) or as stand-alone actions that the therapist can specify in real time. Additionally, the therapist will provide the means by which clinicians can initiate, terminate, and modulate the imitation behavior of the robot or avatar in automated imitation therapies, which will be discussed in the next section.

3 IMITATION THERAPY

Imitation therapy has been shown to provide potential benefits as a tool in the clinical treatment of autism [28]. One form of this therapy involves a therapist or other person imitating some or all of the behaviours of the child with autism. In this form (therapist imitating child), imitation therapy for autistic children has been expanded into the field of robotics, with the therapist directly controlling the robot's motion to imitate the motion of the child [14,17,29]. In a clinical setting, direct robot control would place a prohibitive workload on the therapist, thereby limiting his or her ability to interact with and observe the child.

The members of our research team at Honda Research Institute have developed algorithms and software that may enable real-time, automatic imitation of children with autism. The foundation for this work is the algorithm that enables real-time estimation of human pose from 3D time-of-flight data from a single depth camera sensor [30]. The method is markerless, and does not require an *a priori* model of the human whose pose is to be imitated. The system is capable of estimating pose of a 17 DOF upper body representation at a rate of 10 frames per second on a standard PC. The problem of transferring estimated human pose data to a humanoid robot has also been addressed [7,19] and demonstrated on avatars (Figure 2) and physical robots, including ASIMO (Figure 3).

The ability to estimate and imitate the motion of children automatically may be a valuable tool in autism treatment. To validate this tool, we propose to conduct studies with typical children and children with autism, in which we explore the set of behaviours that may be elicited through avatar- and robot-based imitation involving ASIMO and a custom-built robot whose design is described below.

In a research setting, our interface will allow clinicians to change the behavior of the imitating robot or avatar. For example, therapists will be able to cause the system to amplify or attenuate the imitated motions as a way of investigating the responses that robot imitation elicits in children. The therapist will also be able to disable certain degrees of freedom, change the imitating avatar, or introduce a delay in the imitated motions. This last feature was identified by our team of clinical researchers as an important component in an automated imitation suite; in their experience, children with autism require additional time to process imitated motions.

In addition to the obvious questions related to eliciting behaviors through robot-based imitation therapy, there are other open research questions that must be addressed for this type of system to be used in clinical settings. Calibration of the pose estimation system presents an interesting challenge for children with autism, who may not be able to remain immobile in the calibration pose for the few seconds required by the software. We are investigating the use of a game to help the child to assume the proper pose. Additional challenges include ensuring that the child remains within the usable volume of the camera, and segmenting out therapists or other participants that must pass into the field of view to assist the child.

4 ROBOTIC TOOLS TO ASSIST CLINICIANS

As mentioned previously, robots have the potential to induce behaviours in children with autism that are difficult to elicit in other ways. One important question related to robot-based therapy is how to create robots that elicit desired behaviors repeatably and that encourage generalization/transfer of those behaviors into everyday life. Our work seeks to explore this issue, in part, by developing a robot that (a) encourages joint attention between children with autism and clinicians, parents, etc., and (b) is easily adaptable to enable us to explore the role of robot appearance in the transfer of behaviors. Details of these objectives are discussed below.

4.1 Related Work

Considerable research has been published on the design of

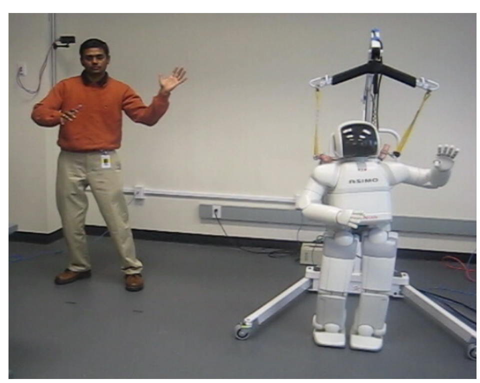

Figure 3. Real-time robot-based imitation using ASIMO.

expressive social robots, although the design and application of robots to autism therapy and diagnosis has been more limited. A brief overview of some of the related work will now be presented. Based on their studies using Robota, a small robot with the appearance of a toy doll [14], researchers at the University of Hertfordshire concluded that the best design for a robot to be used in interactions with autistic children would be one that is child-sized, has the general characteristics of a human face, but that is not so detailed as to overwhelm the children [17]. They have since created the robot KASPAR, which follows these criteria. Researchers at the National Institute of Information and Communications Technology in Japan developed the mechanical-looking robot Infanoid for use in human-robot interaction studies. In studies with children with autism, they observed that the children often focused more on the robot's mechanical parts than on the social interaction. The robot Keepon, with its simple, snowman-like design, was developed to address this concern [20]. Tito, a cartoon-like humanoid robot, was developed at the University of Sherbrook to combine the benefits of interacting with anthropomorphic forms with the appeal of less realistic robots [21]. To assist them in teaching complex social skills to high-functioning children with autism, researchers at the University of Pisa have developed the Face robot, which is designed to appear very human and realistically represent human emotions [22]. Other researchers have used non-humanoid, mobile robots to develop therapies for children with autism [13, 26]. For example, the toy dinosaur robot Pleo has been used to engage children with autism in triadic interactions with researchers [24].

4.2 Requirements for Robot Design

A robot designed to support the therapies proposed in this paper should be capable of general motions to enable imitation therapies and general behaviors choreographed by the therapist. Furthermore, based on discussions with our colleagues from the fields of psychology and communication disorders, it would be highly desirable to create a robot capable of engaging children with autism in exercises designed to encourage joint eye gaze and response to pointing [8]. Specifically, the robot should have the ability to point at an object or person with its arm and simultaneously direct its gaze to the same location. A therapist will be able to command the robot to point and gaze at a number of pre-programmed objects or locations in the room; the therapist will then attempt to engage the child in joint attention activities centered on the robot's pointing behaviors.

With these capabilities in mind, we are developing a small upper-body anthropomorphic robot with 4 degrees of freedom (DOFs) in each arm to enable general motions (including pointing), a 2-DOF neck to enable general gaze directions, and a simple cartoon-like mechanical face to represent basic emotions. We acknowledge that the capabilities of such a robot do not differ significantly from systems developed by other researchers. However, when combined with the pose estimation and imitation capabilities described previously, the system we are developing will provide unique capabilities as a research tool. Moreover, the system's ability to coordinate eye gaze and arm pointing will enable us to explore interesting questions related to joint attention and nonverbal social cues as they relate to children with autism.

Another facet of our research is to investigate if any advantage may be gained by replacing a typical mechanical robot face with a computer-generated avatar face displayed on a small monitor mounted to the robot neck. This approach has been demonstrated by researchers at Carnegie Mellon University with general-purpose robots such as GRACE [23], although we are not aware of this approach having been taken with robots for interacting with children with autism. We have chosen to include this feature in the robot under development because a computer-generated face will allow us to explore more thoroughly the relationship between appearance and clinical benefit, while still maintaining the physical embodiment that seems to be one source of the appeal of robots to children with autism. We acknowledge that moving away from a 3D face to a 2D screen may present challenges when interacting with children with autism; studies using this robot/face combination will allow us to ascertain the nature of those challenges. Furthermore, for children with SLI, interacting with a robot with a 2D face may not create the same type of challenges as it would for children with autism.

5 MOVING FORWARD

The use of robots as therapy tools for the treatment of children with autism and SLI represents an exciting and promising direction in the field of HRI. The research described in this paper is designed to move this work forward by developing new tools for therapists, in the form of novel interfaces, robot platforms, and algorithms for imitation therapy. The aim of these robot tools is to improve the effectiveness of treatment for children with autism and SLI by bringing to the forefront the relationship between child and therapist. Working with colleagues at Honda Research Institute and in the fields of psychology, communication disorders, computer science, and mechanical engineering, we will continue to develop these tools through clinical trials with children with autism and SLI at the Communication Disorders Clinic at Brigham Young University.

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REFERENCES

[1] K.I. Hart, M. Fujiki, B. Brinton, and C.H. Hart. The Relationship Between Social Behavior and Severity of Language Impairment. *Journal of Speech, Language, and Hearing Research*, 47: 646-662 (2004).

[2] M. Fujiki, M.P. Spackman, B. Brinton, and A. Hall. The Relationship of Language and Emotion Regulation Skills to Reticence in Children with Specific Language Impairment. *Journal of Speech, Language, and Hearing Research*, 47: 637-646 (2004).

[3] M.P. Spackman, M. Fujiki, and B. Brinton. Understanding Emotions in Context: The Effects of Language Impairment on Children's Ability to Infer Emotional Reactions. *Int. Journal of Language and Comm. Disorders,* 41(2): 173-188 (2006).

[4] M. Fujiki, M.P. Spackman, B. Brinton, and T. Illig. The Ability of Children with Language Impairment to Understand Emotion Conveyed by Prosody in Narrative Passage. *Int. Journal of Language and Comm. Disorders,* 43(3): 330-345 (2008).

[5] B. Brinton, M.P. Spackman, M. Fujiki, and J. Ricks. What Should Chris Say? The Ability of Children with Specific Language Impairment to Recognize the Need to Dissemble Emotions in Social Situations. *Journal of Speech, Language, and Hearing Research,* 50: 798-811 (2007).

[6] H. Kozima, C. Nakagawa, and Y. Yasuda. Interactive robots for communication-care: a case-study in autism therapy. *Procs. IEEE Int. Symp. on Robot and Human Ineractive Communication* (RO-MAN05), Nashville,

USA, (2005).
[7] B. Dariush, M. Gienger, A. Arumbakkam, C. Goerick, Y. Zhu, and K. Fujimura. Online and markerless motion retargeting with kinematic constraints. *Procs. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems* (IROS 08), Nice, France (2008).
[8] B. Brinton, M. Fujiki, L. Robinson, and M. South. Personal communication.
[9] A. Duquette, F. Michaud, and H. Mercier. Exploring the use of a mobile robot as an imitation agent with children with low-functioning autism. *Autonomous Robots – Special Issue on Socially Assistive Robotics* 24(2):147-157 (2007).
[10] F. Tanaka, A. Cicourel, and J.R. Movellan. Socialization between Toddlers and Robots at an Early Child Education Center. *Procs. of the National Academy of Sciences of the United States of America*, 104:17954-8 (2007).
[11] C.M. Stanton, P.H. Kahn Jr., R.L. Severson, J.H. Ruckert, and B.T. Gill. Robotic Animals Might Aid in the Social Development of Children with Autism. *Procs. ACM/IEEE Int. Conf. on Human-Robot Interaction*, Amsterdam, Netherlands (2008).
[12] B. Robins, P. Dickerson, P. Stribling, and K. Dautenhahn. Robot-Mediated Joint Attention in Children with Autism: A Case Study in Robot-Human Interaction. *Interaction Studies*, 5(2): 161-198 (2004).
[13] D.J. Feil-Seifer and M. Mataric. Robot-Assisted Therapy for Children with Autism Spectrum Disorders. *Procs. Conf. on Interaction Design for Children: Children with Special Needs*, Chicago, USA (2008).
[14] B. Robins and K. Dautenhahn. The Role of the Experimenter in HRI Research—a Case Study Evaluation of Children with Autism Interacting with a Robotic Toy. *Procs. IEEE Int. Symp. on Robot and Human Ineractive Communication* (RO-MAN06), Hatfield, UK (2006).
[15] B. Scassellati. How Social Robots Will Help Us to Diagnose, Treat, and Understand Autism. *Procs. 12th Int. Symp. on Robotics Research*, San Francisco, USA (2005).
[16] B. Robins, K. Dautenhahn, and J. Dubowsky. Robots as Isolators or Mediators for Children with Autism? A Cautionary Tale. *Procs. Social Intelligence and Interaction in Animals, Robots and Agents* (AISB05), Hatfield, UK (2005).
[17] B. Robins, K. Dautenhahn, and J. Dubowsky. Does Appearance Matter in the Interaction of Children with Autism with a Humanoid Robot? *Interaction Studies*, 7(3): 479-512 (2006).
[18] J.A Kientz, S. Boring, G.D. Abowd, and G.R. Hayes. Abaris: Evaluating Automated Capture Applied to Structured Autism Interventions. *Procs. Int. Symp. on Ubiquitous Computing.* Tokyo, Japan (2005).
[19] B. Dariush, M. Gienger, B. Jian, C. Goerick, and K. Fujimura. Whole body humanoid control from human motion descriptors. *Procs. IEEE Int. Conf. on Robotics and Automation* (ICRA 08), Pasadena, USA (2008).
[20] H. Kozima, C. Nakagawa, and Y. Yasuda. Interactive robots for communication-care: a case-study in autism therapy. *Procs. IEEE Int. Workshop on Robotics and Human Interactive Communication* (2005).
[21] A. Duquette, H. Mercier, and F. Michaud. Investigating the use of a mobile robotic toy as an imitation agent for children with autism. [Online] http://www.csl.sony.fr/epirob2006/posters/Duquetteetal.pdf.
[22] G. Pioggia, R. Igliozzi, M. Ferro, A. Ahluwalia, F. Muratori, and D. De Rossi. An android for enhancing social skills and emotion recognition in people with autism. *IEEE Trans. on Neural Systems and Rehabilitation Engineering*, 13(4): 507-15 (2005).
[23] R. Simmons, D. Goldberg, A. Goode, M. Montemerlo, N. Roy, B. Sellner, C. Urmson, M. Bugajska, M. Coblenz, M. Macmahon, D. Perzanowski, I. Horswill, R. Zubek, D. Kortenkamp, B. Wolfe and B. Maxwell. GRACE: An Autonomous Robot for the AAAI Robot Challenge. *AI Magazine* (2003).
[24] B. Scassellati. Personal communication.
[25] B. Robins. Personal communication.
[26] K. Dautenhahn and I. Werry. Towards interactive robots in autism therapy: Background, motivation and challenges. *Pragmatics & Cognition*, 12:1-35 (2004).
[27] G. Conti-Ramsden, Z. Simkin, and N. Botting. The prevalence of autistic spectrum disorders in adolescents with a history of specific language impairment. *Journal of Child Psychology and Psychiatry*, 47:621-628 (2006).
[28] T. Field, C. Sanders, and J. Nadel. Children with autism display more social behaviors after repeated imitation sessions. *Autism*, 5:317-323 (2001).
[29] H. Kozima and C. Nakagawa. Interactive robots as facilitators of children's social development. *Mobile Robots Towards New Applications*, A. Lazinica, ed., pp. 784 (2005).
[30] Y. Zhu, B. Dariush, and K. Fujimura. Controlled human pose estimation from depth image streams. *CVPR Workshop on Time of Flight Camera Based Computer Vision*, Anchorage, USA (2008).