Towards Spatial Methods for Socially Assistive Robotics: Validation With Children With Autism Spectrum Disorders

David Feil-Seifer
University of Southern California
Los Angeles, CA, USA
dfseifer@usc.edu

Socially Assistive Robotics (SAR) defines the research regarding robots which provide assistance to users through social interaction [Feil-Seifer and Matarić, 2005]. Socially assistive robots are being studied for therapeutic use with children with autism spectrum disorders (ASD). It has been observed that children with ASD interact with robots differently than with people or toys. This may indicate an intrinsic interest in such machines, which could be applied as a robot augmentation for an intervention for children with ASD. Preliminary studies suggest that robots may act as intrinsically-rewarding social partners for children with autism. However, enabling a robot to understand social behavior, and do so while interacting with the child, is a challenging problem. Children are highly individual and thus technology used for social interaction requires recognition of a wide-range of social behavior.

This work addresses the challenge of designing behaviors for socially assistive robots in order to enable them to recognize and appropriately respond to a childs free-form behavior in unstructured play contexts. The focus on free-form behavior is inspired by and grounded in existing approaches to therapeutic intervention with children with ASD. This model emphasizes creating circles of communication and fostering engagement through play. A key aspect of this approach is to recognize social behavior and use engagements to bolster social interaction behavior, and to study the ethical implications of therapeutic robotics applications.

This research will present a methodology and a validated experimental framework for enabling fully autonomous robots to interact with both typically developing children and children with autism spectrum disorders (ASD) in undirected scenarios using socially appropriate behavior especially where spatial interaction is concerned. This work holds autonomous operation as a critical aspect of the development and implementation of a robot system. Save for safety interventions by a human operator, the robot system presented in this work acts of its own accord. The methodology of this work holds that free-form interaction is best served by allowing a child to move about a space as they choose, and we wish to enable a robot that can allow for such freedom and function effectively for its interaction goals. As such, the robot and child interact, in part, though distance-oriented behavior, and the robot must be able to recognize those behaviors and appropriately respond to them.

An overarching goal of this work is to develop a methodology which did not preclude human-human interaction, and in fact encourages human-human interaction. We wish to use this system was to be used as an augmentation, rather than a replacement for a human therapist. There is no substitute for human-human interaction in social interaction. However, the compelling interaction between children with ASD and robots is encouraging for their use as a therapeutic aid. This work aims for the following with an eye toward therapeutic potential:

- **Detection and mitigation of a childs distress:** we define a methodology for learning and applying a data-driven spatio-temporal model of social behavior based on proxemic features to automatically differentiate between typical child-robot interactive behavior and behavior that would suggest an aversive response. Using a Gaussian Mixture Model learned over proxemic feature data the developed system is able to detect and interpret social behavior of the child with sufficient accuracy to recognize distress on the part of the child. The robot uses this model to change its own behavior to encourage positive social interaction [Feil-Seifer and Matarić, 2011a].
- **Encouragement of human-human and human-robot interaction:** we aim to demonstrate a global and local motion planner that would use the above spatio-temporal model as part of the determination of a motion trajectory to maintain the robots spatial relationship with the child that sustains interaction while also encouraging the child to move toward another proximal person (usually a parent).
- **Encouragement of turn-taking behavior:** we will present a methodology for robot behavior designed to encourage turn-taking behavior, which is based on therapeutic interaction between a human behavior therapist and child. This will be validated using an spatial imitation game, which can not only be used to gauge the presence of turn-taking behavior, but also the developmental level of such turn-taking behavior.

These above are being developed and validated in several robot systems employing the Behavior-Based Behavior Intervention Architecture (B^{3}IA), a novel robot control architecture developed for Human-Robot Interaction (HRI). B^{3}IA uses autonomous person sensing, behavior interpretation, and action selection, for the purposes of detecting, provoking, and encouraging both human-human and human-robot social interaction. The validated systems are tested in experiments that evaluate the system design, the accuracy of the robots child behavior interpretation, the appropriateness of the robots response, and the quality of the child-robot and child-parent social behavior interaction. The evaluation experiments are conducted with both children with ASD and typically developing children. The systems are also used to explore the therapeutic potential of socially assistive robots facilitated by the developed models, architecture, and experiment framework.

Over the course of this work, the ethical application of robotics has been a focus. From how benchmarking [Feil-Seifer *et al.*, 2007] and performance metrics [Tsui *et al.*, 2008] can have an effect on how systems are evaluated, to ethical principles of SAR [Feil-Seifer and Matarić, 2011b], how such machines can be ethically applied is a concern. In particular, such appraisals explores how unintended deception regarding human-robot interaction in general and therapeutic robots in particular can have a negative effect for a user.

Continuing work has shown that children have varied reactions to a socially interactive robot, some positive, some negative [Feil-Seifer and Matarić, 2008]. This is not surprising, as children with ASD are not likely to enjoy any robot 100% of the time. Some past work has reported more uniformly positive child responses to robots [Dautenhahn *et al.*, 2002; Kozima *et al.*, 2007] but may not have involved the same spectrum of severity of ASD diagnoses. We found that there were specific morphological and behavioral features of the robot that some children, especially those with more severe diagnoses, identified as distracting or annoying. This led us to explore methods for autonomously detecting negative behaviors in order to minimize distress and respond properly, in order to facilitate effective human-robot interaction.

Prior work has shown that negative reactions can be readily identified and classified by a human observer from overhead video data alone, and that an automated position tracker combined with human-determined heuristics can differentiate between the two classes of reactions. Current work describes and validates an improved, non-heuristic method for determining if a child is interacting positively or negatively with a robot, based on Gaussian mixture models (GMM) and a naive-Bayes classifier of overhead camera observations. The approach achieves a 91.4% accuracy rate in classifying robot interaction, parent interaction, avoidance, and hiding against the wall behaviors and demonstrates that these classes are sufficient for distinguishing between positive and negative reactions of the child to the robot.

The purpose of this work is not to avoid the above negative reactions or to completely manage a therapeutic interaction, although we do wish to avoid negative reactions and work toward therapeutic goals whenever possible, but rather to recognize when such action might be necessary, and for the robot to autonomously take appropriate action. To that end, the above features of this robot system are designed with such autonomous behavior in mind. Discussions with experts in ASD treatment have stated that a robot which can avoid distressing a child, direct a child to human-human as well as human-robot interaction, and can engage in positive social interaction, such as turn-taking would be a start to serving therapeutic goals.

Acknowledgments

We gratefully acknowledge the resources provided by the Autism Genetic Resource Exchange (AGRE) Consortium and the participating AGRE families. The Autism Genetic Resource Exchange is a program of Autism Speaks and is supported, in part, by grant 1U24MH081810 from the National Institute of Mental Health to Prof. Clara M. Lajonchere (PI). We thank Ryan Butler for his assistance with recruitment.

This work was supported by the the National Science Foundation (CNS-0709296, IIS-0803565), the Nancy Lurie Marks Family Foundation, the LA Basin Clinical and Translational Science Institute, and the Dan Marino Foundation.

References

[Dautenhahn *et al.*, 2002] K. Dautenhahn, I. Werry, J. Rae, P. Dickerson, P. Stribling, and B. Ogden. Robotic playmates: Analysing interactive competencies of children with autism playing with a mobile robot. In K. Dautenhahn, A. Bond, L. Canamero, and B. Edmonds, editors, *Socially Intelligent Agents: Creating Relationships with Computers and Robots*, pages 117–124. Kluwer Academic Publishers, 2002.

[Feil-Seifer and Matarić, 2005] D. Feil-Seifer and M. Matarić. Defining socially assistive robotics. In *Proceedings of the International Conference on Rehabilitation Robotics*, pages 465–468, Chicago, Il, Jul 2005.

[Feil-Seifer and Matarić, 2008] David J. Feil-Seifer and Maja J. Matarić. Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. In *11th International Symposium on Experimental Robotics 2008*, volume 54, pages 201–210, Athens, Greece, Jul 2008. Springer.

[Feil-Seifer and Matarić, 2011a] David J. Feil-Seifer and Maja J. Matarić. Automated detection and classification of positive vs. negative robot interactions with children with autism using distance-based features. In *Proceedings of the International Conference on Human-Robot Interaction*, Lausanne, Switzerland, Mar 2011.

[Feil-Seifer and Matarić, 2011b] David J. Feil-Seifer and Maja J. Matarić. Ethical principles for socially assistive robotics. *IEEE Robotics and Automation Magazine*, Mar 2011. Special issue on Roboethics.

[Feil-Seifer *et al.*, 2007] David J. Feil-Seifer, Kristine M. Skinner, and Maja J. Matarić. Benchmarks for evaluating socially assistive robotics. *Interaction Studies: Psychological Benchmarks of Human-Robot Interaction*, 8(3):423–439, 2007.

[Kozima *et al.*, 2007] H. Kozima, C. Nakagawa, and Y. Yasuda. Children-robot interaction: a pilot study in autism therapy. *Prog Brain Res*, 164:385–400, 2007.

[Tsui *et al.*, 2008] Katherine Tsui, Holly Yanco, David J. Feil-Seifer, and Maja J. Matarić. Survey of domain-specific performance measures in assistive robotic technology. In *National Institute for Standards and Technology (NIST) Performance Metrics for Intelligent Systems Workshop*, Washington, D.C., Aug 2008.