

# Combining Psychological and Engineering Approaches to Utilizing Social Robots with Children with Autism

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**Abstract**—It is estimated that Autism Spectrum Disorder (ASD) affects 1 in 68 children. Early identification of an ASD is exceedingly important to the introduction of an intervention. We are developing a robot-assisted approach that will serve as an improved diagnostic and early intervention tool for children with autism. The robot, named PABI<sup>®</sup> (Penguin for Autism Behavioral Interventions), is a compact humanoid robot taking on an expressive cartoon-like embodiment. The robot is affordable, durable, and portable so that it can be used in various settings including schools, clinics, and the home. Thus enabling significantly enhanced and more readily available diagnosis and continuation of care. Through facial expressions, body motion, verbal cues, stereo vision-based tracking, and a tablet computer, the robot is capable of interacting meaningfully with an autistic child. Initial implementations of the robot, as part of a comprehensive treatment model (CTM), include Applied Behavioral Analysis (ABA) therapy where the child interacts with a tablet computer wirelessly interfaced with the robot. At the same time, the robot makes meaningful expressions and utterances and uses stereo cameras in eyes to track the child, maintain eye contact, and collect data such as affect and gaze direction for charting of progress. In this paper we present the clinical justification, anticipated usage with corresponding requirements, prototype development of the robotic system, and demonstration of a sample application for robot-assisted ABA therapy.

## I. INTRODUCTION

It is estimated that the prevalence of Autism Spectrum Disorder (ASD) is 1 in 68 children [1]. In 2001, the National Research Council estimated that fewer than 1 in 10 children affected with autism received appropriate intervention (National Research Council 2001). Direct services treating ASDs cost 3.2 million dollars over the lifetime of an autistic individual and 32 billion dollars per year to treat all autistic individuals, which does not include additional services and therapies for which many families pay out of pocket [2].

### A. Diagnosis

The DSM-V defines ASD as “persistent deficits in social communication and social interaction across multiple contexts.” [3] Early warning signs include: spinning, rotating, or preoccupation with certain objects, inability to follow gaze or point, limited use of vocalizations or gestures, and rudimentary development of response to joint attention [4]. Early

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identification of an ASD is critical to the introduction of an intervention, which may increase developmental progress. Currently there are no definitive medical tests used to assess and diagnose children with a potential ASD. However, there are various diagnostic tools used by professionals to assist with diagnosis. An in-home system that can quantitatively track eye movement and other factors may lead to improved early detection and intervention.

### B. Social Policy

There are a plethora of interventions for the treatment of autism including educational, therapeutic, and biomedical treatment plans. Treatments are chosen depending on the degree to which the individual is affected by ASD and other disorders. Beyond diagnosis, the results of these tests may be utilized in initiating an effective intervention that corresponds to the severity of symptoms.

Families often struggle in choosing interventions that will benefit their child and are covered by their insurance company. Many insurance companies will cover what is medically necessary, and refusing to pay for services that are considered experimental [5]. Since few services are paid for by insurance companies or state agencies, the financial responsibility often falls on the families and school districts in addition to choosing what path to take in terms of educational services and the intensity and type of treatment, and costs are far from diminutive. ABA therapy can cost upwards of \$100,000 a year [6]. Associated with ABA, the implementation of Discrete Trial Training (DTT) will cost anywhere from \$40,000 to \$60,000 for 2 to 6 years of full time, one-to-one behavior treatment [7].

An affordable and available approach to ASD detection, therapy, and continued assessment is critical; we believe the use of compact, low-cost robotics may prove a viable solution. This paper describes: 1) the intended approach for using robotics to assist in providing therapy to children with ASD, 2) the prototype robotic system that is currently in development, and 3) an exemplary application of the PABI robot in combination with a tablet computer for robot-assisted ABA therapy.

## II. INTERVENTIONAL APPROACHES

### A. Current Interventions

There are many skills and behaviors in which children with an ASD need to be taught, that typical children may learn or pick up on their own. Theory of mind states a neurologically typical person has the ability to infer the full range of mental states including intentions, beliefs, attitudes, and emotions. It

is believed that an autistic individual do not fully understand another's point of view, beliefs, attitudes, and emotions. In effect, individuals affected by autism may fall behind in social contexts and with interpersonal communication [8].

Two classifications of treatment currently exist: *focused interventions* that produce behavior or developmental outcomes, and *comprehensive treatment models* (CTMs). Each form of intervention bears its strengths and weaknesses, providing mixed evidence of effectiveness [9]. CTMs include multifaceted, intense applications such as the Applied Behavior Analysis (ABA), Lifeskills and Education for Students with Autism and other Pervasive Developmental Disorders (LEAP) program, Walden Model, Treatment and Education of Autistic and Communication Handicapped Children (TEACCH), and the Denver Model. ABA (formally known as the Lovaas Model) maintains as one of the most widely used interventions for the treatment of an ASD, and has proven to be effective [10]. Highly behaviorally based, an ABA therapist uses discrete trial training in which tasks are broken down, and appropriate behavior is reinforced. CTMs follow varied theoretical and conceptual frameworks. Treatment can be conducted over a variety of settings, including homes, clinical settings, schools, or a combination. CTMs are strong in operationalization, facilitating implementation of treatment procedures [11]. It is not unusual to see practices and features of various CTMs combined to best suit the needs of each individual. The use of social robots may be complimentary to CTMs. We believe that interaction with compact, non-threatening, and expressive humanoid robots may translate to improved communication skills that extend beyond the robotic intervention.

### B. Social Robots

The idea of social robots strengthening social communication skills may stem from the belief that joint attention builds richer representations of one's self and other, which prompt and optimize early social learning and development [12]. The use of robotic technology may further the opportunity for individuals with an ASD to interact with typically developed people, if they so choose by mediating asocial behavior [13], [14].

Differing from the traditional task-oriented robot, interaction-oriented robots are designed with the intention to communicate and interact with humans [15]. Kimset is an example of an anthropomorphic robot that engaged and communicated with facial expression, body posture, gesture, gaze direction, and voice. Being the first face robot of its kind, Kimset's purpose was to engage in natural and intuitive human interaction [16]. Robins, et al. found a social robot to act as an effective social mediator that aided children with autism to engage in social communication. The effectiveness and attraction to the robot may be due to the variable and incalculable behaviors instead of a toy that produces the same, predictable behaviors [17]. Kozima, et al. describe their simple, therapeutic robot, Keepon, as a means "for helping and encouraging those children practice interpersonal communication in a playful and relaxed mood"

[18]. It was discovered that Keepon prompted didactic (child interaction with Keepon) and triadic (child sharing pleasure and wonder with a third party adult) interactions among the children with autism and related developmental disorders. The Aurora project investigated how toy-like robots can fulfill a therapeutic or educational function for children with autism. The project uses a robotic platform to simplify social behavior in a more appealing environment. Robota (a humanoid robotic doll) [19] and Kaspar (a child sized humanoid robot) [20] teach autistic children basic social interaction skills, with the hopes that the shared attention with the robots will foster more frequent didactic and triadic interactions with peers and adults.

## III. ROBOTIC INTERVENTIONS

### A. System Development

With a rise in prevalence of ASDs, social robots may assist medical and psychological providers in more accurately making a diagnosis in a timely fashion, and from an earlier age. Early detection of autism is crucial to the onset of early intervention (EI), which proves to be considerably significant to the highest attainable progress [21]. Evidence suggests that social robots may be proficient in detecting early vulnerability for autism in infants and toddlers [22].

The proposed system is designed to serve as a tool for both diagnosis and therapy. The robot may simplify the job of diagnosing or treating patients for more highly trained therapists, allowing them to see more patients per day. Further, the robot will assist in providing quantitative measures for initial assessment and charting of treatment progress. For example, one of the behaviors a provider will measure in terms of social cues is gaze direction.



Fig. 1: Current prototype of the PABI humanoid robot. The robot is designed to be low cost, durable, expressive, and capable of meaningfully interacting with an autistic child.

In our efforts to investigate the potential of robotics as diagnostic, therapeutic, and early-intervention tools for children with pervasive developmental disorders, we are

developing a new humanoid social robot, PABI (<sup>©</sup> *Dickstein-Fischer*) which stands for ‘Penguin for Autism Behavioral Intervention’. The cartoon-like embodiment will look at children, make facial expression and utterances, track eye contact, and stimulate a social response in a non-threatening manner [23]. The robotic system has gone through several iterations, and the latest embodiment of the penguin-like humanoid robot is shown in Fig. 1. The PABI is small enough in size that the child can hold it, creating a physical connection which may enhance feelings of affection toward the robot, prolonging the child’s interest in it. The PABI, adorable and visually appealing to children, may serve the function of teaching a child theory of mind [8]. Moreover, the ability of the robot to monitor gaze and social cues may provide diagnostic utility.

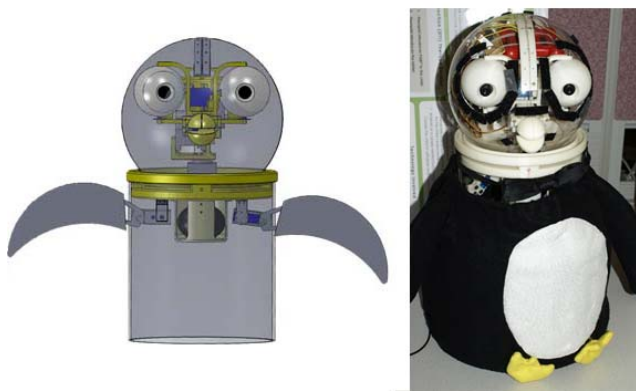


Fig. 2: A conceptual visualization view of the robot (left), and a visualization of the head’s internal structure (right). The robot has 8 DOF motion including the eyes, beak, head, and wings.

The PABI robot consists of the following 8 degrees of freedom (DOF): pan and tilt of the eyes (coupled tilt), beak actuation, head tilt, head rotation, and actuation of both wings. A conceptual CAD model and an internal view of the robot are shown in Fig. 2. Each DOF is actuated via servo motors inside the head or body and the motion is controlled by an intelligent servo controller (DyIO, Neuron Robotics, Worcester, MA) embedded in the head. The robot is configured with internal batteries, an Intel Atom-based single board computer, and wireless communication via WiFi and Bluetooth. However, for prototyping an external computer and power source are used. A speaker is mounted in the head behind the actuated beak for communication of instructions or other utterances. Each eye contains an independent USB video camera coupled to the control computer, and therefore the robot is able to monitor the child and surroundings.

The robotic control system is fully implemented in ROS (Robot Operating System, <http://www.ros.org/>), enabling rapid reconfiguration and application development. Vision processing is primarily implemented utilizing OpenCV (<http://www.ros.org/>). The current system is capable of tracking and maintaining eye contact with the child. We have also demonstrated detection of gaze direction and gesture

recognition. A tablet computer interfaces with the primary computer system; in the current embodiment we use a linux-based tablet also running ROS. The tablet runs the user application, and the following section describes one sample application utilizing the tablet for ABA therapy.

### B. ABA Therapy Application

Applied behavior analysis (ABA) has become an intervention recognized to address the problems of children with special needs, particularly those with autism and mental retardation. In the US, the Individuals with Disabilities Education Act, Section 614 recognizes this with inclusion of behavior intervention as a mandated service [24]. As a result, Individualized Education Plans (IEPs) include appropriate behavioral intervention, and children exhibiting behavior problems resulting in alternative educational placements receive behavioral assessment and intervention services. It is compulsory for school systems to respond to these requirements and have on hand either in-house personnel or consultants with behavioral expertise. Unfortunately, many regions have an insufficient number of qualified applied behavior analysts to meet this need, and as a result many children do not get sufficient and timely services [25].

The PABI is a pilot in the use of robotics in improving diagnostic assessment and early intervention therapy with children with autism. The robot is now capable of demonstrating robot-assisted ABA therapy through Discrete Trial Teaching (DTT) by interfacing wirelessly with a tablet computer displaying various virtual flashcards that the child interacts with while at the same time instructing the child and providing feedback. The robot’s vision system including stereo video cameras in the eyes coupled with the integrated computer is capable of detecting and charting a child’s location, gaze direction, and gestures. A demonstration of the PABI is shown in Fig. 3. The PABI is small enough in size that the child can hold it, creating a physical connection which may enhance feelings of affection toward the robot. The modest size will also allow for easy transportation to increase generalization of social skills across settings. We look forward to utilizing the robot’s ability to monitor gaze and social cues for providing quantitative assessment metrics for diagnosis and charting progress.

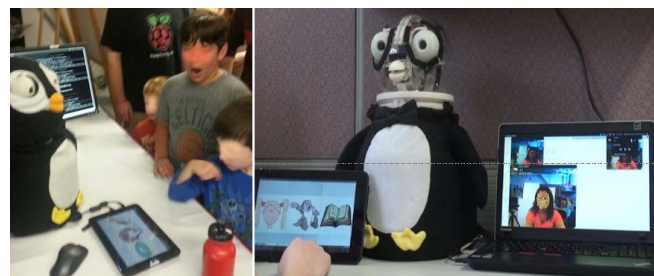


Fig. 3: A demonstration of the robot with children (left), children have shown great enthusiasm and affinity for PABI. An example of face localization and tracking (right), with ‘skin’ removed to see internal structure of the robot.

#### IV. DISCUSSION

With the known causes and cures of autism still nonexistent, working to lower costs without attenuating interventions should remain a purpose of action. Autism advocates should continue their efforts to improve social policy and educate families about their rights in terms of treatment options. Progress in children with autism is perceived to be affected by accuracy, consistency, reciprocity, and immediacy of the intervention [26]. In addition, more treatment time means more progress, and utilizing tools such as social robots may prove to be qualified to improve the capacity and efficacy of interventions all around. We look forward to beginning pilot clinical studies to demonstrate the feasibility and effectiveness of our robot-assisted approach to diagnosis, therapy, and charting.

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