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A robot-assisted behavioral intervention system for children with autism spectrum disorders

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HIGHLIGHTS

- Robot-assisted behavioral intervention based on automated interaction technologies is proposed.
- Socially validated therapeutic protocol is applied to child–robot interaction.
- Reliable eye contact detection is reviewed as clinical evidence.
- Differentiated robotic stimulation is designed to attract children's attention.
- Reinforcement procedure with coping strategy is verified in repetitive training routines for clinical trials.

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ABSTRACT

The purpose of this paper is to propose and examine the feasibility of a robot-assisted intervention system capable of facilitating social training for children with autism spectrum disorder (ASD) via human–robot interaction (HRI) architecture. Based on the well-known discrete trial teaching (DTT) protocol for the therapy of children with ASD, our control architecture configures four modules – human perception, user input, the interaction manager, and the robot effector – such that the robot system generates differentiated training stimuli using motivation and Stroop paradigms and automatically copes with the child's response by using reliable human recognition and interaction technologies. Using these configurations, the proposed system performs the role of training the social skills of basic eye contact and reading emotions in children with ASD. By examining reliable performance evaluations and the positive effect of the training process targeting preschoolers with a high functioning level, we then verify that the proposed system can induce a positive transition in the response of children with ASD and the possibility of a labor-saving effect in carrying out autism treatments.

1. Introduction

Children with autism spectrum disorders (ASD) suffer from a characteristic impairment in the ability to interpret social cues, engage in repetitive patterns of behavior, and often fail to use social gaze in empathetic and joint-attention tasks [1]. These ASD features translate into difficulties in engaging in social activities in early childhood and adulthood. To address the need for appropriate treatment for children with ASD, a range of social mediation techniques have been performed over a series of years [2], and the American Psychological Association recommends that clinicians use medication and behavioral interventions to help children cope with autism [3]. In particular, behavior-based interventions build on the interests of the child and involve the extensive use of visuals to accompany instruction, a highly structured schedule of activities, and transition planning and follow-up. In addition, there has been an increase in the number of university hospitals and research institutions focusing on the early diagnosis of autism and making use of behavioral intervention approaches, such as applied behavior analysis (ABA), naturalistic methods, and milieu teaching through empirical studies [4–6]. Recent research has suggested that robots may be used effectively as clinical tools to improve the social skills of children with ASD [7,8], and some studies have shown that the strengths of these systems include their physical appearance, targeted behavior eliciting active engagement, and robot autonomy during therapy sessions [9–13]. In the technical aspect, the robot can provide children with ASD with a predictable and consistent environment with the ability to

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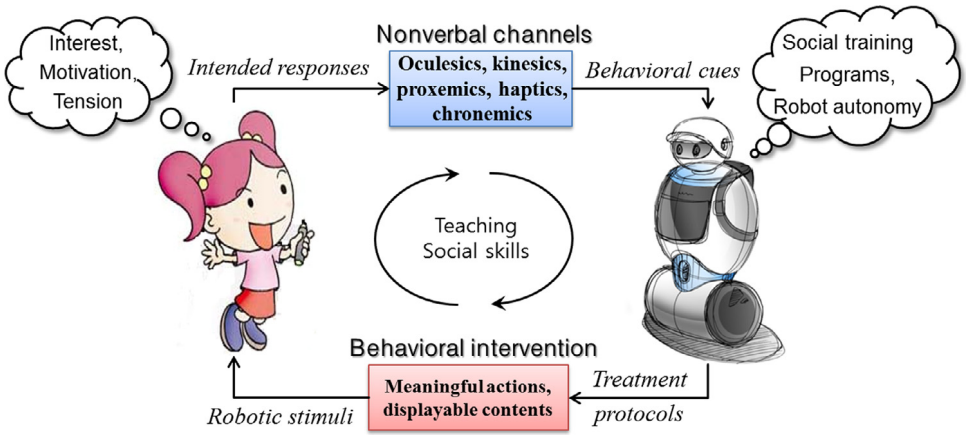

Fig. 1. A basic overview of the robot-assisted behavioral intervention approach for autism treatment.

isolate social input [14]. Additionally, the clinical application of robot technologies to autism treatment can contribute to settling issues of long-term care and the therapist's burden for repetitive behaviors [7,15], and reducing the degree of dependence on the therapist can eventually increase the effectiveness of autism therapy [16].

Considering the published studies, we think that the main role of the robot is to be more autonomous in that it makes a reliable interpretation of interaction signals from children and thereby performs adaptive behaviors as robotic stimuli through the organization of its role during training (see Fig. 1). Furthermore, we are sure that the well-designed training methods incorporating appearance, specialized training content, interaction technologies, and robot feedback with targeted behaviors can be key elements in the facilitation of specific social skills for children with ASD.

The aim of this study is to propose a robot-assisted behavioral intervention system including well-organized instructional approaches and to examine its feasibility through a performance evaluation for the chosen training elements. The proposed system is built using human–robot interaction (HRI) architecture with a highly structured schedule of activities based on well-known behavioral treatment protocols. In the architecture, although there is a therapist's input, the system estimates the extent of the reactivity of the children through interpretation of their behavioral cues after requesting that they perform the training elements of *eye contact* and *reading emotions* and automatically accomplishes pre-allocated acts given by a stimulation configuration and coping strategy. Furthermore, in connection with the interaction design, we adopt automated interaction technologies capable of performing repetitive robot feedback while maintaining consistency in the training process for the purpose of a labor-saving effect. Using these configurations, we examine the performance evaluation for the proposed intervention system and its effectiveness in the clinical environment and thereby verify the system capability of inducing a positive change in the response of children with ASD as well as supporting evidence-based clinical practices.

This paper is organized as follows: Section 2 explains the scope and rationale for our study, Section 3 details the robot system for autism treatments in each part, Section 4 outlines the experimental setup, Section 5 describes our results and discussion, and Section 6 presents our conclusions and future works.

2. Scope and rationale

In autism therapy, the robot's appearance mainly attracts the focused attention and curiosity of children with ASD, and its meaningful actions (e.g., vocal messages, music, color and visual cues, movement) are beneficial for inducing their positive attitude [17–20]. Accordingly, to develop children's social skills, interactive robots have provided social training programs for children with autism in terms of eye contact, joint attention, touch, sharing or turn-taking, and imitation of the robot's behavior [15,17,18,21,22]. Addressing the key characteristics of children with ASD, eye contact training among the primitive social skills allows them to learn more about aligning their gaze with the eyes of others and following their line of sight to provide clearer communication signals [23], and it even heightens the intensity of the effect in a structured test environment [24]. In addition, the reliable analysis of the child's facial gaze is a significant cue in the child–robot interaction for analyzing the degree of the child's interest from the viewpoint of cognitive science. Next, even if human facial expressions serve a crucial communicatory role that enables an understanding of the emotional states of other people, Robins et al. [10] and Yirmiya et al. [25] reported that autistic children have difficulty interpreting and sharing facial expressions and other social cues. However, Clark et al. reported that the identification of emotion from rapidly presented stimuli involving facial expressions in an activity session could be a good indicator for social development including rapid mimicry and empathy [26]. In addition, it will help to secure quantitation for children with ASD. Therefore, these results show that nonverbal behavioral intervention for children with ASD, including eye contact and reading emotions, may be an important therapeutic goal in terms of social interaction. To this end, we designed the system to apply these two elements to the training process through consultation with therapists.

In current trends, behavioral intervention is one of the major autism treatment approaches recommended by the Autism Society of America along with medication [3], and there is evidence that early intensive behavioral treatment may result in substantially enhanced outcomes [27] as the most important instructional method for children with autism. Since then, recent studies have demonstrated that the use of a robot in behavioral therapy helps children with ASD reduce negative avoidance behaviors [28] and share their interaction experiences with their parents [8,21]. In particular, a well-designed intervention approach is an essential part of providing attentional elements, which usually appeal to children in instructional trials, as well as adjusting robot reactions with a differentiated strategy by interpreting interaction signals reliably [7,13,18,28]. The findings from these studies show that more challenging issues in some children with ASD may be resolved through socially validated strategies using structured instruction in combination with a behavioral intervention program. In this regard, the basic assumption of our intervention design relies on the premise that the robot can offer positive autism treatments via the HRI architecture. Accordingly,