Probolino: A Portable Low-Cost Social Device for Home-Based Autism Therapy

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Abstract. Recent research has shown that social robots are beneficial in therapeutic interventions for children with autism in clinical environment. For the generalization of the skills learned in therapy sessions outside the clinic or laboratory, the therapeutic process needs to be continued at home. Therefore, social robotic devices should be designed with smaller sizes, lower costs, and higher levels of autonomy. This paper presents the development of Probolino, a portable and low-cost social robotic device based on the social robot Probo. The system functions as a "robotic cognitive orthotic" which is an intermediate step between a computer and a robot without motion. Interactive games are developed to help children with autism spectrum disorders make social decisions in daily activities. These activities are configured in a time-line by therapists or parents via a web interface. Probolino is expected to enhance the efficiency of current robot-assisted autism therapy.

Keywords: Social robotic device · Robot-assisted autism therapy

1 Introduction

An ongoing research trend in social robots development has been realized to help children with Autism Spectrum Disorders (ASD), i.e. a neuropsychological disorder manifested by a group of lifelong disabilities that affect people's ability to communicate and to understand social cues [24]. Recent research suggests that children with ASD exhibit certain positive social behaviors while interacting with robots that are not observed while interacting with their peers, caregivers, and therapists [20,23]. Therefore, various social robots are developed and used as parts of therapeutic interventions for children with ASD in turn-taking, joint-attention, imitation, self-initiated behavior, etc. The role of these robots is to

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encourage, facilitate, and train social behaviors through embodied social interaction [7]. The advantages of Robot-Assisted Therapy (RAT) can be explained by the social simplicity, predictability and responsiveness of the social robots in use [21].

The presence of a robot in therapeutic intervention is certainly beneficial. In order to have the generalization of the skills learned in therapy sessions outside of the clinic or laboratory, the robot should be brought out of the clinic as a "cognitive orthotic" [4]. A portable robot which children with ASD can hold throughout the day may have the potential of helping them open up the learned skills to peers and family members [20]. However, this possibility faces three big challenges: *dimension*, *cost*, and *autonomy*. First, robots used in RAT are typically big or not portable e.g. NAO [25], FACE [17], Kaspar [5], Probo [29]. Second, these robots are expensive due to the complexity with high degrees of freedom. Even small robots such as Keepon Pro [13], Pleo [11], are also not affordable. A few compact robotic platforms have been developed. ONO robot, with the cost of approximately €300, is at the first steps of development and its electronics need to be improved [30]. Solutions based on modification of commercial robots, e.g. Pleo [9], My Keepon[3], are promising but not a sustainable approach. Third, many of the current approaches restrict to a Wizard of Oz in which the robot is usually remotely controlled by a human operator unbeknownst to the child. In the long-term, the robots need to increase their autonomy to lighten the burden on human therapists and to provide a consistent therapeutic experience [27]. Since all of the above-mentioned challenges are barriers for families of children with ASD to approach RAT, there is a need to have small-sized and low-cost robots with a higher level of autonomy.

In this paper, we present the development of "Probolino" which is a portable and low-cost device based on the current prototype of the social robot Probo developed at the Robotics & Multibody Mechanics Research Group of the Vrije Universiteit Brussel. Probolino functions as a "robotic cognitive orthotic", i.e. an intermediate step between a computer and a robot without motions, with the aim to become a friend of children with ASD and to help them make social decisions. The platform is designed as a stuffed model integrated with a microcomputer and a set of sensors. In order to help Probolino react autonomously and support the therapeutic process, interactive games are developed based on the visual strategies in autism therapy, in collaboration with therapists. Content and settings of the games are configured by therapists or parents via a web interface. For cost reduction, all the components, from microcomputer to sensors, are economically selected, yet still need to be capable to perform the required functions. Additionally, open-source environments are used in the design and development of PCB and software. In the first step, Probolino is tested with the typically developing children to validate its functionalities.

This paper is organized as follows. Section 2 reviews previous studies of Probo and visual strategies in autism therapy. The design of Probolino including the hardware, software, and web interface is presented in Section 3. Section 4

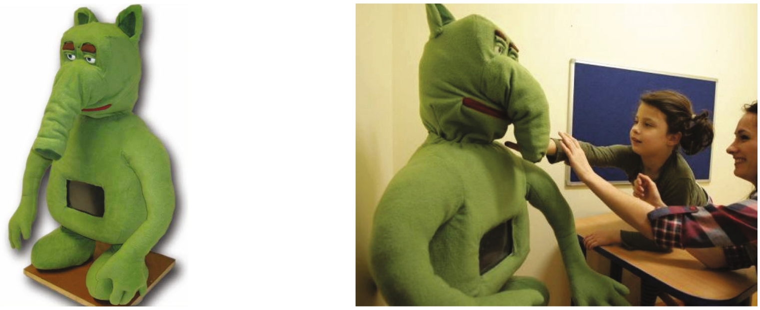


Fig. 1. The HRI platform Probo. Safe and huggable design of Probo allows for both cognitive and physical interactions. Figures reprinted from [29].

describes the interactive games for home-based autism using the Probolino platform. Section 5 shows all the functional testing of these games with typically developing children. Finally, the conclusion and future work are discussed.

2 Related Work

2.1 Probo – The Huggable Social Robot

Following the idea that robots used in autism therapy should be simple but still possess human characteristics, Probo is designed as a zoomorphic social robotic interface with a complementary purpose as a multidisciplinary research platform for Human-Robot Interaction (HRI) [8]. Probo looks and feels like a stuffed animal as can be seen in Figure 1, left. It has a huggable appearance with 20 degrees of freedom in its trunk or proboscis, animated ears, eyes, eyebrows, eyelids, mouth, and neck. A touch screen is attached in its belly. With compliant actuators and a triple layered protection structured with foam and fabric, a safe physical interaction between human and the robot is guaranteed. Probo is able to communicate and interact with human by expressing attention and emotions via its gaze and emotional facial expressions [22].

The first experiments of using the social robot Probo as a facilitator in Social Story Intervention for children with ASD have shown positive results. The study in [29] was carried out on four cases of preschool ASD children (by using the method of single-case experiment). In these experiments, the robot teaches the children how to react in situations like saying "hello", saying "thank you" and "sharing toys" (Figure 1, right). In specific situations, when using Probo as a medium for social story telling, the social performance of children with ASD improves more than when the stories are told by human readers [29]. Other study demonstrated that using Probo can help ASD children to improve their ability to recognize situation-based emotions (both sadness and happiness) and mediate social play skills of children with ASD with their siblings (brother or sister) [18]. These preliminary studies created great expectancies about the potential of using RAT as an added-value therapeutic tool for ASD interventions.

2.2 Using Social Story and Visual Schedules in Autism Therapy

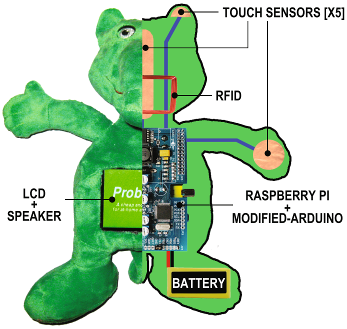
Visual Strategies: Pictures and Schedules. The majority of children with ASD are visual learners. They process and retain information better if it is presented in a format where it can be seen, as opposed to information that is primarily heard. There are clear empirical evidences regarding the benefits of using visual strategies with individuals with ASD [2,14,15]. Individuals with ASD have greater difficulties coping with unstructured activities and time than typically developed people and benefit from increased structure in their lives [28]. Mesibov *et al.* introduced the advantages of using visual schedules with individuals with ASD in [16]. By utilizing the individual's visual strengths, visual schedules provide a receptive communication system to increase his/her understanding and ability to learn new things and broaden their interests. Moreover, visual schedules help the individual to remain calm, reduce inappropriate behaviors, and develop independence and enhanced self-esteem [16]. Faherty suggested that visual schedules may be important to use both at home and at school, because pictures are powerful tools that provide a simple way to make communication more effective with ASD children and less stressful for individuals with ASD [6].

Social Story and Right-Wrong Game. A *Social Story* is a written or a visual guide describing various social interactions, situations, behaviors, skills or concepts in terms of relevant social cues, perspectives, and common responses in a specifically defined style and format [26]. The goal of a Social Story is to share accurate social information in a patient and reassuring manner that is easily understood by its audience [26]. Social Story is based on the theory that individuals with autism have a "Weak Central Coherence", which refers to the detail-focused processing style proposed to characterize ASD [10]. It is different from a "strong" or "typical" central coherence that refers to the tendency to integrate information in context for higher level meaning [1]. Reynhout and Carter found in an earlier review that teachers consider Social Story to be very effective in schools [19]. *Right-Wrong game* is a part of the Social Story. In social situations, some individuals with ASD may pay attention to irrelevant details and fail to understand the meaning of the situation [12]. This game gives children with ASD a set of actions and asks them to choose the correct ones that must be accomplished in an activity. By this way, the Right-Wrong game explains what will happen in that particular situation.

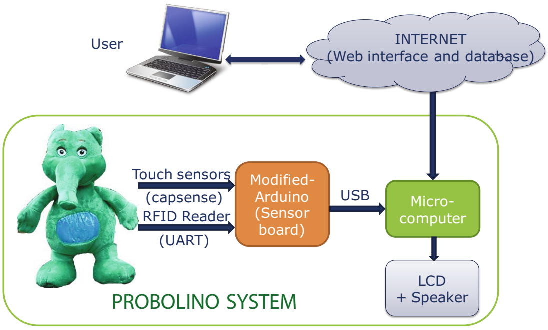
3 Development of Probolino

3.1 Overview

Probolino is developed with the aim to become a friend of children with ASD and helps them make social decisions. The system is designed as a portable social device which autonomously reacts to users' stimulation in interactive games developed in collaboration. The embodiment of Probolino is based on the small



(a) Probolino prototype.



(b) Hardware connections.

Fig. 2. Probolino platform: a stuffed model with a set of sensors, microcomputer, web interface connected to one another by various means of communications.

stuffed model of Probo (150mm x 80mm x 280mm) equipped with a microcomputer, sensors, and a web interface (Figure 2a, left). The hardware allows Probolino to detect touch and objects from external environment. The software embedded in Probolino gathers signals from the sensors and database as the inputs of the interactive games for autism therapy purposes. The web interface allows therapists, parents or teachers to set up and assess the use of the platform. Via an easy-to-use interface, the settings of the interactive games and the schedule of daily activities are configured and uploaded to Probolino.

3.2 Hardware

The functions of the hardware are: (1) to detect touches and iconic objects (RFID tags) from users (i.e., children, parents or therapists), and (2) to update the schedule and activities via a MySQL database.

The microcomputer Raspberry Pi model A, as the center of the hardware, accesses the database to update the schedule and activities. It also controls a speaker and an LCD screen to support human-robot interaction. Raspberry Pi is connected an *Arduino-based board*, opening up more possibilities to integrate the system with different types of sensors. With more built-in modules, it is easy for Arduino to connect with different types of peripherals. The board is designed to be suitable to the shape and the GPIO connector of Raspberry Pi. More modules are added to enhance the functionalities of Arduino. Data gathered from the modified-Arduino are transferred to Raspberry Pi. The connections between the boards and sensors are illustrated in Figure 2b.

3.3 Software

The embedded software handles the communication between Raspberry Pi, modified-Arduino and the MySQL database. The *modified-Arduino's software*

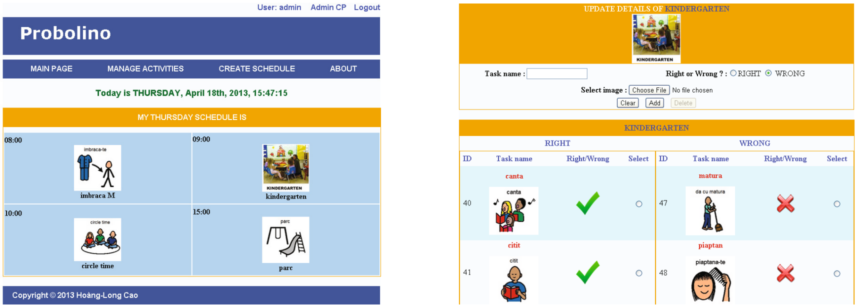


Fig. 3. Web interface: Main page (left), Configuration of interactive game (right).

collects raw data from capacitive sensors and RFID readers. These signals are analyzed and sent to Raspberry Pi in form of keystrokes of a virtual USB keyboard. On the other side, the *Raspberry Pi's software* is written in Python with Pygame modules. It reads the sensor signals after being analyzed by the modified-Arduino. An API allows the software to update schedule and activities from either online or offline MySQL databases. This data functions as resources for the interactive games (see Section 4). In addition, sounds transmitted by the speaker and images displayed on the LCD screen are also generated by this software.

3.4 Web Interface

Probolino's web interface (Figure 3) provides an easy way for the communication between users and Probolino. It can run in most of operating systems and web browsers. No installation is required. Registered users can use their account information to log in and configure Probolino. With this web interface written in PHP, users can create daily schedules for children by selecting activities from a list. New activities and the accompanied description and help functions in the form of images can be further added into the list. These information is stored in a MySQL database. Software in Probolino can access this database to get the schedule and resources for interactive games. The admin control panel is built for future development when there exists multiple users and Probolino platforms.

4 Interactive Game for Home-Based Therapy

4.1 Probogotchi

Probogotchi is a game where children have to interact with Probolino, based on the idea to care for a virtual pet and make it dependent on the users' actions. The goal of this game is to increase the motivation of children by introducing this virtual pet-like character that will react emotionally on the children's actions. In this game, the children have to make Probolino happy by touches and iconic

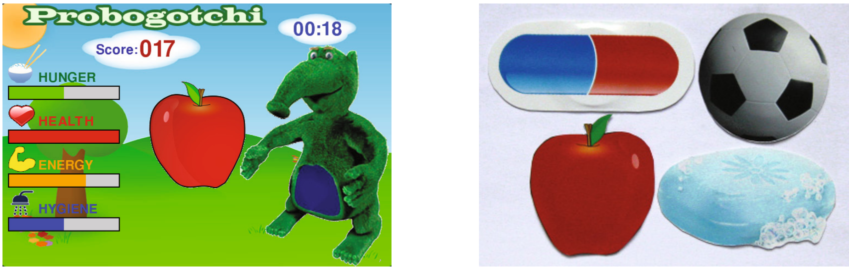


Fig. 4. Progobotchi game interface (left) and iconic objects (right).

Fig. 5. Schedule mode shows the current activity that children have to do (left). Right-Wrong game (right) is associated with this activity to help children select proper tasks.

objects (RFID tags) associated with "Apple", "Medicine", "Ball" and "Soap" (Figure 4). Depending on the detected events, the four properties "Hunger", "Health", "Energy" and "Hygiene" vary from 0% to 100%. Probolino indicates these detections by sounds and images. The instant values of these properties are visualized in the game interface by four progress bars with different colors. The values of the four properties are automatically decreased by 10% after every 10s, 20s, 30s or 40s respectively. The score and time are also displayed on the top of the interface. The game is over after a certain duration and when all the property values reach the value of zero.

4.2 Schedule Mode with Right-Wrong Game

Schedule mode shows the current activity that a child with ASD has to do based on the time-line schedule created online (Figure 5, left). In each activity of the schedule, the child plays a "Right or Wrong" game where he/she learns which tasks are appropriate with the current activity. The game consists of 10 questions. Each of them is composed of one correct task and one incorrect task corresponding to the activity as illustrated in Figure 5, right. The answer is selected by touching one of Probolino's hands. When the game finishes, the result showing the number of correct answers is displayed on the screen.

Fig. 6. A four-year-old typically developing girl playing with Probolino prototype.

5 Initial Testing

At the current stage of this study, the intervention for autism therapy is not yet conducted. Therefore, testing the engagement with Probolino on typically developing children is significantly useful for future development.

We present here a case study of a typically developing four-year-old girl. At the beginning, she was afraid of interacting with Probolino. This reaction is normally observed in children when it comes to encounter a stranger or unfamiliar animal. After several minutes of instruction on how to play, she started to touch and feed it by iconic cards in Probogotchi game. When she got used to interacting with Probolino, she was asked to play the Right-Wrong game in Schedule mode. Her father, a 35-year-old office worker, had no difficulty using the web interface after a quick explanation about the meanings of visual images.

6 Conclusion and Future Work

This paper details how the different hardware, software, and web interface are integrated in Probolino, a social robotic device aimed for use in therapy for children with ASD at home. All elements of the system are designed taken into account the possibility to enhance the system in the future. Interactive games were developed based on the advantages of visual strategies in autism therapy. A web interface was developed for users to configure the content of these games. The cost of Probolino is approximately €100, which is roughly calculated by considering the main parts. Price of each part can be reduced in mass production. Compared to the current Probo platform, Probolino prototype is basically smaller, cheaper, and more interactive through the games and the web interface. The results of usability testing, although preliminary, prove that Probolino is ready to be utilized in home-based autism therapy.

Although the achieved results fulfill the requirements, Probolino system still needs further improvements e.g. the sensitivity of installed sensors or appearance of the platform. More functions will be further added into Probolino as a result of the collaborative working process with the therapists (e.g., monitoring the interaction, enhancing the interactive games). More importantly, the value of Probolino in therapy still needs to be validated by the results of interventions on children with ASD in specific therapeutic scenarios.

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