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CHARLIE : An Adaptive Robot Design with Hand and Face Tracking for Use in Autism Therapy

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Abstract Basic turn-taking and imitation skills are imperative for effective communication and social interaction (Nehaniv in Imitation and Social Learning in Robots, Springer, New York, 2007). Recently, research has demonstrated that interactive games using turn-taking and imitation have yielded positive results with autistic children who have impaired communication or social skills (Barakova and Brok in Proceedings of the 9th International Conference on Entertainment Computing, pp. 115–126, 2010). This paper describes a robot that plays interactive imitation games using hand and face tracking. The robot is equipped with a head and two arms, each with two degrees of freedom, and a camera. We trained a human hands detector and subsequently, used this detector along with a standard face tracker to create two autonomous interactive games: single-player ("Imitate Me, Imitate You") and two-player ("Pass the Pose".) Additionally, we implemented a third setting in which the robot is teleoperated by remote control. In "Imitate Me, Imitate You", the robot has both passive and active game modes. In the passive mode, the robot waits for the child to initiate an interaction by raising one or both hands. In the second game mode, the robot initiates interactions. The "Pass the Pose" game engages two children in cooperative play by enlisting the robot as a mediator between two children alternately initiating and imitating poses. These games are designed to increase attention, promote turn-taking skills and encourage child-led verbal and non-verbal communication through simple imitative play. This research makes two specific contributions: (1) We present a low-cost robot design which measures and adapts to a child's actions during interactive games and, (2) we train, test and make freely available, a new hand detector, based on Haar-like features, which is usable in various kinds of human-robot interactions. We present proof-of-concept experiments with a group of typically developing children.

Keywords Human-robot interaction · Hand detection · Hand tracking · Adaptive robotics

1 Introduction

Robot-assisted autism therapy employs robots as social mediators for promoting and teaching communication and social skills in autistic children. Robots have been used effectively to engage autistic children in interactive game playing and research has demonstrated that robot-assisted autism therapy promotes increased speech and increased child-initiated interactions in children with Autism Spectrum Disorder (ASD) [3, 4]. The goal of our research is to provide parents and therapists with an effective, widely usable, interactive robot that will broaden the impact of traditional therapies. Research in robot-assisted autism therapy typically emphasizes specific objectives for ideal human-robot interaction including an increased attention span, eye contact, proactive interaction with the robot initiated by the child, verbal and non-verbal cues, turn-taking, imitative game playing and overall use of language [5, 6]. The robot produced by this research is specifically designed to engage an autistic child in order to promote turn-taking and imitative game playing. It is our expectation that field tests will also positively impact attention focus, proactive child-robot interaction and, in some cases, increased eye contact with

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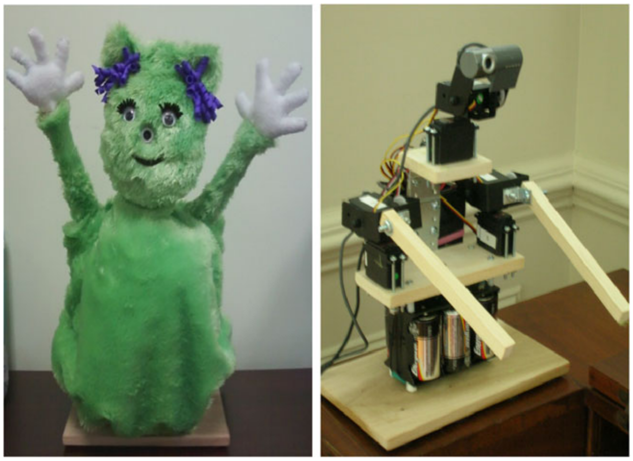

Fig. 1 CHARLIE. (*Left*) Completed robot. (*Right*) Internal structure

co-present others. It is important to note that the robot described herein is intended to be used as a *tool* by the therapist, teacher or parent to help promote the overall goals of autism therapy, and not as a replacement for established methods. Further, we expect that the robot's effectiveness as a therapeutic tool will vary greatly depending on a child's developmental ability and personality.

In this paper, we describe a simple interactive robot, named CHARLIE (CHild-centered Adaptive Robot for Learning in an Interactive Environment), which uses a turn-taking game for the purpose of engaging autistic children during therapy. See Fig. 1. The robot is designed with a head and two arms, each with two degrees of freedom, and a camera for face and hand detection. The camera is mounted inside the robot head which moves, as needed, to maintain visibility of the face whenever possible. We show that basic commodity hardware is sufficient to implement face and hand tracking for interactive games designed for use in autism therapy. Due to its relatively low cost and in elaborate hardware, CHARLIE is intended to be accessible to a larger population of children than many of the robots currently used for autism therapy.

In general, the implementation of a robust hand tracking system can greatly improve the quality of human-robot interaction, especially when the robot is intended for rehabilitative or therapeutic purposes. Because of its hand tracking capability, CHARLIE can autonomously participate in a wider range of user-driven, interactive games where robot actions are determined by the actions of the child. Furthermore, the robot can automatically collect information about the child's interactions and provide a summary report for evaluation at a later time. This useful feature frees the therapist, teacher or parent from having to keep track of total session time, number of child-led and robot-led interactions and allow for more attention to and participation in the game process. A child's progress and preferences can be measured objectively by monitoring response times, length of engagement and number of user-led responses. Ultimately, these measurements when considered along with the amount of eye contact and number of verbal and nonverbal cues can be used to gauge a child's progress from one session to the next and to assess the overall benefit of the robot to each child. In the longer term, we expect the insight gained from this research to generate deeper understanding of the unique nature of robot interactions with the developmentally disabled, leading to broader innovations in robot software for therapy and assistance to this population.

A preliminary version of this work appeared at ICSR 2010 [7]. This paper presents (1) modifications to the existing hardware to improve safety, (2) additional hardware for auditory feedback, (3) a new interactive game designed to promote cooperative play between two children, and (4) a teleoperation mode that allows children to control the robot directly.

The remainder of this paper is structured as follows. We begin with a short description of the motivation and context for our research in Sect. 2. Section 3 is a review of related work. Then, we detail the fundamental methodology and approach underlying the robot and game design in Sect. 4. In Sect. 5, we present a description of the preliminary test design and results. We conclude the paper with a summary of our research and a brief discussion about future work in Sect. 6.

2 Motivation and Context

It is widely known that the frequency of diagnosis of autism has been increasing over the last decade, with some reports citing a 57% increase in autism prevalence between 2002 and 2006 [8]. Two of the most significant problems stemming from the increased prevalence of autism are the additional strain placed on existing resources for treating autistic children and the additional financial strain placed on families who care and seek treatment for their children with autism. The costs associated with additional therapy, specialized and medical care for an autistic child in the United States are estimated to be approximately 8.5 to 9.5 times more than raising a typically developing child [9]. For some families, this additional financial burden may mean having to choose between incurring debt to get the proper care for their child(ren) or limiting the amount of therapy their child receives. Although several existing robots have been used with autistic children, they are still generally cost prohibitive for widespread use by special education instructors and therapists.

In response to these existing needs, the long term vision of this research is to produce a low-cost, adaptable robot which is widely accessible to a large population of autism therapists, teachers and parents for use as part of an overall early intervention strategy for autistic children. In addition to meeting the hardware and software goals of this research, we paid special attention to the design and development of an appropriate and effective testing protocol.

Recent research in the area of robotics for children with special needs has yielded a comprehensive study by the IROMEC project [10] which describes the types of robot technologies and play scenarios most effective for children with various disabilities, how robots can be best used in therapeutic or educational settings, as well as detailed accounts involving the use of robots used for play activities and possible play-based methodologies. The testing protocol developed for the introduction and use of CHARLIE as a play tool for children with autism is based on the guidelines detailed in the IROMEC study.

First, the play scenario is defined in terms of: (1) a main target group, (2) a play type, (3) actors involved, (4) a setting, and (5) the duration of the play activity. The main target group consists of a small group of children ages 4 to 11 who have been diagnosed with autism and have documented communication deficiencies. The play type consists of a very simple game of imitation with a basic set of rules and is designed to engage one teacher or one child at a time. The tests take place in a closed classroom, where both the child and teacher are seated across from the robot and the robot will be seated atop and securely attached to a nearby desk so that the robot's head is at approximately the same height as the child's. The duration of the play activity is variable. The length of a typical session with the robot is based on the normal amount of session time allotted for that particular child, the perceived benefit of the robot to the child's development and the child's interest in the robot.

Second, we prepared a detailed description of how CHARLIE is introduced to each child and how play proceeds during the first and subsequent sessions. Prior to introduction, a baseline for communication skills and developmental ability is established for each child using assessment information provided by the child's teacher. At the first meeting, the teacher introduces CHARLIE and explains and/or demonstrates how to play the imitation game. The teacher then invites the child to play with robot and provide guidance, when necessary. For children who prefer to examine the robot and learn about its capabilities independently, the teacher assumes a more passive role, as an observer and guide.

Third, we identified measures for success using the baseline communication skills identified prior to the child's first session. Initially, the child's level of interest in CHARLIE is noted in addition to any specific robot characteristics that are especially interesting to the child. During each session, communication between the child and robot, and the child and teacher is documented by the teacher or researcher. Because the robot measures successful imitations between the robot and child it is not necessary to document these interactions, but other nonverbal and verbal communication occurring during the session is noted for subsequent analysis. Measures of success and user information collected during an interactive game can be used to assess the child's readiness for more advanced, child-initiated games such as collaborative group play and story-telling.

3 Related Work

Autism therapy ultimately seeks to promote human-to-human interaction. Over the past decade, the use of robots as social mediators has been explored as a tool for supplementing traditional autism therapies in order to teach and improve social skills. Robots are well-suited for interactive games with autistic children since they tend to be perceived as predictable, non-threatening, and are able to perform repetitive tasks consistently and reliably [11, 12]. Most importantly, an increase in basic social and interaction skills has been observed when using robots for turn-taking and imitation games [13].

Some of the most promising results from robot-assisted autism therapy include an increased attention span, eye contact, child-led speech, improved turn-taking and imitative game playing skills and overall use of language [14]. Minimally expressive robots such as KASPAR [15] have been used to explore the efficacy of robot-mediated therapy for autistic children. That research revealed that relatively low functioning autistic children, who would not normally seek physical or eye contact, directly engaged with the robot and, in some cases, proactively touched and gazed at co-present others during sessions with KASPAR.

Other research used for assisting autistic children has resulted in the design and development of various robotic systems. With Keepon [16, 17], it was observed that a very simple robot interface could be used to engage the attention of autistic children and facilitate social interaction. The Bubblebot research [18] showed that human-robot and human-human interaction is increased with a responsive robot whose actions are contingent on user commands. The IROMEC project [19] identified three play scenarios and five distinct developmental areas most beneficial for collaborative, interactive play with autistic children [20].

The robot described herein incorporates key characteristics from each of the above studies. The toylike appearance of the Keepon and the user-directed modality of the Bubblebot were used as the basis for the development of the robot architecture and the three types of play scenarios identified in the IROMEC study, (1) turn-taking, (2) sensory reward and (3) imitation were used to design the games detailed in this paper. The unique contribution made by this research is the low-cost design and additional functionality provided with the face and hand tracking system. With face and hand tracking, the robot will not only be able to participate in qualitatively different interactive games but it will also allow the robot to collect pertinent information regarding a child's specific progress that may be difficult or impossible to obtain otherwise.

4 Methodology and Approach

The approach taken for this research is based on the integration of robot and game designs that are known to be effective with autistic children. This section is organized into the following parts: Sect. 4.1 presents a discussion of the rationale for hardware design and a detailed description of the robot's physical and mechanical hardware components. CHARLIE'S basic components are detailed in Sect. 4.1.1 and a description of hardware features designed for safety and robustness is included in Sect. 4.1.2. The software developed for face and hand detection and tracking, interactive game design and data collection is presented in Sect. 4.2. Section 4.2.1 briefly describes the classifiers used for face and hand detection while Sect. 4.2.2 details the implementation of face tracking. Finally, discussion of the interactive game design in Sect. 4.2.3 and data collection in Sect. 4.2.4 are presented.

4.1 Robot Hardware

We carefully designed the outward appearance of the robot with the end-user in mind. Recent research has shown that robots with a simple interface are generally better received initially by children with autism, than robots with a more realistic, human-like appearance [21]. The implication is that low-tech robots, when designed appropriately for the particular needs of the autistic child(ren) they will serve and the context in which they will be used, can be used effectively to teach and promote social skills. In addition to the low cost mentioned above, CHARLIE'S physical design is intended to be toylike to create a friendly and approachable outward appearance and to more easily attract the attention of a child.

4.1.1 Basic Components

CHARLIE's hardware includes 6 servos, 3 pan-tilt platforms, an 8 channel servo controller, a consumer-grade web cam, and 2 D-cell battery packs. The robot's body is padded for safety, and its outer surfaces are covered with a bright green, fur-like material to achieve a non-threatening appearance. During active game play the child's attention is typically focused near CHARLIE's hands, so one LED is embedded in each of the hands to provide positive feedback during interactive games. A speaker is also included in the CHARLIE's body in order to provide optional auditory instructions for playing interactive games and positive feedback. Exclusive of the computing hardware, the retail cost of the robot's components is approximately 200 USD. In a production version of this robot, a computer could be integrated into the robot's body, or users could connect via USB to a standard laptop or desktop PC.

4.1.2 Features for Robustness and Safety

In general, children are curious about robots and many enjoy exploring the physical features of the robot as much as interacting with it. This can present hazards to both the child and to the robot's mechanical hardware. In order to minimize potential hazards and to improve the robustness of the robot, two characteristics were included in the robot's design. First, the body of the robot is secured to a platform that may be strapped to a desk or table. Immobilizing the robot in this way prevents the child from being able to pick up the robot and potentially harm him/herself, others in the room or the robot itself. Second, the arms and head of the robot are attached to the robot's body using snap fasteners so that excessive force will not cause damage to the servo motors, but will instead allow that piece to snap off (Fig. 2). Furthermore, allowing the arms and head of the robot to detach, affords the child more continuous free play since there will be less concern over the child's safety and the integrity of the robot's hardware. As described in the IROMEC study [10], while the adult must fulfill a more active role for promoting play skills with autistic children, "much of the literature on childhood play emphasizes the importance of free play and the need to interfere as little as possible in the child's actions, thus underscoring the creative aspects that in essence cannot be controlled or oriented." It is expected that longer, uninterrupted interactions will maximize the opportunity for each child to benefit from each session.

4.2 Robot Software

There is very little existing research using face detection or tracking with autism therapy [22] and of those studies, most use head or face tracking to determine the autistic child's focus of attention [23]. To our knowledge, there is no published research using hand detection for autism therapy. Hand and face detection is important because it enables the robot to detect physical cues from a child during interactions. Section 4.2.1 describes the methods used from the Open Source Computer Vision Library (OpenCV) [24], a cross-platform library for real-time computer vision applications, for the implementation of the face classifier and the training of the hand classifier. OpenCV provides a facility for object detection based on an extended set of Haar-like features [25]. Informally, this method works by

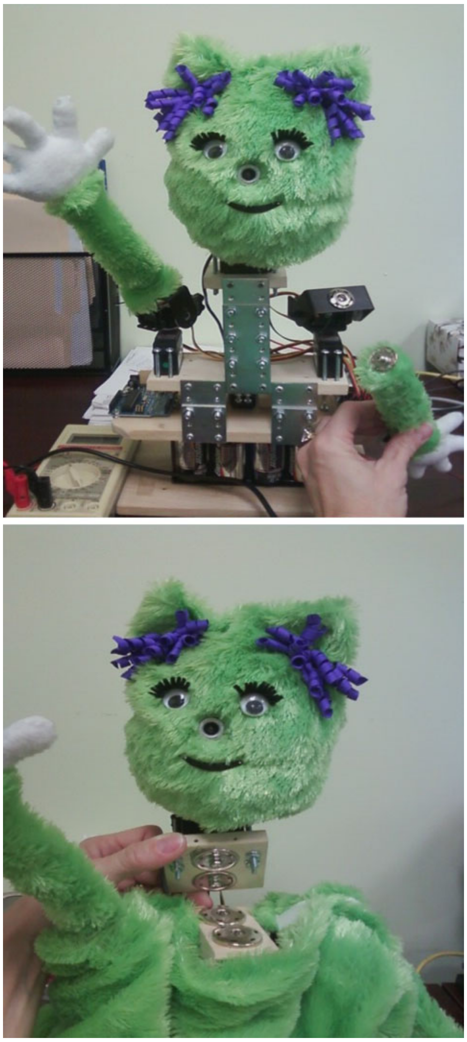

Fig. 2 (*Top*) Snap off arm. (*Bottom*) Snap off head

screening small portions of an image for visual characteristics of the target object. To train a classifier to identify a specific class of objects, OpenCV uses Adaptive Boosting (AdaBoost) [26] to create a cascade of boosted classifiers defined over these features. Section 4.2.2 details CAMSHIFT, a face tracking algorithm employed in conjunction with the OpenCV face detection to improve real-time performance of face tracking during child-robot interactions. Section 4.2.3 is a description of the original software developed for implementing the imitation games produced by this research.

4.2.1 Face and Hand Classifiers

The frontal face classifier we used for face detection (more specifically, a cascade of boosted classifiers working with Haar-like features) was provided by OpenCV. Haar-like features are used as an abstraction of RGB pixel values for object detection since image intensities are computationally expensive to work with. Each feature type is used to screen a given portion of an image for different characteristics of the target object. The extended sets of rectangular Haar-like features used for the face and hand detectors described in this paper are applied to assess whether a particular rectangular portion of a video frame contains a face or hand by summing the pixels contained within the rectangle and determining whether it matches the characteristics of the target object as defined by the classifier.

Whereas face detection is a well-studied problem [27, 28], and effective face classifiers are freely available through OpenCV, robust and real-time hand detection in diverse environments is a topic of continuing research. Numerous approaches for developing robust hand detectors have been explored [29, 30], but the resulting classifiers have not been made freely available to the research community. Further, some hand classifiers that are freely available such as the gesture letter "A" detector by Juan Wachs from the Ben Gurion University of the Negev, Israel and Washington Hospital Center [31], are too narrow in scope for use in this context and others are not accurate or efficient enough for our application. The process of classifying a hand in a given image, requires the definition of pixel patterns that are typically representative of the images used to train the classifier. In this way, a classifier identifies an object in a scene using the pixel patterns found in positive training images (with hands) to "classify" the object.

In order to implement a hand detector suitable for our purposes, we trained a new hand classifier to detect hands in various lighting conditions, rotations, scales and finger positions. For example, images were acquired from children aged 4 to 14 in order to adequately classify hands of varying sizes. Additionally, images were taken from various locations (offices, hallways, and rooms with natural ambient light) in order to account for expected variances in lighting conditions. Approximately 750 positive hand images of various size, color and position and approximately 3300 negative images were collected and cropped to a uniform pixel size of 40 × 40. Representative examples are shown in Fig. 3. To create additional positive training samples representing variations in lighting, rotation and scale, ten distortions were applied to 100 of those samples, yielding a total of approximately 1750 positive hand samples. We trained a twenty-stage cascade on these samples, yielding an error rate on the training set approaching zero. Section 5 presents a quantitative evaluation of the classifier performance. An illustration of the face and hand detection is included in Fig. 4.

4.2.2 Face Tracking

To make face tracking fast, efficient and appropriate for use in real-time tracking applications, we implemented

Fig. 3 Sample images used to train the hand detector. (*top*) Positive examples. (*bottom*) Negative examples

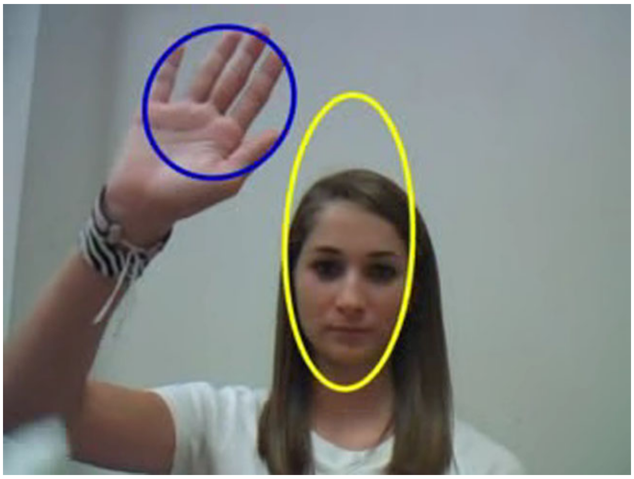

Fig. 4 Face and hand detection

a face tracking algorithm instead of repeating the computationally intensive detection process each frame. We implemented tracking using the Continuously Adaptive Mean Shift (CAMSHIFT) algorithm [32] to track detected faces.

CAMSHIFT incorporates the MEANSHIFT algorithm which is based on a nonparametric technique for climbing density gradients to find the peak of the probability distribution of the position of a given target object. For face tracking, this translates to identifying the center of the target color distribution in a given video frame. Once the face is detected by the classifier, the location of the detected face is used by CAMSHIFT to create a color histogram to represent the face and a face probability is computed for each pixel in successive video frames. With each frame that follows, the algorithm "shifts" the location of the face rectangle. This process is much faster than face detection since the algorithm uses a region of interest (or location) obtained a priori to determine where to begin scanning each successive frame for the face. To overcome occasional errors resulting from drift in the CAMSHIFT algorithm, the robot periodically repeats the full face detection process. In the event that the robot cannot detect the face, the robot head is reset to a neutral position and searches outward in an increasingly larger area.

4.2.3 Interactive Game Design

Two basic but essential skills used for learning effective communication are turn-taking and imitation [1]. The interactive games designed for this research are designed to help autistic children with impaired basic communication or social skills learn these essential skills. We have designed and implemented two interactive games to appeal to autistic children of a wider range of ability and skill. The original game we developed is a single-player game which engages a child in a game called "Imitate Me, Imitate You". In this game, the child may either initiate a pose for the robot to imitate ("Imitate Me") or the child may follow the robot's pose ("Imitate You"). The single-player game is intended for the autistic child who is comfortable interacting with an autonomous robot but who may not be ready for turn-taking with another child.

Single-player "Imitate Me, Imitate You" The "Imitate Me, Imitate You" game is detailed in Fig. 5 and consists of two primary modes: passive and active. Within each of the two modes, there are five poses: neutral (both hands down), left

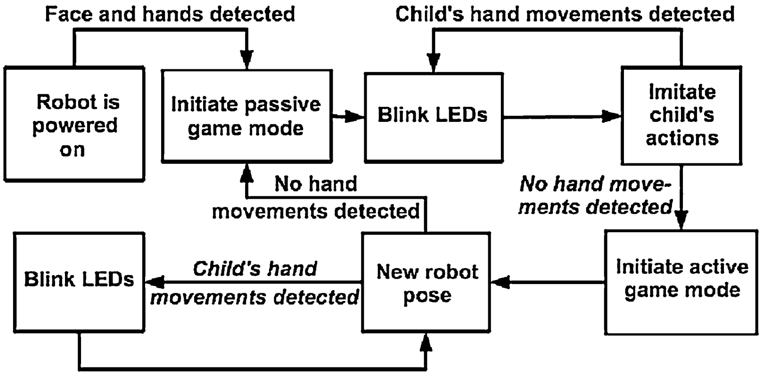

Fig. 5 State diagram for CHARLIE's "Imitate Me, Imitate You" autonomous interactive game

Fig. 6 CHARLIE poses. From *left* to *right* : Left hand high. Right hand high. Both hands high. Neutral. Peek-a-boo

hand raised, right hand raised, both hands raised and peek-a-boo, as shown in Fig. 6. In order to give the child initial control over the robot's actions, the default robot state is the passive game mode. Once the robot detects and begins tracking the child's face and hands, the robot indicates that it is ready to interact by moving to the neutral pose and blinking the LEDs in its hands three times. The robot then immediately enters the passive game mode and waits for the child to initiate a game by raising one or both hands. As the child's hand movements are detected, the robot responds by imitating the child's hand positions and lighting the LED in the corresponding hand while simultaneously detecting any additional hand movements. If ten seconds elapse without any detected hand movement, the robot will transition to the active game mode.

During the active game mode, the robot initiates a new game and attempts to engage the child by raising or lowering one or both arms, or beginning a game of peek-a-boo. Each pose assumed by the robot in the active game state is selected randomly in order to avoid repetitive patterns of poses. When a positive outcome is detected (the child successfully imitates the robot's pose), positive sensory feedback is generated by the robot. A positive sensory response entails the robot lighting a small LED in the hand corresponding to the raised hand or hands of the imitated pose. As with the passive game mode, the robot will wait ten seconds for the child's response. If ten seconds elapse and a positive response has not been detected, the robot will transition back to the passive game mode, waiting again for the child to initiate a new game.

Two-player "Pass the Pose" The second interactive game we created is a two-player game described in Fig. 7 called "Pass the Pose". In this game, two players interact directly with the robot and indirectly with one another. With the optional sound enabled, the "Pass the Pose" game works as follows: Game play begins with CHARLIE describing how to play "Pass the Pose" and asking the first player (seated to the right of the robot) to assume a pose. Once she has detected the pose, CHARLIE indicates that she has learned the pose by saying "Ok, I got it. Now let me try", turns to the second player (seated to the left of the robot), asks the child if he/she can follow her and then assumes the same pose learned from the first player. If the second player successfully imitates the pose assumed by CHARLIE, she responds by saying "You got it!", claps her hands and giggles. If the player does not immediately imitate the correct pose, CHARLIE will ask the child to try again. If the child does not correctly assume the pose after three tries, the robot asks the current player to initiate a new pose and the game continues, this time with the second player initially "passing" the pose to the robot.

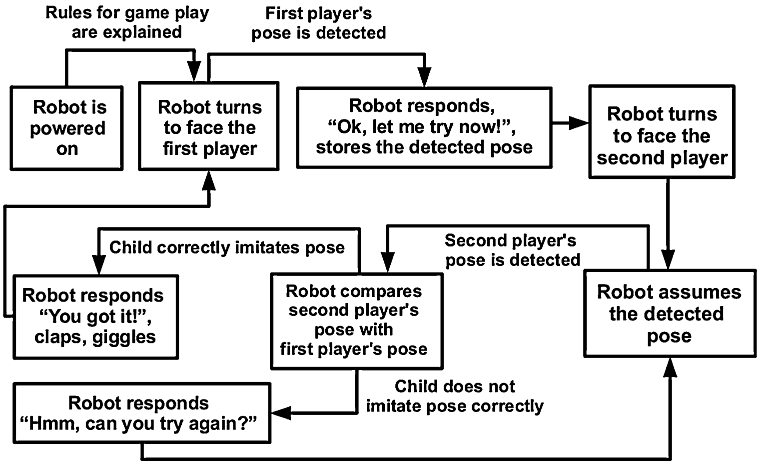

Fig. 7 State diagram for CHARLIE's "Pass the Pose" autonomous interactive game

If the sound is disabled, we expect that the teacher, therapist or parent will describe how to play the "Pass the Pose" game. Next, CHARLIE turns to the first player and waits for the child to assume a pose. Once CHARLIE has detected the pose, she turns to the second player and assumes the same pose. If the child correctly imitates the pose, CHARLIE claps her hands and waits for the second player to initiate the next pose. If the second player does not correctly imitate the pose, CHARLIE lowers her head and shakes it slowly from side to side. Should the child fail to imitate the pose correctly after three tries, CHARLIE resumes a neutral position and waits for the second player to start a new game. This two player game is ultimately designed to promote shared attention and cooperative play. We anticipate that the "Pass the Pose" game will be most useful for children who have already demonstrated some level of proficiency with turn-taking and imitation and who are able to play a game with a simple set of rules.

Teleoperation In addition to the two autonomous games, we developed and implemented software that allows for the robot to be teleoperated so that when a button is pushed on the remote, the player is given complete control over CHARLIE's limbs and head. While each of the four push buttons on the remote correspond to specific pre-programmed poses, the two joystick buttons provide continuous control for the movement of each arm and a single directional button allows for continuous control of the head. This game play is expected to be useful for the autistic child who may be initially wary or hesitant to interact with the robot. By temporarily disabling the robot's autonomous actions, the child is given the freedom to learn about CHARLIE's various capabilities at his or her own pace.

4.2.4 Data Collection

There are two distinct kinds of user interaction information collected by the robot. Information pertaining to the user's overall progress such as (1) the total length of active engagement (time spent actively engaging in either passive or active mode), (2) number of child-led actions and (3) the number of successful interactions is continuously captured during each session. At the end of the session, this information is used to create a user progress report for analysis and for future sessions with the same child. The second type of user information, such as the length of the intervals between interactions, is used for controlling the robot state.

5 Experiments

As a proof of concept for CHARLIE's effectiveness, preliminary tests were conducted using the single-player game with a small group of typically developing children. See Fig. 8. A relatively large age range (4–11 years) was selected to test the reaction times of the robot when used with children of varying levels of ability. Each child participated in an 8–10 minute session, in which both game modes (passive and active) were tested and the accuracy of the hand and face detectors was measured. The duration of each game mode was recorded to ensure that adequate time is given for the child to respond before a transition is made to the alternate game mode and the effectiveness of the positive sensory feedback (LEDs in hands indicating successful detection) was assessed (Table 1).

We conducted experiments to measure the speed and accuracy of the face and hand detector and to assess the appropriateness of CHARLIE's timed responses during game play. The accuracy of the face detector and tracker was determined by calculating the ratio of successful face detection time to the total session time. The face detector averaged an accuracy of 86% across all sessions and users. This accuracy rate is artificially low because it includes as misses the aggregate time when participants moved outside of the video frame. The accuracy of the hand detector and tracker was calculated similarly. In a typical session, users averaged 33

Fig. 8 Children Interacting with CHARLIE.

child-initiated hand movements and imitated 16 robot movements per minute. The hand detector accurately detected the child's hands an average of 92% of the total session time, with 244 hits out of 265 total hand events.

Nearly all of the children expressed a preference for the passive game mode, where the robot imitates the child's hand actions, and their comments were supported by the significantly greater amount of time each of those children spent in the passive mode compared to the active mode during their respective sessions. Our hypothesis is that autistic children interacting with CHARLIE may also prefer the passive game mode, since this affords the child the greatest amount of control over the robot. We consider these preliminary results as an important proof-of-concept in preparation for controlled tests with autistic children.

6 Future Work and Conclusions

This research resulted in the design and development of a low-cost, adaptive robot and a dual-mode interactive game for use in robot-assisted autism therapy. One of the aims of this research was to create a robot that is financially accessible to a greater population of therapists and families with autistic children in order to broaden the impact of traditional therapies. The second objective was to develop a hand detector enabling a larger scope of interactive games in which the robot can engage autonomously. Achieving this second objective also allows for real-time collection of important user interaction information specific to the preference and

Table 1 Data collected from an interactive session with CHARLIE

Participant	Child1	Child2	Child3	Child4	Average
Age (years)	8	8	4	11	7.75
Interaction time	152 s	198 s	156 s	144 s	162 s
Lost face time	22 s	30 s	36 s	18 s	26 s
Face detection hit rate	**87.0%**	**87.0%**	**81.0%**	**89.0%**	**86.0%**
Passive time	30 s (19.7%)	124 s (62.6%)	89 s (57.0%)	118 s (82.0%)	90 s
Active time	122 s (80.3%)	74 s (37.4%)	67 s (43.0%)	26 s (18.0%)	72 s
Actual passive hand actions	29	48	37	84	50
Passive hand detections	24	41	35	81	45
Passive hand hits	**83.0%**	**85.0%**	**95.0%**	**96.0%**	**90.0%**
Actual active hand actions	19	39	4	5	17
Active hand detections	17	38	4	4	16
Active hand hits	**89.0%**	**97.0%**	**100.0%**	**80.0%**	**92.0%**
Response to appearance	“She's so adorable, funny”	“Fuzzy, furry and cute. I want to take her home”	“I like her fur”	“Looks like a friendly monster”	

progress of each child undergoing autism therapy. Collectively, these contributions produce a new robot which is designed to be child-centered, adaptive to user preference, and to fulfill a key supportive role for therapists by automatically generating user progress reports.

Work on the hand classifier is ongoing in order to produce a more robust hand detector that can recover quickly from erroneous hand detections with improved accuracy. To further improve the accuracy of hand and face detection and to explore the remote detection of user stress levels, we are researching the use of infrared sensing to collect physiological information using a prototype similar to the one used for this research. Additionally, we are currently exploring the use of a high precision infrared sensor capable of measuring very small changes in the temperature of the skin near the nose and mouth in order to obtain data about a user's breathing frequency and the duration of individual breaths. Since breathing is strongly correlated to heart rate, it is expected that this information can be used to effectively detect the general stress state of an individual user.

Field tests for a population of autistic children have been designed and are planned for 2011. Future testing will explore the role of the robot as a mediator, suitable interactive distances between the child and the robot, and patterns of child-robot and child-child interactions as a result of engaging in the interactive games. Discussions with clinicians currently working with autistic children from the South Carolina Department of Disabilities and Special Needs and the South Carolina Autism Treatment Network most recently resulted in the recommendation that young autistic children undergoing early intervention, Applied Behavioral Analysis (ABA) would be good candidates for interacting with CHARLIE. A cornerstone of ABA relies on the assessment and documentation of interventions to ensure their efficacy and to promote progress from one session and from one therapist to the next. In addition, they recommended that two physically distinct robot prototypes be tested. To complement the "soft and fuzzy" appearance of CHARLIE, we are designing a robot with a more mechanical, "robotic" outward appearance in order to appeal to a broader scope of children. Ultimately, we will consider four general elements for evaluating CHARLIE's design: (1) child's response to CHARLIE's physical appearance, (2) improved eye contact with co-present others, (3) overall increased child-led interactions (measured during game play) and, (4) overall effect on verbal and nonverbal communication.

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References

1. Nehaniv C (2007) Synchrony and turn-taking as communicative mechanisms. In: Dautenhahn K, Nehaniv C (eds) Imitation and social learning in robots, humans and animals. Springer, Berlin
2. Barakova EI, Brok JCJ (2010) Engaging autistic children in imitation and turn-taking games with multiagent system of interactive lighting blocks. In: Proceedings of the 9th international conference on entertainment computing, pp 115–126
3. Dautenhahn K (1999) Robots as social actors: Aurora and the case of autism. In: Proc cognitive technology conference, pp 359–374
4. Welch KC, Lahiri U, Warren Z, Sarkar N (2010) An approach to the design of socially acceptable robots for children with autism spectrum disorders. Int J Soc Robot 391–403
5. Goldstein H, Thiemann KS (2001) Social stories, written text cues, and video feedback: effects on social communication of children with autism. J Appl Behav Anal 34:425–446
6. Dautenhahn K (2000) Design issues on interactive environments for children with autism. In: Proceedings international conference on disability, virtual reality and associated technologies, pp 153–161
7. Boccanfuso L, O'Kane JM (2010) Adaptive robot design with hand and face tracking for use in autism therapy. In: Proceedings of the second international conference on social robotics, ICSR'10. Springer, Berlin, Heidelberg, pp 265–274
8. (2009) Prevalence of autism spectrum disorders, autism and developmental disabilities monitoring network, United States, 2006. Surveill Summ 58(10)
9. Shimabukuro TT, Grosse SD, Rice C (2008) Medical expenditures for children with an autism spectrum disorder in a privately insured population. J Autism Dev Disord 38(3):546–552
10. Caprino F, Besio S, Laudanna E (2010) Using robots in education and therapy sessions for children with disabilities: guidelines for teachers and rehabilitation professionals. In: Computers helping people with special needs, vol 6179, pp 511–518
11. Marti P, Pollini A, Rullo A, Shibata T (2005) Engaging with artificial pets. In: Proc conference on European association of cognitive ergonomics, pp 99–106
12. Lusher D, Castiello U, Pierno AC, Maria M (2008) Robotic movement elicits visuomotor priming in children with autism. Neuropsychologia 46:448–454
13. Duquette A, Mercier H, Michaud F (2006) Investigating the use of a mobile robotic toy as an imitation agent for children with autism. In: International conference on epigenetic robotics
14. Dautenhahn K, Werry I (2000) Issues of robot-human interaction dynamics in the rehabilitation of children with autism. In: Proc international conference on the simulation of adaptive behavior, pp 519–528
15. Robins B, Dautenhahn K, Dickerson P (2009) From isolation to communication: a case study evaluation of robot assisted play for children with autism with a minimally expressive humanoid robot. In: Proc international conference on advances in computer-human interactions.
16. Kozima H, Nakagawa C, Yasuda Y (2007) Children-robot interaction: a pilot study in autism therapy. Prog Brain Res 164:385–400
17. Kozima H, Michalowski M, Nakagawa C (2009) Keepon. Int J Soc Robot 1:3–18
18. Tapus A, Tapus C, Matarić MJ (2008) User-robot personality matching and assistive robot behavior adaptation for post-stroke rehabilitation therapy. Intell Serv Rob J (April):169–183
19. Patrizia M, Claudio M, Leonardo G, Alessandro P (2009) A robotic toy for children with special needs: from requirements to design. In: Proc IEEE international conference on rehabilitation robotics, pp 918–923
20. Ferrari E, Robins B, Dautenhahn K (2009) Therapeutic and educational objectives in robot assisted play for children with autism.

In: Proc IEEE international symposium on robot and human interactive communication

21. Robins B, Dautenhahn K, Boekhorst R, Billard A (2004) Robots as assistive technology—does appearance matter. In: Proc IEEE international workshop on robot and human interactive communication, pp 277–282
22. Harrington K, Fu Q, Lu W, Fischer G, Su H, Dickstein-Fischer H (2010) Cable-driven elastic parallel humanoid head with face tracking for autism spectrum disorder interventions. In: Proceedings of IEEE engineering in biology and medicine conference, Buenos Aires, Argentina
23. Prigent A, Estraillier P, DaSilva MP, Courboulay V (2009) Fast, low resource, head detection and tracking for interactive applications. Psychol J 7:243–264
24. Bradski G (2000) The OpenCV library. Dr. Dobb's J Softw Tools (November):120–126
25. Lienhart R, Maydt J (2002) An extended set of Haar-like features for rapid object detection. In: Proc IEEE international conference on image processing, pp 900–903
26. Schapire RE (2003) The boosting approach to machine learning: An overview. In: Denison DD, Hansen MH, Holmes C, Mallick B, Yu B (eds) Nonlinear estimation and classification. Springer, Berlin
27. Viola P, Jones M (2001) Rapid object detection using a boosted cascade of simple features. In: Proc IEEE computer society conference on computer vision and pattern recognition, vol 1, pp 511–518
28. Viola P, Jones M (2004) Robust real-time face detection. Int J Comput Vis 57(2):137–154
29. Dadgostar F, Barczak ALC (2005) Real-time hand tracking using a set of co-operative classifiers based on Haar-like features. Res Lett Inf Math Sci 7:29–42
30. Huttenlocher D, Zisserman A, Buehler P, Everingham M (2008) Long term arm and hand tracking for continuous sign language tv broadcasts. In: British machine vision conference
31. Wachs J (2011) Enhanced human computer interface through webcam image processing library—aGest.xml, March 2011
32. Bradski GR (1998) Computer vision face tracking for use in a perceptual user interface. Interface 2(2):12–21

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