Assistive Technologies and Child-Robot Interaction

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Abstract

Mobile robots are machines that can move and act in the real world, making it possible to generate a multitude of interplay situations, which can engage children and encourage interaction in a variety of different ways. Mobility, appearance, interaction modalities (e.g., sound, light, moving parts) and behaviour (predetermined and adaptive) can all have an influence in sustaining the interest (and therefore learning) of typically developing children or children with specific deficits such as autism. This paper summarizes findings from two of our on-going projects, one using a spherical mobile robot and the other using a humanoid-like robot toy.

Introduction

Mobile robotic technology has the ability to become a useful tool to both study and contribute to child development and rehabilitation. In this paper, we present our latest work in two of our projects in this area: adapting the robot's behavior based on perceived interaction using proprioceptive sensors, and studying if a mobile robot can, by being predictable, attractive and simple, facilitate reciprocal interaction such as imitation. These projects started with robotic objectives but revealed to be rich sources of interesting problems to resolve that involved interdisciplinary collaborations.

Behavioral Adaptation Using Proprioceptive Perception

Adapting the robot's behavioral reactions according to children's responses will create and sustain more meaningful and broader range of interactions. However, natural communication or interaction with robots can be somewhat of an arduous task. While video and audio are typically used for communication and interaction between humans and robots, other sensors such as contact, infrared, proprioceptive and temperature sensors can provide additional means of communication related to touch (Kerpa, Weiss, & Worn 2003; Miyashita *et al.* 2005). We believe that touch can be indirectly captured through proprioceptive sensors on-board the robot, usually exploited for its guidance and control. By looking at sensory data patterns coming from these sensors, our objective is to identify the types of interaction the robot is experiencing both with people, and the environment, and ultimately use this information for achieving behavioral adaptation.

Our experiment consisted of using Roball (Michaud & Caron 2002; Michaud *et al.* 2005), a spherical robot shown in Figure 1, to study how sensory data patterns could be used to characterize the interactions experienced by the robot. Roball is a robot that is well suited to interactions with children. Its spherical shape makes for a variety of interesting play situations with children. The safe and simple design of Roball also makes it very suitable for interacting with children that have cognitive difficulties, such as children with Autism. Roball's proprioceptive sensors consist of three accelerometers, one for each axis (X, Y and Z), and three tilt sensors, one for left tilt, one for right and one for forward/backward tilt. The configuration of the tilt sensors allows the detection of either left or right tilt with both sensors giving the same value, and also allows detection of rotation with readings from the sensors giving opposite left/right tilt values due to centrifugal acceleration.

This study involved different sets of trials. Trials were conducted both and without children. The function of the robot during all of the trials with children was to act as a moving toy and to engage the child and encourage interaction.

We first conducted a set of trials which involved a series of laboratory experiments without children, followed by a second series of trials held at both a playgroup and a school setting. The laboratory experiments were used to investigate whether measurements from these two different types of proprioceptive sensors could record things such as jolts to the robot, the robot receiving general interaction, the robot being carried or the robot being spun. Trials in a playgroup and school setting were used to confirm laboratory sensor readings were also found in real life environments. These trials showed that it is possible to detect different en-

Figure 1: Roball.

vironmental conditions through the analysis of proprioceptive sensors (accelerometers and tilt) (Salter *et al.* 2005).

More specifically, the accelerometer and tilt readings can be classified into zones which detect four different modes of interaction: *Alone*, *General Interaction*, *Carrying* and *Spinning*. A fifth condition, named: *No Condition*, is necessary for situations that can not be classified. We then developed an algorithm based on the five heuristic rules derived from this analysis (Salter, Michaud, & Letourneau 2006). The algorithm uses the following five rules:

- A) If the average difference between the X and Z accelerometers readings is above 0.05, set current condition to 'ALONE'.
- B) If the average difference between the X and Z accelerometers readings is below 0.03 and above zero, set current condition to 'GENERAL INTERACTION'.
- C) If the average difference between the X and Z accelerometers readings is negative, set current condition to 'CARRYING'.
- D) If the tilt sensors show different readings, set condition to 'SPINNING'. Another way to detect spinning is if the average reading for the Z axis is positive and coupled with an average Y axis reading of above 0.05.
- E) If the sensor readings do not fall into one of the above categories, set the condition to 'NO CONDITION'.

The algorithm uses a temporal window of 4 seconds to calculate an average of the sensor readings and thus derive which condition it believes the robot is currently experiencing. This window is moved forward in time by 0.10 sec increments.

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A third set of trials, without children, (3 per each mode of interaction, lasting 4 minutes each) was conducted at the laboratory to test the algorithms ability to detect the four different modes of interaction: 1) the robot is alone; 2) the experimenter stimulates general interaction;3) the experimenter carries the robot; 4) the experimenter spins the robot.

This resulted in 2360 interaction classifications per experiment, with the objective of maximizing valid identification and minimizing false detection. Roball was able to identify *Alone* (97%), *Carrying* (92%) and *Spinning* (77%) with reasonable accuracy. However, identifying *General Interaction* (10%) was more difficult. The probable causes for this are that firstly at times the robot is in fact spinning or alone during the Interactions trials. Such conditions would therefore beidentified under the corresponding categories, (D) 45% and (A) 19%of the time. Therefore, adding the results for conditions A, B and D, a total of 74% classifications that were correctly identified by the algorithm during the General Interaction experiment. Also, the experimenter's simulation of general interaction that would be made by children was fairly vigorous.

Following on from developing the algorithm, we used the algorithm to create an adaptive controller for the robot. In total three adaptive behaviors were added to the robot: two behaviors involved vocals and one behavior involved motion coupled with vocals.

1. When the robot classifies its sensor readings as SPINNING the robot produces the sound: 'Weeeeeee'.
2. When the robot classifies its sensor readings as CARRYING it stops all motion and says 'Put me down'.
3. When the robot classifies its sensor readings as ALONE it says 'Play with me'.

We then experimented with the adaptive controller implemented on-board Roball with children in real life settings to test the effects of adaptation. During its interactions with the children, the robot did for the most part respond appropriately. For example when the children spun the robot, it produced the sound 'Weeeeeee'. The other notable difference from this study and all those preceding it was that there was an increased level of interest and engagement from the children, based on the experimenter's observations. It was noticed at times that the robot did not react correctly, in particular the robot often thought it was being carried when it hit the wall of the pen, causing the robot to stop and say 'put me down'. Interestingly, as a side effect, this seemed to cause an even higher level of engagement and interaction from the children. For example, the child might look at the experimenter and say "its asking me to put it down" and then proceed to aid the robot by moving it so that it could progress on its way. We are currently trying to investigate the cause of these incorrect reactions, whether it is because of a hardware failure, environmental configuration (e.g., when the robot hits a wall, it records the same readings as being carried), adapted responses of the robot (e.g., creating an interaction pattern from its autonomous actions), a change in the way children interacted with Roball, or the inability of the algorithm to identify the correct interaction type.

Overall, the response of the children was very encouraging. The study shows that, in principle, it is possible to adapt the behavior of a robot using sensor readings. Importantly, the more complex behavior of the robot appeared to increase the level of engagement of the children. This is important because children rapidly become bored of simple robots. This could be particularly pertinent when robots are used in a therapy context.

Learning to Imitate Using a Robot

Unpredictability and complexity of social interactions are important challenges for a low functioning autistic child.

Since 1999, we conducted a series of experiments involving mobile robotic toys and autistic children [7]. Tito was designed to study if and how a mobile robot can, by being predictable, attractive and simple, facilitate reciprocal interaction such as imitation with autistic children.

Five years old children diagnosed with low-function autism are in many ways comparable to 8-9 months old children of regular development. They will often present the same sensory interests. However, children with autism usually have sensory play patterns that are more repetitive (Blanc *et al.* 2002), their imitation is selective and is used with an aim of increasing the stimuli (Lemay 2004). They also present unexploited abilities (e.g., attribute intentions to the imitator; plan and induce imitative behaviors and understand incitation to imitate) (Nadel 2002) and deficits in sharing attention (avoiding eye contact, lack of smiling) and conventions (poor imitation of facial expressions and gestures) for communicating common interests (Lemay 2004). Also noted is the quasi-absence of verbal language and pretend play. (Blanc *et al.* 2002). These deficits are explained by a difficulty in perceiving and processing stimuli from their environment, affecting comprehension of social signals (gestures, words and intentions of others). (Zilbovicius 2004).

Thus, low-functioning autistic children need interventions which take into account their particular interests and their decoding deficits by a predictable and simple medium, able to catch their attention. Mobile robots show potential in this regard and because they can be designed in accordance with particular interests and decoding deficits of children with autism. They generate more interest and a wide variety of interplay situations compared to static objects, and bring into play social interactions skills (visual contact, imitation) (Michaud *et al.* 2007; Michaud, Duquette, & Nadeau 2003; Robins *et al.* 2004).

Our motivating research hypothesis is to verify that an animated object, by being predictable and less complex than interacting with humans, would make an autistic child demonstrate reciprocal communication, observed by: 1) the reduction of avoidance mechanisms, namely repetitive and stereotyped plays with inanimate objects; 2) the increase in shared attention and shared conventions; and 3) the manifestation of symbolic mode of communication like verbal language.

Methodology

We conducted an exploratory study following a single case protocol (Kazdin 1976) (22 exposures, 5 min cases, 3 times/week over 7 weeks). We evaluated shared attention and shared conventions with four 5 years old low-functioning autistic children (3 boys and 1 girl) selected at the Centre de réadaptation le Florès of Laurentides, Québec, Canada.

Our experimental procedure consisted in having a group of children interact with a robotized mobile mediator (animated object with human-like appearance), and another group interact with a human mediator. The two mediators executed the same imitation plays involving facial expressions (joy, sadness, angry), body movements (raise the arms. dance, move forward or backward), familiar actions with objects (to point and to give a hat, to point the door, to point the mediators picture) or without objects (wave hello or bye-bye, play peek-a-boo). For familiar actions, the mediator executed the actions and names it out loud using simple words.

Based on the deficits of low-functioning autistic children and of their shared interests with 8-9 months old regular development children, we elaborated twenty activity sessions following the same general scenario, i.e.:

- Before entering the experimental room (a square room), the educator explains to the child that a play period is planned by showing a picture of the mediator. This picture is either put on the door or on the wall inside the room, depending on the activity session. The child enters the room, and 12 seconds later the educator directs the child to the chair placed at the center. The childs favorite toy is placed at its feet. The educator then sits on the other chair placed near the door. A panel is placed in the room so that the mediator can hide behind it.
- Execute an activity session. Each activity session involves the three levels of imitation (facial expressions, body movements or familiar actions). They are organized to facilitate the childs familiarization with the mediators action. The activity sessions are composed of imitative plays during which the mediator ask the child to imitate it while, for instance, expressing happiness or anger, smiling, saying hello, moving both arms, moving forward or backward, pointing an object, etc.
- At the end of each session, the mediator points the door and says “Door” to indicate to the child that the activity is ending. The mediator then waves and says “Bye bye”, and goes behind the panel. When the educator goes toward the child to leave the room, the robot exists from behind the panel, waves and says “Bye bye”, and again goes back behind the panel.

In all of the activities, if the child imitates correctly the mediators activity, the mediator smiles and raises both its arms and say “Happy!”.

The robot mediator designed for this experimental procedure, named Tito, is shown in Figure 2. Tito is approximately 60 cm tall and is colored red, yellow, and blue. Its clothes are washable and made of soft material. It uses wheels to move, but its structure shows two feet and two legs. Tito has two arms that can move up and down rapidly, a head that can rotate (to indicate ‘no’) and rise up (to express surprise), a mouth (for smiling), two eyes, a nose and hair (made from fiber optic cable to illuminate). Also, a small wireless microphone-camera device was installed in one eye of the robot. Different parts of Tito’s body can be illuminated. and it is able to sense if it is being shaken or if it has flipped over. Tito generates vocal requests through prerecorded messages. A wireless remote control (using a video

Figure 2: Tito.

game controller) was designed for teleoperation, and an onboard microcontroller enables pre-programmed sequences of behaviors (motion and vocal messages). Examples of pre-programmed behaviors are: moving the left arm while saying goodbye, expressing happiness by moving its arms, singing and rotating on the spot, or shaking its head to indicate no. Tito records and stores internally the timing between the interactions of the child (from sensory data and according to the experimental scenarios). Tito also emits a sound when it starts the execution of an experimental scenario, allowing synchronization of video data recorded with an external camera. The activation button on Tito is hidden at the bottom of the robot so that the child is not tempted to play with it.

Results

Three variables were observed in our trials: shared attention (visual contact / eye gaze directed toward the mediator for more than 3 sec; physical proximity; imitation of facial expression or gesture, but not directed toward the mediator); shared conventions (facial expression, gesture, actions and words, all directed toward the mediator); absence of sharing (no visual contact, leave the communication area, avoid the mediator, sensorimotor play, mannerisms, ritual, aggression). These variables were coded over 12 sec windowing, by two coders (98% fidelity) analyzing video footage of the trials (Camaioni & Aureli 2002).

Results (Duquette 2005; Duquette, Michaud, & Mercier 2007) show that the forms of shared conventions such as imitation of body movements and of familiar actions are higher with the two children paired with the human. This may be explained by the children diagnosed with low-functioning autism having more difficulty in understanding the communication intent from the limited motion capabilities of the robot. It is possible that a robot having arms that have higher degrees of freedom may have helped with this understanding. Imitation of words only appeared for one participant, who was paired with the human mediator. We can however report that the two children paired with the robot demonstrated:

- More frequent shared attention by having more visual contact and proximity compared to the children paired with the human mediator. This confirms the hypothesis that shared attention is facilitated by the appealing characteristics and predictability of the robot. In fact, when the robot expressed emotions of joy and sadness or made simple actions, the autistic children reacted to the voice intonation. They also reacted to the lights that represented emotions and the simple slow motion of the robot, by looking and moving towards the robot. Tito was designed to facilitate decoding of these interaction cues by the autistic children.
- Reduced repetitive plays with inanimate objects of interest (their favorite toy), and no repetitive or stereotyped behavior toward the robot. These reduced behaviors can be explained by the interest children have for the sensory properties of the robot (movements, colors, lights). Their attention is focused on the robot rather than on the inanimate object.
- More imitation of facial expression of joy (smiling). The results are possibly explained by the ease of understanding the expression of the robot (illuminated smile). Emergent interactions were noted with the pre-verbal autistic child and the robot through imitation of gestures (handing back the hat, pointing at the door, waving good bye). There was also imitation of motor noises at the same rhythm as the robot (more specifically when the robot was waving when saluting). Furthermore, the child reproduced the same posture as the robot (e.g., by kneeling).

Further study of the video footage of the trials revealed that the robot appears to be an interesting way in helping children initiate contact, something that typically developing children can do when meeting strangers. The children that were paired with the robot first created a distance with the robot, allowing them to initiate interactions such as eye contact and smiles. Then, the children moved closer to the robot, enabling them to continue interacting with the robot. Despite at times the children displaying ritual behavior and at times also leaving the communication area, which can be associated to an avoidance behavior, they did so as part of a familiarization process as described by Ricard and Gouin-Decarie (Ricard & Gouin-Decarie 1990). This pattern was not observed with the children paired to the human mediator, nor did we see behavior associated with a familiarization process.

Finally, another interesting observation is that children eventually made the discovery that Tito was teleoperated, which generated enthusiastic interactions between the child and the experimenter. This concurs with Robins et al.'s (Robins *et al.* 2004) observation that a robotic device reveals to be an interesting intermediate between the child and an educator.

In conclusion, this study helps us to understand the processes for decreasing autistic children anguish and increasing their attention to learn certain forms of communication. Our results are very encouraging and support the continuation of work on this research question, repeating the trials with a greater number of subjects and consolidate these conclusions.

Conclusion

Mobile robots as assistive technologies are a rich source of novelty in creating interplay and learning situations, allowing implicit or explicit adaptation to children and the environment, helping keep children engaged. Findings from these experiments confirm the engaging factor mobile robots generate with children, leading us to prepare more experiments in natural living environments. We plan to measure the predominant factors required to sustain interest, and to compare observations of normally developing children and children with autism.

At the same time, conducting trials with children and mobile robots is highly challenging, with a great set of factors (hardware, software, human, environmental) influencing the process and results. Robot design and conducting rigorous experimentations with people are two very demanding tasks, critical in making solid scientific contributions with concrete benefits. For efficient and fulfilling efforts in doing such work, it is important to start small and increase the complexity of the experiments (e.g., test population size, robot's capabilities, experimental methodology).

For our future work, to enhance the interaction modalities between the robot and the children, we are also developing a robotic arm using variable impedance actuators, capable of safely interacting with children, and an embedded sound source localization and separation device for real-time tracking of vocal interaction.

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