A Preliminary Investigation into the effects of Adaptation in Child-Robot Interaction

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Abstract

The work described in this paper investigates the potential effects of a robot exhibiting an adaptive behaviour to a child's interaction. In our laboratory we develop robotic devices for a diverse range of children that differ in age, gender and ability, which includes children that are diagnosed with cognitive difficulties such as autism. All children vary in their personalities and styles of interaction. Therefore, it would follow that adaptation could bring many benefits. In this abstract we examine a series of trials which investigate the effects of a fully autonomous rolling robot exhibiting adaptation (through changes in motion and sound) compared to it exhibiting pre-programmed behaviours. We investigate sensor readings from on-board the robot that keep a record of the level of 'interaction' that the robot received from a child and also we discuss the results from analysing video footage looking at the social aspect of the trial. We discovered surprising benefits to having adaptation on-board Roball.

Figure 1: Roball, an autonomous rolling robot.

1 Introduction

Increasingly, researchers are looking at the domain of Child-Robot Interaction (CRI). There is great potential for robotic devices when being applied with children, from play to assistive applications. There are now many robotic devices aimed at children that are meant for entertainment, but also there are robotic devices aimed at the more serious world of child development [2, 1, 6, 5]. When developing a system that is meant for interaction with children, it is important that the device can amongst other things i) gain the interest of individual children, ii) sustain this interest and iii) achieve this in the child's own natural environment (i.e., in the wild).

It would seem that a shortcoming of many devices aimed at children such as conventional toys is that they do not change to aid a specific child. Traditional toys are often developed to encompass the largest range of children possible. One of our main aims for developing adaptation has been the vast array of end users that our robots can come into contact with. This includes children from as young as 10 months old to young adults at high school. Also, we work with children that are typically developing and children that have special needs such as autism. Whether you are looking within age groups or categories (e.g., typically developing, special needs, autism), children all have very different 'personality' traits e.g. shy, boisterous, cautious, outgoing. It is easy to realise that a robot that exhibits only one type of behaviour will not be suitable for all children.

Our research aims to develop a robot that can 'fit' its behaviour to the individual child it is interacting with. We hope to change the robot's behaviour to adapt to different play styles such as, boisterous or shy. For example, we are working on adapting the robot's behaviour so that it will not overwhelm an anxious child, and also not bore a confident child. We are developing robotic behaviours that we believe to be encouraging in its manner to make it more appealing and less daunting for an anxious child. We are developing behaviours that are faster and more exciting for a more confident child.

We have developed an adaptation algorithm, based on the readings coming from sensors on-board Roball, (shown in Figure 1) a fully autonomous rolling robot. We use touch or contact as our metric to recognise interaction and thus enable adaptation. In this paper, we report on a series of trials that were conducted to test the potential of the adaptive behaviour we have developed. We investigate whether the adaptive behaviour would *gain* and *sustain* the interest of five individual children. The same children also interacted with Roball when it was exhibiting a very simple basic pre-programmed behaviour and also a behaviour that was more complex but nevertheless pre-programmed. We compare and analyse the results from the three separate sessions that were conducted with each of the five children. We investigated both data from on-board sensor readings and video footage of the trials.

2 Roball - The Robot

Roball is 6 inches in diameter and weighs about 4 pounds [4, 3]. It consists of a plastic sphere (a hamster exercise ball) constructed from two halves that are attached to each other. The plastic sphere is used to house the fragile electronics (sensors, actuators, processing elements), thus making it robust and ideal for interaction with children. The fact that Roball is spherical encourages a wide range of play situations. Roball is programmed to execute two simple behaviors as standard: wandering and obstacle avoidance. These behaviors are carried out for the duration of each trial. There is also has the ability to adjust its own motion or play sounds such as, vocal messages or music. Roball's function is to act as a mobile, moving toy.

2.1 Distinguishing a child's interaction

Our work lies in recording the touch or interactions that a child applies when it plays Roball. Roball is running a PIC18F458 microcontroller with 32 kBytes of internal memory, 1.5 kBytes of RAM and operating at 40 MHz (10 MIPS). Roball has three accelerometers, one for each axis (X, Y and Z). During these trials Roball can be set in three different modes; (A) Basic, (B) Pre-programmed and (C) Adaptive. When set in (C) Adaptive Mode it is the accelerometer sensor readings that are analysed to ascertain the robot's current environmental status, e.g. receiving interaction or not. These records come from sensor readings indicating that sensor data is falling in pre-defined boundaries. These boundaries have been previously defined in both lab based experiments and out in the wild [7]. Records of 'Interaction' come from being pushed, banged, spun, picked up or some other such type of physical interaction. In previous, work we investigated different categories or modes of interaction such as 'spinning' or 'being carried' [7]. However, for this work, these types of activity are all condensed into one category of 'Interaction'. Records of 'No Interaction' come from sensors recording that the robot is wandering about with any form of interaction being recorded. The robot should not classify interactions such as hitting a wall as an 'Interaction'.

Therefore sensor data is classified to define two different categories: NO INTERACTION and INTERACTION. If interaction is classified, a INTERACTION counter is accumulated; if no interaction is classified, a NO INTERACTION counter is accumulated. Test within the laboratory showed that the maximum either counter can record in a five minute period is 7 (see Figure 2).

2.2 Interaction Modes

During a session, one of three different interaction modes is executed on Roball; (A) Basic, (B) Pre-programmed or (C) Adaptation. The first two modes do not have any reaction to the child's interaction. The final Adaptive Mode reacts according to how the child interacts with Roball. More specifically, if Roball does not receive any human interaction, it employs a variety of responses: Roball can request "Play with me"; Roball can slow down or stop all together; it can play a gentle lullaby song, attempting to gain the interest of children. If the child interacts with Roball by playing with it, Roball can giggle or speed up and play lively music in an attempt to sustain the interaction. Listed below are the three different interaction modes along with a description of the robot's behaviour:

A ***Basic Mode***. This mode involves a simple wander and obstacle avoidance behaviour.

B ***Pre-programmed Mode***. This mode uses behaviours of mode A, but also once a minute the robot is programmed to either:

- play a child's lullaby music song at 0:45 minutes, 2:45 minutes and 4:45 minutes
- to stop all motion and ask the child to "Play with me" at 1:45 minutes and 3:45 minutes

These extra behaviours are carried out for 15 seconds respectively.

C ***Adaptive Mode:*** (Figure 2)
This mode uses behaviours of mode A with an added layer of adaptation. The adaption is possible by using the interaction counters on-board (either NO INTERACTION or INTERACTION, see Section 2) to trigger varying simple behaviours,

and thus change the robot's behaviour to suit that of child interacting with it. Below are the varying responses that are triggered by the counters.

When an adaptive response is triggered, it lasts up to a maximum of 15 seconds (after this, Roball returns to a wander state). These responses are:

- NO INTERACTION Responses:
  - Play an audio track that says "Play with me"
  - Slow down speed
  - Play an audio track of simple lullaby music
  - Stop all motion
- INTERACTION Responses:
  - Play an audio track of children giggling
  - Increase speed
  - Play an audio track of simple (but lively) child's music

Adaptive responses can be executed separately or together. For example: if the robot is not receiving interaction, it may play the audio track "Play with me" for 3 seconds, however it may at the same time execute the "Stop" behaviour for up to 15 seconds. The robot can switch between NO INTERACTION & INTERACTION modes in a single adaptive session.

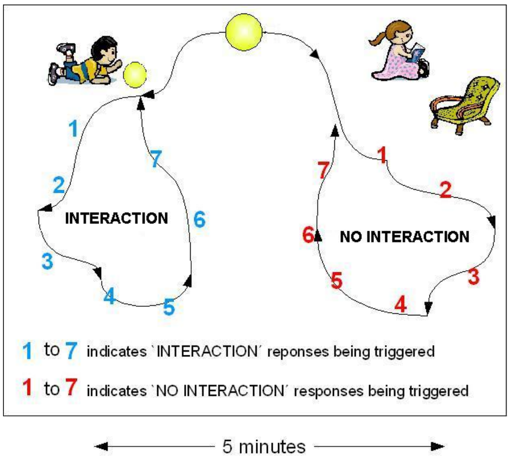

Figure 2: Adaptive Mode. Based on the child's interaction. The different loops show different behaviours being executed.

3 Experimental Approach

In our laboratory we often use a rapid prototyping method to gain information as swiftly as possible. In this vain we conducted a set of preliminary tests to investigate the benefits of our 'Adaptive Mode'. This work builds upon previous work we have carried out which investigated what behaviours a robot should exhibit in order to gain the interest of children and, how to sustain this interest. In previous work, we found that a robot exhibiting a stopping motion seems to attract the attention of children towards it [8]. In this series of trials our aim was to specifically investigate the benefits of an adaptive behaviour over less complex pre-programmed behaviours.

Figure 3: The only girl within the group interacts with the robot. It is possible to see the different floor coverings.

These trials were held at a day care center in Québec, Canada. The approach to this study was to make each session as natural as possible and, in this vein, to limit the use of cameras, etc. This was an attempt to limit "audience effect". Audience effect is the impact a passive audience has on a subject performing a task, which, for instance, would be the experimenter watching the child interact with the robot. Inspired by the work of the RUBI Project [9], the experimenter spent a lot of time just helping out in the day care where the study was to be held. This was to familiarise with the children in an attempt to *not* be seen as an experimenter. The experimenter was introduced to the children as *"a person who would bring a robot to play with them later on, but for now was helping out in the day care"*. The experimenter would help with all the normal activities of working as a day care worker, e.g., playing games with the children, helping feed the children at lunch time. The children were very interested in the possibility of a robot coming and would ask *"has she brought the robot today?"* when the experimenter arrived at the day care. There was a lot of interest when the robot was finally taken to the day care center.

3.1 Experimental Settings

There was an area set aside for the trial which was normally used by the children. It was intended that only the child participating at that moment would be allowed in the experimental area. Due to the relaxed nature of the trial at times, some other children did come into the experimental area. However, they were told that they could not touch the robot until it was their turn. The area had large pieces of furniture that were moved to the side, but there was still an array of different places for the robot to get stuck under, e.g., antique cot, television cabinet. Within the area there were three different floor coverings: hard wood, carpet (rug) and brick work (in front of the fire place), as shown in Figure 3. Also, at times there were other toys within the area such as, balloons, or toy trucks. Having these other toys in the area did not seem to take the interest away from the robot.

Every experiment was video taped for verification of sensor readings and also to later confirm a child's interest or lack interest in the robot. A questionnaire about the child's interest in the robot was filled out by an independent adult (one of the day care workers) while the trial was being conducted, and this was used to confirm findings from the coding of the video data.

Pre-trial tests were conducted to confirm that the sensors recorded correct information in the setting that was to be used. We conducted this series of trials over a six day period. The exact dates of the trials were dictated by attendance of the same children and convenience for the day care. As with many other trials involving trials conducted with children and robots, in this preliminary investigation we used a small sample size. The participants were made of five typically developing children (four boys and one girl), aged 2 to 4. Each child played with the robot in three separate sessions of 5 minutes. Each time the child played with the robot, it exhibited a different interaction mode. The order of behaviours was randomised to test for internal validity. For example, one child's order would be Mode (A), (C) and finally (B) another child's order would be Mode (C), (B) and finally (A). After 5 minutes the robot stops by itself, ending the trial.

4 Results

Although not perfect, for the most part the recorded interaction levels did enable the robot to correctly change its behaviour at appropriate times during the (C) Adaptive Mode. This was seen as a success. After all the trials were completed we compared the on-board data levels of NO INTERACTION and INTERACTION for each of the sessions and also video footage of each trial[1]. First we describe information obtained from sensor readings then we describe information gained from analysis of video footage.

There are two interesting observations that can be derived from the recorded interaction levels.

- Firstly, there is a prolonged and sustained level of interest and interaction indicated by the records from the sensors. We have not seen this result in any of our other trials with children. There are many different reasons why this may have occurred. For instance, we believe that the natural conditions surrounding this study may have contributed to the sustained interest. However, there is also the possibility that the robot displaying a different behaviour each time the child interacted with it helped to sustain the interaction. Therefore, the Adaptive Mode would have played a role.

- Secondly, the (C) Adaptive Mode did not appear to significantly increase the INTERACTION level during any of the children's session. This was not the expected result. However, we have learned from this trial that an increase in interaction does not necessarily, just come from the exact same physical contact with robot. We have discovered that different behaviours from the robot can elicit different types of physical interaction from a child. For instance, when the robot played music the most physical child interacted in a gentler, softer way. This recorded lower levels of interaction compared to his normal pushing and banging of the robot. Also, there can be other forms of interaction such as the child being verbal that are not recorded by the sensor data. These ideas are explored further on in this section and is shown in Figure 4.

To analyse the above findings further and from a different perspective, the video of each of the trials was coded. At times it was very difficult to code the video. This was due to the fact that only one camera was used and it was difficult to obtain a view of the whole experimental area with just one camera. Also, the experimenter did not stand behind the camera to point it in the direction of the child and the robot. As previously mentioned, the use of one camera and the lack to directing was due to an attempt to make each session as natural as possible for each child. The behaviours that were coded were chosen because it was believed they would show whether the child was interested in the robot or not. The coding was done on a second

[1] Unfortunately, listing all the results from the analysis of sensor and video data in table format is not possible due to the length of the paper. Therefore, we have decided to summarise our findings and not to show tables of results obtained. The data is available upon request and will be included in subsequent publications.

by second basis. The following are the behaviours that were coded:

1. LOOK - The child's gaze is directed towards the robot.
2. TOUCH - Touching the robot in a purposeful way e.g. moving towards the robot and touching it, either with feet, hands or another part of the body (Accidental touching such as the robot rolling into the child was not included).
3. TOWARD - Moving towards the robot in a purposeful way.
4. AWAY - Moving away from the Robot e.g. moving their body so that the robot could proceed or running away when the robot moved towards the child.
5. CAN'T SEE - It is not possible to see the above variables from the video footage.
6. SMILE/LAUGH - The child makes facial gestures or noises to indicate happiness e.g. laughing, smiling, giggling.
7. ASK QUESTION - The child asks a question to another human being in the room e.g. an adult care worker.

- It is clear to see from Figure 4 that there is an increase in the amount of smiling, laughing, giggling and asking questions during the (C) Adaptive Mode. We looked for instances where the child either smiled, laughed or giggled and that this action was performed as a way to communicate with either an adult or child present in the room. We did not include instances where the child laughed at something happening in the background of the day care center. We looked for instances where the robot was acting as a catalysis or mediator for communication. Also, we reviewed the video tapes looking for anytime that the children had asked either an adult or another child a question to do with the robot, e.g., what is the robot doing? It is possible to see, that indeed, the only time any child asked a question about the robot was during the Adaptive Mode.
- Again, as we found with the sensor data, there did not appear to be any *significant* increase in either interest or interaction directed towards the robot which was brought upon by the (C) Adaptive Mode.
- Also, again there was a sustained level of interest over the three sessions that we have not found in other trials. As stated before, there is the possibility that the robot displaying a different behaviour each time the child interacted with it helped to sustain the interaction. Therefore, the Adaptive Mode would have played a role.

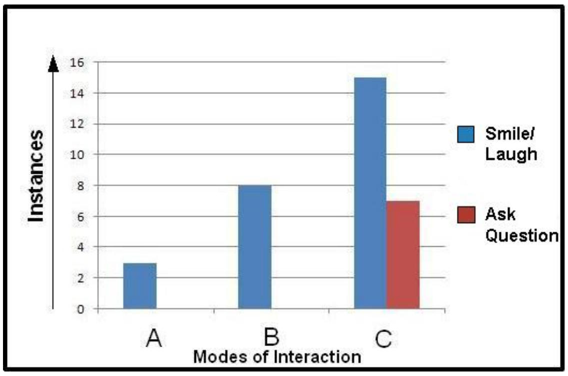

Figure 4: The coded behaviours of Smile/Laugh/Giggle and Asking Questions, summed for all children according to the three different interaction modes (A, B and C).

Other observations were made by the experimenter and the adults present with regard to what caused interest towards the robot.

- The robot producing speech in the adaptation and pre-programmed modes raised communication between the children and nearby adults. The only time children actually asked a question was within the Adaptive Mode.
- Giggling from the robot seemed to produced a response of intrigue from the children and increased their communication with adults. This also increased the child's own giggling, smiling or laughing.
- Music seemed to produced two behaviours from the children that were not seen at other times: dancing and a more careful interaction.
- Generally the robot increasing its speed worked well, but unfortunately at times, this did not appear to be noticed. It is believed this was due to the fact that the child was being active with the robot, e.g., pushing, spinning the robot. Therefore, the change was lost within the general interaction.
- One clear case of the robot encouraging interaction was with the child that had one of the lowest levels of interaction. When the robot stopped all motion, Edward, who was sitting far away from the robot, went to move in the direction of the robot. It appears that the lack of motion encouraged Edward to approach the robot.

- As we have previously found, the robot getting stuck seems to cause interest with children. One child would pick the robot up and walk it back to the place that it got stuck.

5 Conclusions

In this paper we investigated the Child-Robot Interaction benefits of adaptation. We described a study in which we tested the same robot but with three different behaviours: (A) Basic, (B) Pre-programmed and (C) Adaptation. We looked at which behaviour, A, B or C would gain and sustain the interest of five different children the most.

Our adaptation behaviour is still in its preliminary stages and thus has been developed to be simple and uncomplicated to enable us to incrementally build on our discoveries. Although the impact of the Adaptive Mode was not quite as expected, these session do show that adaptation has a role to play within the domain of Child-Robot Interaction as it increased communication and apparent enjoyment.

In future work, we plan to investigate different responses within the Adaptive Mode, with the aim of increasing the effectiveness of the mode. Such as, increasing the length of time the robot stops all motion when it is not receiving interaction from a child. We plan to test this system with other groups of children such as those diagnosed with autism to see how other children respond to adaptation. Finally, we have already begun testing the system with the added new feature of different coloured LED's, preliminary results are positive.

The knowledge we have gained from this study is that adaptation to an individual child is an incredibly complex task. That a human's ability to do this is immense and robots have a long journey before achieving a similar level of competence. Whilst humans do use touch as a form of communication, they also use many other subtle and complex ways to convey meaning or communication, such as body gestures, vocals and facial expressions. From this study we have shown that by employing a simple and basic adaptation technique based on a child's physical interaction there were some signs of increasing and sustaining interaction. Also, there were clear signs of increased communication with other people present and also, finally, that the children seemly enjoyed the experience of interacting with our robot in the Adaptive Mode more, i.e., increased smiling, laughing and giggling! Enjoyment, surely, must be a stepping stone towards our goal of gaining and sustaining a child's interest in a robot.

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