Lekbot: A talking and playing robot for children with disabilities

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Abstract

This paper describes an ongoing project where we develop and evaluate a setup involving a communication board and a toy robot, which can communicate with each other via synthesised speech. The purpose is to provide children with communicative disabilities with a toy that is fun and easy to use together with peers, with and without disabilities. When the child selects a symbol on the communication board, the board speaks and the robot responds. This encourages the child to use language and learn to cooperate to reach a common goal. Throughout the project, three children with cerebral palsy and their peers use the robot and provide feedback for further development. The multimodal interaction with the robot is video recorded and analysed together with observational data in activity diaries.

1 Background

The vision of our project is to utilise current technology in human computer interaction and dialogue systems to provide young people with communication disabilities with a fun and exciting toy. Currently there are not many opportunities for children with severe disabilities to play independently and to interact on equal terms with typically developing children. Our hope is that the toy will give children, with and without disabilities, the opportunity to interact and play with each other. As a side effect this can also help them develop their communicative skills.

Figure 1: The robot and the communication board

We are developing a remote-controlled robot that can be used by children with severe physical and/or communicative disabilities, such as cerebral palsy or autism. The child communicates by selecting a symbol on a communication board, which is translated into an utterance using a speech synthesiser. The robot responds using synthesised utterances and physical actions, that the child in turn can respond to. The communication board acts as an extension of the child, by giving the child speech as a means of communication. The robot and its communication board is shown in Figure 1.

Technically the robot is controlled wirelessly,

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with no speech recognition. The spoken dialogue is there for the benefit of the child, and enables the child to engage in a spoken dialogue, without having the physical and/or cognitive ability to do so. Our hope is that this will facilitate the child's own language development while having fun with the radio-controlled robot.

1.1 The Lekbot project

The Lekbot project is a collaboration between DART,[1] Talkamatic AB and the University of Gothenburg. It is funded by VINNOVA[2] and runs from March 2010 to August 2011.

The project is similar to the TRIK project (Ljunglöf et al., 2009), which developed a drawing robot that was controlled in the same manner as above. The very limited user study that was conducted suggested that the product had great potential. The current project can be seen as a continuation of TRIK, where we perform a more full-scale user study, with video recording, transcription, interaction analyses, etc.

1.2 Dialogue systems and robots

Most existing dialogue systems are meant to be used by competent language users without physical, cognitive or communicative disabilities; either they are supposed to be spoken to (e.g., phone based systems), or one has to be able to type the utterances (e.g., the interactive agents that can be found on the web). Dialogue systems for users with disabilities have so far been targeted at people with physical disabilities, who need help in performing daily activities.

Dialogue systems have also been used for second language learning; i.e., learning a new language for already language competent people. Two examples are the artificial agent "Ville: The Virtual Language Tutor" (Beskow et al., 2004), and "SCILL: Spoken Conversational Interface for Language Learning", a system for practicing Mandarin Chinese (Seneff et al., 2004).

However, we are not aware of any examples where a dialogue system is used for communicating with people with communication disorders.

With the advent of tablet computers, there now exist several spoken-language and touch-screen apps for children's games and interactive and linguistic training. In these apps, the interaction is between the child and the tablet, whereas in Lekbot the child and the tablet act together as one dialogue participant, interacting with the robot. The Lekbot robot is also a physical agent, acting in the world, thus adding another dimension to the interaction.

When it comes to robots, there are a number of past and present research projects on robots and children. An early inspiration is the LOGO robot developed at Massachusetts Institute of Technology for teaching children to use computers and program simple applications (Papert, 1993). There are several robots focusing on children with disabilities (Robins et al., 2008; Saldien et al., 2006; Kozima et al., 2007; Lee et al., 2008; Arent and Wnuk, 2007), and most commonly autism. Some of these communicate with children in different ways. For instance, KASPAR is a child-sized humanoid robot for children with autism, and it trains interactional capabilities through gesture imitation.[3] Probo, developed for hospitalised children, produces nonsense speech intended to convey different feelings.[4] KOALA is a small round ball that interacts with children with autism using lights and sounds (Arent and Wnuk, 2007). However, none of these robots and research projects involves natural language communication in any form between the child and the robot.

2 Project description

Our basic idea is to use a dialogue system to stimulate play and interaction for children with severe communicative disabilities. There are already communication boards connected to speech synthesis in the form of communication software on computers. The main values that this project adds to existing systems are that:

- the child is offered an exciting, creative and fun activity

[1] Centre for AAC and AT at the Queen Silvia Children's Hospital

[2] The Swedish Governmental Agency for Innovation Systems

[3] http://kaspar.feis.herts.ac.uk/

[4] http://probo.vub.ac.be/

- the child can play and interact with other peers on equal terms
- the child can explore language in stimulating cooperation with the robot and with other children

By being able to use a symbol-based communication board the children are given an opportunity to play, interact, explore language, and at the same time learn to use tools for alternative and augmentative communication.

2.1 Description of the system

The child has a communication board that can talk; when the child points at one of the symbols it is translated to an utterance which the board expresses via speech synthesis in Swedish. This is recognised by a robot that moves around in the room, and performs the commands that the child expresses through the board. The robot has an incarnation as a toy animal, currently a bumblebee. It has a very basic personality which means that it can take the initiative, without the child telling it, refuse actions, or even negotiate with the child.

The inspiration for the robot comes from robot toys such as babies, dogs and dinosaurs, but also from electronic pets such as Tamagotchi and Talking Tom. The main difference is that our robot is able to have a dialogue with the child, to find out what to do, or just to be teasingly playful.

The Lekbot robot can move forward and backward, and turn right and left. Furthermore it can perform actions such as laughing, dancing, yawning, farting and eating. The functionality is constantly improving during the evaluation, to keep the children interested in playing with the robot.

2.2 Needs and potential

The target audience is children with severe physical, cognitive or communicative disabilities. These children depend on assistive devices and persons to be able to interact with other people and artifacts. The idea is that the robot will be a fun toy that gives the child an opportunity to control the artifacts itself, without the help of other people. Hopefully this will increase the child's confidence, and also promote language development.

2.2.1 The importance of play

Play may be defined by the following terms (Knutsdotter Olofsson, 1992):

- spontaneous; the child takes the initiative, not the adults
- not goal-oriented; the game does not have an explicit purpose
- fun and pleasurable
- repeating; that it can be played many times as one wants
- voluntary

For children with severe disabilities, playing requires adult help, and it is difficult for the adult not to control the game, especially if the child has problems communicating what it wants. Often play is used as a tool for development training, and many times play is so scheduled that it is no longer spontaneous (Brodin and Lindstrand, 2007). A toy that is always available for the child to play with whenever it wants, and on its own terms can help the child to play "for real".

Children learn from each other, and a toy that is used on equal terms by children, with and without disabilities, encourages interaction that otherwise would not have been possible between children with such diverse backgrounds.

2.2.2 Educational advantages

As discussed in section 3.3 later, the setup works without the robot and the communication board actually listening to each others' speech – instead, they communicate wirelessly. However, there is an important educational point in having them (apparently) communicate using spoken language. It provides the child with an experience of participating in a spoken dialogue, even though the child is not physically able to speak. For children who are more advanced in their language development, the robot can offer the opportunity to understand the basic properties of the dialogue, such as taking turns, asking and answering questions, the importance of providing sufficient information, and cooperating to achieve a shared goal. Another educational advantage is that the child learns to use tools for alternative and augmentative communication.

3 Implementation

This section describes some technical aspects of the implementation of the Lekbot system.

3.1 Components

The final Lekbot setup consists of the following components:

- a simple LEGO Mindstorms robot which can turn and move in all directions, can perform different specialised actions, and has a “costume” which makes it look like a bumble-bee
- a touch-screen computer which functions as a communication board, and a custom support frame for the computer
- the dialogue system GoDiS (Larsson, 2002), using Acapela Multimedia text-to-speech with Swedish voices
- Bluetooth communication and wireless audio transmission, from the touch-screen computer to the robot, and two sets of loudspeakers, for the computer and the robot

If the target user already has his or her own Windows based communication device, with adapted accessibility for him or her, this special software for the robot play can be installed on this device.

Note that it is the communication board computer that controls the robot via the dialogue system, but the intention is that it should seem like the robot is autonomous. Every utterance by the robot is executed by the speech synthesiser, and then sent to the robot via radio.

3.2 LEGO Mindstorms

The robot is built using LEGO Mindstorms NXT,[5] a kind of technical lego which can be controlled and programmed via a computer. Apart from being cheap, this technology makes it easy to build a prototype and to modify it during the course of the project.

[5] `http://mindstorms.lego.com/`

3.3 Perfect speech recognition

Typically, the most error-prone component of a spoken dialogue system is speech recognition; the component responsible for correctly interpreting speech. This of course becomes even more problematic when working with language learning or communication disorders, since in these situations it is both more difficult and more important that the computer correctly hears and understands the user’s utterances. An advantage of the Lekbot setup is that we will, in a sense, have “perfect speech recognition”, since we are cheating a bit. The robot does not actually have to listen for the speech generated by the communication board; since the information is already electronically encoded, it can instead be transferred wirelessly. This means that the robot will never hear “go forward and then stop” when the communication board actually says “go forward seven steps”.

3.4 The GoDiS dialogue manager

A dialogue system typically consists of several components: speech recogniser, natural language interpreter, dialogue manager, language generator, speech synthesiser and a short-term memory for keeping track of the dialogue state. One can make a distinction between dialogue systems, which (ideally) are general and reusable over several domains, and dialogue system applications, which are specific to a certain domain. The dialogue manager is the “intelligence” of the system, keeping track of what has been said so far and deciding what should be said next.

The GoDiS dialogue manager (Larsson, 2002) has been developed at the Department of Philosophy, Linguistics and Theory of Science at the University of Gothenburg over several years. It is designed to be easily adaptable to new domains, but nevertheless be able to handle a variety of simpler or more complex dialogues. For example, GoDiS can either take initiative and prompt a user for information, or take a back seat and let the experienced user provide information in any desired order, without having to wait for the right question from the system.

From the viewpoint of dialogue systems research, there are some interesting aspects in the Lekbot setting:

- *Constantly changing environment*: the surroundings of the robot can change all the time, and the dialogue system needs to adapt
- *Alternative input modalities*: instead of speech input, we are using a touch screen interface, on which the symbols on the screen also changes depending on the current dialogue state
- *Utterance generation*: it is important for everyone, but in particular children with communicative disabilities, that information is presented in a correct way – with correct and consequent grammar, lexicon and pronunciation

3.5 Utterance generation

Clear pronunciation is important, and perhaps even more important when we are dealing with communicative disabilities. We are experimenting with using different utterance generation strategies and stressing important words to make the children understand the robot better. Interestingly, user feedback from children and preschools during the project has also indicated when default intonation does not work and needs to be modified.

The Lekbot system uses two different voices, one for the touch screen, acting as the child's voice, and one for the robot. Whereas the touchscreen voice is a vocalisation of something the child has already seen on the screen, the utterances of the robot have no visualisations. Hence, it is particularly important that the robot's utterances are as clear as possible, and the TTS voice chosen for the robot is therefore the voice that was determined to have the best and most flexible intonation in informal perception tests at the start of the project.

3.5.1 Contextual intonation

We have incorporated models of information structure in GoDiS to enable the appropriate assignment of phonological emphasis (Ericsson, 2005).

Lekbot uses a fairly basic dialogue-move-to-string mapping for the creation of output utterances, which are then fed to the speech synthesiser. Determining the information structure of an utterance to be generated, involves the determination of what is informative in the utterance – the focus – and what is a reflection of something already in the context – the ground (Vallduví, 1992). The system assigns emphasis to all alternatives, that is, all contrasting elements, in alternative questions, that are produced by the robot. Consider the following example:

> *User*: Go forward.
>
> *Robot*: Do you want me to go forward a lot or go forward a little?

For the generation of the robot utterance, the system determines "go forward a lot" and "go forward a little" as alternatives, and assigns emphasis to these. Future development of the system may involve the inclusion of information structure also for utterances other than non-alternative questions, to determine appropriate intonation assignment more generally.

Unfortunately, we have not yet been able to use this feature in the actual demonstration system, since the Swedish TTS voices do not emphasise properly with regard to the markup. Instead we have tuned the utterances lexically and syntactically to make the best possible use of the default TTS intonation.

4 Evaluation

We are evaluating the Lekbot system during spring and summer 2011, in parallel with continued development, in the spirit of eXtreme Programming (XP). Some major themes in XP that were deemed particularly interesting in this project are i) the need to involve the users in the development process, ii) to work in short iterations with frequent releases to get a nearly constant feedback from users, and iii) to always prioritise the tasks that provide the greatest benefit to users.

4.1 Users

A test group was recruited consisting of three target children with peers and staff, at three different pre-schools, was recruited. The target children, two boys and one girl are in the ages 4–6 years, two boys and one girl. They have cerebral palsy with complex communication needs. They also have a poor gross motor control, but are able to use their hands for activating a touch screen on a computer. They serve as the test group and as a basis for the specifications of the further development of the system. During the course of development the children in the test group use the system to verify that it works as intended and help to identify the most important qualities to develop. The project group works with one month iterations with a new public release every second month. Therefore, the users have in the end used about six releases of the robot.

Along with the target children, three typically developed peers, of the same age, or slightly younger, were recruited at each pre-school. The three peers were all girls. Hence, there are three groups of children playing with the robot. At various occasions other children in the pre-school group are involved in the robot play.

The children were assessed regarding their receptive language levels by using Test for Reception of Grammar (TROG) (Bishop et al., 1998). Their communication levels were estimated by the project group in cooperation with the pre-school staff using Communication Function Classification System (CFCS) for Individuals with Cerebral Palsy (Hidecker et al., 2009). The pre-school staff also completed Swedish Early Communicative Development Inventories (SECDI) forms for each child (Eriksson and Berglund, 1999; Berglund and Eriksson, 2000). A pre-school form (Förskoleformulär) was also completed (Granlund and Olsson, 1998). It consists of questions concerning the child's engagement in various situations, the pre-school teacher's perception of the interaction between her and the child as well as the interaction between the child and other children.

With the two youngest target children TROG testing was not feasible, while the oldest one appeared to have some difficulties in understanding verbs, prepositions and sentences containing these components, thus a bit lower than his age. The three peers showed results matching their age. From here on the target children will be named Per, Hans and Greta.

The purpose of CFCS is to classify the every day communication performance of an individual with cerebral palsy. The levels are ranged between 1 and 5, where 1 is the highest and 5 the lowest.

- The 6 year old Per shows a level of 3: Effective sender *and* effective receiver with familiar partners.
- The 5 year old Hans is estimated to level 5: Seldom effective sender and effective receiver with familiar partners, and
- The 4 year old Greta is at level 4: Inconsistent sender and/or receiver with familiar partners.
- All the peers, of course, reach the level of 1.

The CFCS levels will be estimated over again when the Lekbot testing is finished.

The results of SECDI and the pre-school form will be presented at a later stage of the Lekbot project, as they will be redistributed.

4.2 Evaluation tools and methods

The tools used to evaluate the robot play are three:

- Talking Mats,[6] which is an established communication tool that uses a mat with attached symbols as the basis for communication. It is designed to help people with communicative and cognitive difficulties to think about issues discussed with them, and provide them with a way to effectively express their opinions. Both the target children and their peers were interviewed about the robot and the interaction, in order to get

[6] `http://www.talkingmats.com`

feedback for evaluation and for developing the system.

They were asked questions about the behaviour of the robot and answered by putting symbol cards either at the "fun" side of the mat or at the "boring/not nice" side. It is also possible to put symbols between "fun" and "boring/not nice". The answers were then checked and evaluated together with the children. An example is shown in Figure 2.

- Video recordings during the robot play were made by the project group from January to May 2011, six recordings from each peer group, in all 18 recordings. The duration is between 20 and 30 minutes each and shot with one camera by one of the project members. Short sequences from the videos have been transcribed and analysed with focus on cooperation between the children and joyfulness. Transcriptions were made in CLAN[7] with detailed descriptions of the non-verbal actions, signs and gaze. We got permissions to do the recordings from the parents of the children.

- Weekly Activity diaries were kept by the pre-school staff, where they could provide their reflections about the play sessions. The diaries included headings regarding numbers of play occasions, duration of the play, persons participating, what happened in the play, functionality of the robot, suggestions for improvement and the children's satisfaction with the play perceived by the staff.

Furthermore, the interaction between the communication board and the robot is logged by the system, providing valuable information.

Beside these evaluation tools there have also been discussions with the designated staff at the current pre-schools.

[7] http://childes.psy.cmu.edu/clan/

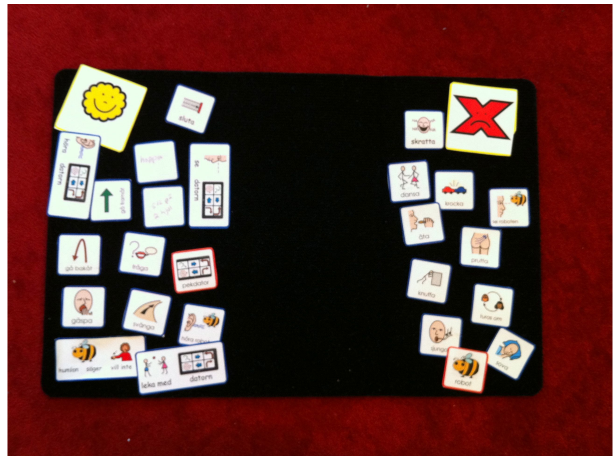

Figure 2: Talking Mats

4.3 Preliminary evaluation results from the activity diaries

According to the activity diaries, Lekbot was used 56 times during releases 2–5; just below 10 times each for the early releases, and 20 times each for releases 4 and 5. There is a great variation in numbers of performed play sessions and in completed activity diaries, mainly due to illness in children or staff, orthopedic surgery in one child and holidays. In the beginning there was always the same peer, and only that one, attending the play sessions. Further on in the project the staff chose to engage more peers from the pre-school. That means that sometimes there was a different peer than originally and sometimes there was a group of peers interacting in the play. The support person attending the play sessions was always the same. She also was the one completing the activity diaries.

4.3.1 Functionality

15 comments were given about the system working well, where release 5 got the best scores. Problems with the system were reported 16 times. Comments were given about rebooting the system, loosing the commands, or problems with activating them. Dissatisfaction with the actions of the Lekbot was reported 5 times, mainly about the delay between activating a command and the activation of the robot. There were also reports of improved accessibility of the system, by finding a mobile piece of furniture

for the stand and by changing the angle of the display.

4.3.2 Interaction

The project group chose not to give strict instructions on what to do in the play, just to let everyone use the Lekbot at suitable level. Thus, there was a variation in complexity of the comments, as the headings in the activity diaries gave a structure of open questions. The collected, written comments were categorised in five groups; Preparations for the Lekbot play, Explicit support from adult, Target child's activity and perception of the play, Peer's activity and perception of the play and Shared activity and perception of the play between target child and peer(s). The three latter are reported together release by release.

Preparation for the Lekbot play occurred mainly for Per's group, where he and his peers built different tracks for the robot to follow. Explicit support by adult is mentioned only for Per's group, where the adult chose target point for the robot and she used the play for educational matters regarding letter teaching. She also mediated between the children which improved their cooperation. In the final sessions Per initiated turn taking after being urged by the adult.

4.3.3 Activity and perception

Target child's activity and perception of the play is mentioned a lot, especially for Per and Greta. Most frequent among the comments are those concerning Shared activity and perception of the play between target child and peer(s).

Release 2: Per initiates turn taking, reacts to the event followed by the activation of the command on the display, protests when his peer choses "the wrong command". Together they repeatedly perform turn taking and use Per's digital communication device in the Lekbot activity. Hans and his peers make a tunnel and the children give commands that make the robot go through it. Greta has high expectations on the play before the session. Repeatedly she is unwilling to stop the play and she gives oral comments to the activities of the robot.

Release 3: Per explores the commands and what happens when using them to answer the newly implemented supplementary questions. Around Hans there is turn taking. Several children are playing together and the children most frequently choose the dance command. Greta is excited and unwilling to stop the play. She protests when the adult makes the choice for the robot.

Release 4: Per shows the new commands for his peer, and the children imitate the robot. Per and his original peer chose one new peer each. Interaction between the children takes place through dancing and hand clapping. Hans plays with the robot together with adults from outside the preschool. Greta likes going backwards, turning and hitting things with the robot. She starts telling her peer how to act by using the commands on the display and her paper communication chart. Her peer enjoys following Greta's "instructions" and she likes dancing. There are repeated turn taking between them and they enjoy to cooperate getting the robot to move from one spot to another.

Release 5: Per plays with the new commands, by himself. He finds strategies for the robot in finding food. When there are more than two children in the play, Per chooses to be the one controlling the display. He cooperates more – waits for his turn and shows better understanding for the other's turn. All children repeatedly use communication charts and Blissymbolics to express themselves. They imitate the robot and they act instead of it when it is out of order. In Hans's group there is dancing and looking for food play. Turn taking takes place and all children want to participate in the Lekbot play. Greta decides whose turn it is to control the robot. Her peer likes the play of finding food.

4.3.4 Satisfaction

Starting in release 3, the level of satisfaction with the play session was noted in the activity diary. The staff was asked to estimate how satisfied the target child and the peer were on a scale from 1 to 5, where 1 is the lowest and 5 the highest. This was done every time at some pre-schools and some times at others. The tendency is that the target children seem to be more satisfied with the play than their peers from the start of the play session. This is most protruding regarding the oldest pair. At release 4 where Per and his peer interact as a group for the first time, the scores suddenly are reversed so the Per is perceived to 3 on the satisfactory scale and the peer(s) at 5. In release 5 the scores get a more even variation.

4.4 Video recordings

Most of the interviews with Talking Mats were video recorded. The full analysis will be done later in the project. The analysis of the video recordings of the robot interaction is an ongoing work were three of the project members participate. This part of the work is time consuming and only minor sequences are transcribed and analysed so far. Through micro analysis the fine grained interactional movements and the cooperation between the children and the teacher appears, as well as the joy of playing.

Figure 3 contains a segment from the transcription. The participants are Per, his peer Selma and his teacher Isa; and the Computer and the Robot. In the excerpt we can see how Per asks for Selma's attention and with the help of Isa and the communication map tells Selma to take her turn, which is to make a new command for the robot to perform. Finally they both dance to the music.

126 %gaze: Per looks at Selma

127 %move: Selma is standing on her knees, sits down on her heels, keeps booths hands on her skirt

128 %gaze: Selma looks toward the mirror on the wall

129 %move: Per touches the left hand of Selma, keeps his arm stretched when Selma moves a bit

131 %gaze: Isa looks at Per's hand

132 *Selma: ————————

133 %comment: Selma is singing while Per stretches toward her left hand

134 %gesture: Isa draws the pointing map closer

135 %gaze: Per looks down at the map

136 %gaze: Selma looks down at the map

137 *Per: ————————

138 %move: Selma stands up on her knee, departs on a movement forward

139 *Isa: eh::: (0.3) your turn (0.3) Selma's turn

140 %gesture: Isa moves her finger back and forth over the 6th picture on the map

141 %gesture: Isa rests her finger at the picture, then withdraws it

142 %gesture: Per points at the map

143 %move: Selma moves toward the screen

144 (2.1)

145 %action: Selma makes a fast press at the screen

146 %gaze: Per looks at the screen

147 *Selma: dance: my king ————————

148 %move: Selma moves left with arms swinging, bends forward, landing on hands and knees

149 %action: Per looks at Selma, smiles

150 *Computer: dance

151 *Selma: mi:ine ñ: ñ: —(1.8)—

152 *Robot: okay I gladly dance

153 (1.0)

154 *Robot: plays music 11 sec

155 %comment: both children are dancing, Selma on her knees and Per sitting down

Figure 3: An example transcription segment, translated to English

4.5 Conclusion

All target children have enjoyed the Lekbot play from the beginning. The more commands and abilities the robot has received the more appreciated has the play become also by the peers. Improved play and interaction skills can be observed in varying degrees depending on the level of each child. The Lekbot has been a nice and fun artefact for the children to gather round and it has given both the target children and their peers experiences of playing with each other. From Talking Mats interviews performed with Per and Greta it was revealed that they had no problems handling the computer display or seeing and hearing the display and the robot. Making the same interview with Hans was not feasible, though the project group experienced that he seemed to deal pretty well with the system, although he needed a little more support than the two other children, who were able to control the toy autonomously. More results will be presented when the video sequences are analysed, later on in the project.

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