Robot Systems for Play in Education and Therapy of Disabled Children

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Abstract From a developmental and educational perspective, play is a "natural" way in which children learn in an enjoyable manner. It can be relaxing, exciting - children can play a role and it is an important possibility to get in touch with other children. On the other hand, disabled children have limited possibilities for interaction with social and material environment. This paper is focusing on two particular projects coordinated by the author. The PlayROB system is a robot which supports severe handicapped children for playing with LEGO™ bricks. For a long-term field trial six PlayROB systems have been realized and installed at selected Austrian education institutions. The user tests revealed that the goal to make autonomous play for children with physical handicaps possible has been fully achieved. The second presented project – the EC-funded project IROMEC – is dealing with an interactive robot system for use in education and therapy. A novel framework for this application area is being developed and evaluated by means of a dedicated robot setup. The main research focus of IROMEC is on the user oriented definition of appropriate play scenarios, development of evaluation methods, and finally on the definition of robot behaviors and interaction modes. Robustness, dependability as well as "plug&play" operation of the robot system are specifically addressed.

1 Introduction

In the past "child's play" has often been neglected in comparison to educational objectives such as developing mathematical or language skills. However, state of the art research emphasises the important role of play in children's development, a crucial vehicle to learn about themselves, the environment, and to develop social relationships. The research activities described in this paper target children who are prevented from playing, either due to cognitive or multiple impairments which affect their playing skills, leading to general impairments in their learning potential and more specifically resulting in isolation from the social environment,

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including family members and peers. The underlying assumption is that providing tailored means to encourage play using a robotic toy will break down barriers for development through play, fostering individual development up to the person's full potential.

1.1 Play for Enjoyment and Learning

Play in humans is a complex phenomenon, and its roles in development are diverse. Through play, juveniles interact with their physical and social worlds and 'construct' their mental worlds. Thus, play is more than merely 'having fun' or 'practising skills for adulthood'. Opportunities to play e.g. with peers or family members benefit social competence and confidence. Skills acquired through social play behaviour are instrumental in developing and maintaining social relationships and bonds that may last a life-time. Also, from an educational perspective, play is a "natural" way in which children learn in an enjoyable manner. In play, the complexity of stimuli and activities can be gradually increased, thereby guiding the child through a series of experiences that can be designed according to the children's cognitive, emotional, individual and – when applicable – therapeutic needs and possibilities.

Research in the field of educational technology and special education is only recently approaching the right of children with disabilities to play like all their peers. Robots could contribute to change this situation: their nature itself is joyful, they can possess a potentially huge variety of interaction skills, and their power to inspire identification and empathy has been clearly demonstrated. The new technological possibilities offered by robotics have strongly shed light on the early years of children with disabilities, however the appropriate use of technological toys and play activities is still widely unexplored – a situation that the two projects described here aim to remedy. Both projects are an interdisciplinary initiative combining robotics, ICT and other disciplines like cognitive sciences, developmental psychology, pedagogy, human-machine interface in order to demonstrate a novel potential role of advanced robots in society – a role where playing setups for cognitive or multiple disabled children supported by robotics technology finally contribute to enhancement of the following three aspects.

(1) "Quality of Life":

Playing is a substantial and joyful part in the life of children, it can be relaxing, exciting, children can play a role and it is an important possibility to get in touch with other children. In the very recently published "children version" of the ICF (International Classification of Functioning and Disability) the World Health Organisation has carefully considered and described playing activities, both under the "Activities and Participation" and the "Environmental Factors" [1]. Play is then considered as one of the most important aspects in a child's life, a parameter to be considered for assessment of children's quality of life (QoL).

(2) "Social Inclusion":

Children with a disability not only have to deal with the physical and psychological consequences of this impairment itself; the disability also will affect the development of their social roles. For participation in society communication and interaction skills are necessary – functions which could be improved during the play with the robot. Facilitating this development despite of the disability has a life long positive effect on the individual. It will enhance the social inclusion with other children and adults, and this will continue while growing up and in their adult life.

(3) "Learning and Therapy":

There is considerable evidence and recognition of the important role of play activity which validates the high didactic and educational value of play at every stage of life. The most innovative, psychological and educational trends have highlighted the importance of active teaching and the use of a didactic methodology based on the constructivist concept of learning for the correct development of learning processes. Playing and acting in playful environment is the basic key for children's learning; the role of social relationships to increase the children's cognitive skills has been demonstrated firstly in the educational psychology field by Lev Vygotskij [2] and has been confirmed in subsequent studies. More recently, scientific literature in the field has shown the role that playing activities and interactions in technological environments can have and it's positive influence on children's learning skills. This has been demonstrated also for children with cognitive and with physical impairment.

1.2 State-of-the-Art in 'Robot Assisted Play'

Due to the many related activities in different application fields an analysis of the state-of-the-art must observe several areas, like toy market, toy adaptation research (plus assistive devices) as well as activities in the area of 'personal robotics'. For the (robot) toy market several systems – from simple and cheap devices up to very complex and expensive ones – are (or have been) commercially available[1], e.g. AIBO robot dog from Sony Inc., MyRealBaby from Hasbro, or MINDSTORMS from LEGO Inc. Previous research from several groups worldwide however has shown that these kinds of systems are rather limited for the desired purpose of a playing assistant for disabled children.

Other ongoing research projects are investigating different setups and interaction possibilities between robot and human(s) in the framework of "personal robots", e.g. NEC Research laboratories are developing the personal robot PaPeRo to become "family member". Similar work – but more related to Human-Robot-Interaction (HRI) – can be observed in different research laboratories world-wide.

[1] See also http://www.robotoys.com/ or http://www.robotshop.ca/robot-toys.html

The IST-FET project Cogniron studies a cognitive robotic companion to be used in domestic scenarios [3]. MIT Media Lab (and other groups) is working on the interaction aspects for sociable robot systems in a laboratory setting; one study is aimed for weight management for people who have lost weight and want to keep it of. The published results demonstrate that this kind of HRI work with typically developing children or adults but cannot be directly applied to the area of assistive technology. For example, work at ATR with Robovie, as well as other work, has shown that interaction levels with children decrease over repeated exposure, while e.g. two independent studies with autistic children by Robins et al. [4] and children with developmental disorders by Kozima et al. [5] have shown that interaction levels increase in a longitudinal study. Other related research by Takanori Shibata at AIST and collaborators (seal type robot PARO) has shown first promising results in using an interactive robot in therapy for children and support for the elderly [6] – a similar approach is by Omron with their NeCoRo robot system, and Michaud et al. [7] who are designing robots for child-development studies.

In the area of robot-assisted playing early research was done by A. Cook and his collaborators where a small industrial robot was used for a particular play setup for children with physical disabilities [8]. Howell et al. [9] presented a robotic system installed at an elementary school utilized for science instruction. Davies described a prototype for a "playing robot" which aims to give assistance during either a painting or a building scenario [10]. The common theme for all of these scenarios is to use the robot for improved interaction with and exploration of 3D objects. The Adaptive Systems Research Group of the University of Hertfordshire has investigated since 1998 the role of robotic toys in therapy and education of children with autism demonstrating that a robot can potentially play a useful therapeutic role encouraging basic social interaction skills (e.g. joint attention and imitation), as well as using the robot as a social mediator facilitating interaction with peers and adults [11], [12].

2 PlayROB and IROMEC – Two Selected Examples for 'Robot Assisted Play'

In the following chapter two selected examples for application of robotics technology as playing assistant for disabled children will be described in more detail. The first described setup – robot system PlayROB – has been designed as assistive system helping severe disabled children in playing with LEGO™ bricks. In this setup the robot is not the toy – but the robot helps to use the toy. On the other hand, the second system described – robot system IROMEC – is representing a special designed robotic toy serving as a mediator for playing activities for cognitive and physically disabled children.

2.1 Playing Assistant PlayROB

"PlayROB" is a remote controlled robot system which aims to assist the severe physically disabled child during play. The main idea behind this system is that – different to many other approaches – the robot should serve as an assistant only. The way of playing is defined by the child, which ensures maximum autonomy. The robot is not the toy – but the robot assists in using the toy, which leads to a "Robot Assisted Play" setup. Using the functionality of such a robot system, the user is now in the position to manipulate real objects (toys) in the real world, despite of her/his impairment.

2.1.1 First Prototype

In a first feasibility study, a dedicated 3DOF[2] Cartesian robot system has been designed for manipulation of LEGO™ bricks (Fig. 1). The design is following a "low cost" approach by using standard components for the entire system.

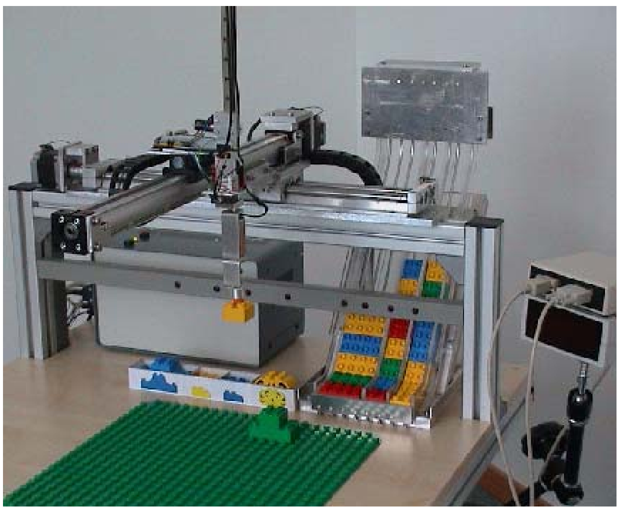

Fig. 1. First prototype of the robot assistant PlayROB – a 3DOF robot with special gripper device and storage system for different kinds of toy bricks

System evaluation, User Trials

The prototype mentioned above was finalized late 2003. In the following, first user trials with this robot prototype were composed of different steps. In a starting series of expert tests the concept per se as well as the functionality and stability of

[2] DOF – Degrees of Freedom

the system could be evaluated. It should be mentioned here that these expert tests and system refinement before starting the tests with end users turned out as very important in order to avoid frustration for the children if the system breaks down.

For next stage of user tests six children were invited to use the robot prototype. For first trials three able-bodied children (between 5 and 7 years old) were confronted with the system for three playing sessions each. Beside further evaluation of the system concept and the user interface (all children have used a 5-key input device) there was also an evaluation of different playing setups (i.e. "free playing", reconstruction of pre-defined figures). In a second series, three disabled children (between 9 and 11 years old; child 1 – multiple physical impairments; child 2 – tetra paresis; child 3 – transverse spinal cord syndrome) were asked to use the robot in the same playing setups as used in the previous series. For both series, no quantitative criteria were used (e.g. time per inserted brick, number of "wrong placements", etc.) – main interest was on acceptance of the system and intuitiveness of the user interface concept.

Fig. 2. Robot prototype during user tests

The user tests (Fig. 2) revealed that the chosen approach for a robot system can be an attractive device for children with physical disabilities [13]. The very positive feedback from children, but also from parents and teachers, have encouraged to perform a redesign of the system and the realization of a small series of the robot assistant for a multi-center evaluation study.

2.1.2 Multi-center Evaluation with Redesigned PlayROB System

An important research question for the proposed "Robot Assisted Play" setup is to investigate possible and estimated learning effects. A multi-center study should help to get reasonable answers to that question. Thus, six redesigned systems were installed at selected schools and therapy institutions in Austria since winter semester 2004 in order to introduce the system to many children. Playing with the robot has being included into the regular therapy plan in order to support the evaluation of learning effects.

Main criteria for the redesign were further reduction of the system costs as well as improvement of system safety. The robot system is now completely integrated into a mobile rack – most of the moving parts are covered by the robot housing made from perspex (Fig. 3). Depending on the activity level of the particular user, the system can also be used with locked doors (acrylic glass) in order to avoid any manual intervention during robot operation. Redesign was subject to all system components, i.e. gripper system, storage as well as control system [14]. For efficient execution of the long-term user evaluation, each single playing session is being recorded into a "log-file" in any detail – including name of the player, duration of the playing session and each particular playing sequence.

Fig. 3. Redesigned system "PlayROB"

Multi-center System Evaluation

For investigation of possible learning effects in a multi-center study, six PlayROB systems were installed at selected schools and therapy institutions in winter semester 2004 and in summer semester 2005 in order to introduce the system to as many children as possible.

For the desired evaluation of learning effects the following parameters have been recorded for every playing session:

- Duration of playing session
- Number of used bricks and number of different brick types
- Time required for brick placement (bricks/min)
- Utilization of the playground area (%)

The six systems were installed at three institutions in Austria (Waldschule[3], Institut Keil[4], Vereinigung zu Gunsten körper- und mehrfachbehinderter Kinder und Jugendlicher[5]). At each of the three sites, about 5-10 children have used the PlayROB system on regular basis. All of the users are showing significant physical disabilities – in most cases together with different degree of mental retardation. Most of the pupils are not able to speak.

In the first stage of the study (until March 2006) no instructions about what to build were given to the children ("free playing"). Main goal for this first phase of user trials was to evaluate the impact of the redesign measures. Results show that the new system design and the new functions – like laser guidance during brick insertation, new interfaces for children and teacher, new starting procedure, etc. – result in an enhanced acceptance at children and teacher side. Beside of this functional evaluation also first small learning effects came to the fore. The children more and more got a feeling about what kind of figures could be possible by using the bricks – figures also became more complex. Children had a lot of fun during playing – playing to them was not a kind of "learning exercise" but very enjoyable activity. In addition it was reported from the institutions that the experience of "autonomous playing" had a very positive effect on the self-esteem of the children.

During the second phase of the user trials additional playing scenarios have been defined and improved together with the institutions. Different from the original plan, not all children finally could be transferred from "free playing" to "instructed playing" where instructions about what they have to build are given to each child first verbally, then as sample constructions to copy and finally as construction plan. The main reason for not using "instructed playing" for all children was that most of the children had not the cognitive abilities to construct something according to a plan. For some children the proposed "instructed playing"-mode was not that fun as "free playing".

The results obtained during this stage of user trials were confirming the results of previous phases. Most of the children have shown significant advancement in terms of endurance and concentration, but also of spatial perception. Furthermore general improvement of motivation during the lectures has been identified as result of the work with PlayROB. The robot system also has turned out as optimal tool for training with input devices – children were learning different features of the particular input device in a playful environment and with high motivation. In depth analysis has shown a considerable improvement of the recorded parameters for many children [15].

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[3] Waldschule/ Wr. Neustadt is a school for children with multiple disabilities.

[4] Institut Keil/Vienna is a special therapy institution for children with cerebral palsy.

[5] Vereinigung zu Gunsten körper- und mehrfachbehinderter Kinder und Jugendlicher/Vienna is a parents association for ambulant care for children with physical and or multiple disabilities.

- Placement of bricks has being optimized in terms of time and accuracy.
- Entire area of the playground has being used after some playing sessions.
- "Distance" between selected and "optimal" brick placement has being reduced after some playing sessions.
- With each playing session the number of different bricks used by the player has increased.

Aside of this quantitative analysis there also has been a qualitative evaluation by the teachers/therapists from each involved institute. Teachers/therapists were interviewed about the progress of the children. For example one institute reported that after a 6 month evaluation period – from 7 children playing regularly – one child finally was able to play without any manual or verbal intervention, one other child was able to play with only needing minor verbal intervention. One child has finally used the entire playground area and has created rather complex constructions. All three institutes were reporting that the children are playing with high concentration and fun – also over a longer period of time. There was no significant reduction of interest in playing with PlayROB in course of this long term evaluation. Using the robot has been recognized as "learning with great fun". In addition they reported that the PlayROB was also an attraction for children who were normally able to play with bricks.

Tests on the other hand also have demonstrated that – even if the robot system allows autonomous playing and even if the setup time for the robot could be reduced – introduction of such a robot system to the regular therapy plan also results in an additional working load for the already overloaded teachers and therapists. As a consequence the utilization of the robot systems was a little behind the expectations. Other problems which were significant during the evaluation phase include organizational matters. In all three institutions it was difficult to find a dedicated place/room for the PlayROB continuously. Another problem was the lack of personal. During the evaluation phase it became evident that the two institutions with the therapeutic focus could use the PlayROB more often than it was possible in the school. The reason therefore is – as mentioned before – mainly the lack of personal and the fixed day structure in the school. For the desired "routine use" of the PlayROB system such limiting factors need to be considered and an appropriate framework for efficient use must be developed.

2.2 Toy Robot System IROMEC

Similar to the PlayROB project described above, IROMEC targets children who are prevented from playing, either due to cognitive, developmental or physical impairments which affect their playing skills, leading to general impairments in their learning potential and more specifically resulting in isolation from the social environment. A novel framework for robotic social mediators is being developed and evaluated by means of a dedicated robot setup in the context of therapy and education. The IROMEC project aims on a user centered definition of appropriate play scenarios, development of evaluation methods, and finally on the realisation of a dedicated interactive robot system. IROMEC investigates how robotic toys can provide opportunities for learning and enjoyment. The developed robotic system is tailored towards becoming a social mediator, empowering children with disabilities to discover the range of play styles from solitary to social and cooperative play. Robustness, dependability as well as ease of use are specially addressed.

One of the major aspects of IROMEC is the study of the role of a robot as an enjoyable toy and a social mediator which is widely unexplored and has so far only be demonstrated in very small-scale pilot studies. Further, the project is emphasizing on the development of a dedicated framework encompassing a wide range of children with different kinds of disabilities, rather than purely focusing on specific user groups. Results of IROMEC aim to generalize research on robot mediated play in a social context across different scenarios and user groups. The research focus of IROMEC is on participative design, development of play scenarios which cover all phases of play, definition of robot behaviors and interaction modes resulting from these scenarios, integration of appropriate communication and control technology, and consequent application of a “plug&play” strategy.

2.2.1 IROMEC Play Scenarios

Scenarios serve as central representations throughout development cycles, first describing the goals and concerns of current use, and then being successively transformed and refined through iterative design and evaluation processes [16]. In the IROMEC project the concept of scenarios has been adopted and used for an additional purpose. Here, scenarios are seen as higher level conceptualizations of the ‘use of the robot in a particular context’. Scenarios are used not only as intermediary steps or tools in the design and development process of the robot, but more importantly as play contexts which allow users to evaluate specifically implemented functionalities of the IROMEC robot.

Development of IROMEC scenarios has been performed in several phases. The preliminary concepts for play scenarios were based on a detailed literature review as well as experimental investigations and were related to existing technology used in play activities by the various target user groups. The results from the experimental investigation of various concepts of play scenarios together with outcome of the consultation with the panel of expert users (different panels of teachers, therapists, parents related to the different target user groups) were then merged to form “Outline Play Scenarios” that reflect the user requirements and are not related to any specific technological solution/robot. During the final phase of scenario development, these “Outline Play Scenarios” have further been developed, against specific therapeutic and educational objectives, and finally reflect the specific functionalities to be implemented in the IROMEC robot and its various modules. After final discussion with the user panel the following IROMEC Play Scenarios (IS) have been selected for implementation (Fig. 4).

No.	Title of scenario	Characterization	User groups			Social mediation*	Play type				Solitary play	Collaborative play
			AUT	SMI	MMR		EX	SY	AS	GR		
IS01	Turn taking	Turn taking game with a mobile robot	●	⌖	⌖	H	✓			✓		✓
IS02	Sensory reward	Turn taking game for sensory reward	●	⌖	⌖	H	✓			✓		✓
IS03	Imitation game	Imitation game	●	⌖	⌖	H	✓					✓
IS04	Make it moves	Cause and effect game	⌖	●	⌖	M	✓			✓	✓	✓
IS05	Follow-Me	Coordination game	⌖	⌖	●	H	✓	✓				✓
IS06	Dance with me	a composition game		●	⌖	L	✓			✓	✓	
IS07	Build a tower	Solitary constructive game		●	⌖	L			✓		✓	✓
IS08	Bring me the ball	Cause and effect game	⌖	●	⌖	M	✓				✓	✓
IS09	Get in contact	Sensory stimulation game	⌖	⌖	●	M	✓	✓			✓	✓
IS10	Pretending to be a character	Pretend play		●	⌖	H		✓				✓

Fig. 4. Selected IROMEC Play Scenarios with relevant user groups and play type [17]. Definition of play types is using the ESAR classification from IROMEC partner AIJU [18]

IROMEC project claims to strictly adhere to a user-centered design approach. Different kinds of users, therapists, care-givers, children and parents have been iteratively involved in the design of the robot. However, transfer of the play scenarios and the requirements collected during the user panels into a robotic design has been a very challenging task. Problems range from the difficulty of reconciling conflicting needs and different expectations about the final system to the problems of a more direct user involvement into the design process. The final design solution includes a modular and configurable robot platform which allows addressing the very specific needs of each user group and leaves room for the further investigation of consolidated play activities as well as definition and implementation of new scenarios at a later stage. Main components of the robot include *a mobile robot platform*, a dedicated *interaction module* and a *teacher console*. The interaction module mainly consists of a *body* with GUI elements, a *head* with a digital display for both expression and orientation, and *manipulator arms* to guarantee basic manipulation features. Some *add-on components* – like exchangeable coatings for the body with different effects, physical face mask, fur elements, etc – provide additional means for personalization and customization of the robot.

The robot has two main configurations: horizontal and vertical (Fig. 5). In both configurations the body of the robot has a bilateral symmetry. Furthermore, in both configurations the position of the head clearly shows the front of the robot. In vertical configuration the interaction module can be used in "stand-alone" mode – i.e. without need to be connected to the mobile platform and resembles the shape of a human body. In horizontal configuration – in connection with the mobile

Fig. 5. Basic design of the IROMEC robot in vertical and horizontal configuration

platform – the robot supports a complete set of activities requiring wider mobility and dynamics. In this configuration the robot has a vehicle-like appearance that suits the requirements of Action and Coordination Games. [19]

2.2.2 Prototype and First User Trials

Based on the aforementioned scenario descriptions and the design concept a first prototype of the IROMEC robot has been realized by end of 2008. An evaluation phase has been started in order to assess the prototype's usability, taking into consideration the robot's general usability, the valuation of the play scenarios and, finally, checking the enjoyment and motivation levels experienced by users with regard to the robot.

During this phase the robot has been at six different centres (all over Europe) between February and April 2008. Over the period of evaluation, the robot has been used in a number of trials that have provided some important results for redesign of the robot and implementation of new functions.

Fig. 6. IROMEC robot (in horizontal configuration) during user trials

37 users participated in the robot's first assessment phase. This includes autistic users with several motor impairments and children with mildly mental retardation. Concluding the trials, the robot has been very positively valued by all the experts who took part in the evaluation. The feedback collected from the secondary users shows that the robot found high interest. Overall assessment is very positive as regards of usability and playability. Another result of the trials is a set of proposals and requirements for redesign and extended functionality which will further improve the performance of the IROMEC robot.

Conclusion

This paper reports on a new research topic dealing with "Robot Assisted Play" for disabled children. Two robot systems are under development coordinated by the author. The PlayROB system aims to assist in manipulation of standard toys and thus allows autonomous playing. A first prototype system as well as a small series of six robots for playing with LEGO™ bricks have been developed and successfully evaluated during a couple of user trials. The second system described here – the IROMEC robot system – is designed to serve as a mediator during playing, increasing the interaction between disabled children and addressing basic objectives according to the ICF-CY classification. Also in this case a first prototype has been developed and could already demonstrate its appropriateness and possibilities to users.

Concluding this paper it should be accentuated that disabled children should get improved access to toys to play with and – besides learning – to simply have great fun. Up-to-date technology can be a useful tool to realize adapted toys for any kind of disabled children.

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