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Robot Assistance in Playful Environment – User Trials and Results

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Abstract — **From a developmental and educational perspective, play is a "natural" way in which children learn in an enjoyable manner. Through play, juveniles interact with their physical and social worlds and 'construct' their mental world. This paper describes a dedicated robot system realized by Austrian Research Centers GmbH – ARC, which supports children with severe physical impairments for interaction with standard toys. Beside of a description of the robot system the paper gives first results from user trials and outlines future development.**

I. Introduction

It is a well known fact in the field of developmental psychology that interacting is substantial for child development [1], [2]. Playing is an important part of daily life interactions as well as 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". Play is then considered one of the most important aspects in a child's life, a parameter to be considered for assessment of children's "Quality of Life". On the other hand, children with physical disabilities only have limited possibilities for interaction with social and material environment.

Based on a related study accomplished by the authors [3], the question arose whether a remote controlled robot system could be able to assist severe physically disabled children when playing with toys. The main opinion derived from interviews with therapists and parents was that children with physical disabilities cannot have the same interaction experiences which able-bodied children have. In most cases they are not able to manipulate real objects – they very often need a person who can complete actions through the child's orders. Resulting from this lack of experience the disabled children often have to suffer from a second handicap – in most cases a developmental delay [4]. Most of the therapists and parents are in complete agreement that the use of new technology (for playing and learning) offers benefits for this target group. However children should play and learn – at least in the early stages of development – in *real* environments, as this is seen as the basis for a good performance in the virtual world (PC-based play and learning; cf [5]) as well. A main wish expressed during the interviews is that the target group should receive more opportunities for doing activities independently. Technical toys can be a reasonable solution for this user group. Such a setup should give the experience to move objects and initiate actions in their own environment.

In the following, this paper discusses the use and the effects of applying a first solution of such a toy robot system for physical disabled children in order to support playing and learning.

II. Related Work

For the (robot) toy market several systems are commercially available, e.g. AIBO robot dog from Sony Inc., MyRealBaby from Hasbro, or MINDSTORMS from LEGO Inc. These systems are moderately successful as toys and also sometimes used for educational purposes. Previous experience however has shown that these kinds of systems are limited for the intended use in a playing scenario with severe disabled children.

Other ongoing research projects are investigating different setups and interaction possibilities between robot and human(s) in the framework of "personal robots", like the NEC Research laboratories developing the personal robot PaPeRo to become a "family member". Similar work – but more related to Human-Robot-Interaction (HRI) – can be observed in different research laboratories world-wide. MIT Media Lab – for example – is working on the interaction aspects for sociable robot systems in a laboratory setting; a recent 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 cannot be directly applied to the area of assistive technology. For example, work at ATR with Robovie, as well as other work,

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has shown that interaction levels with children decrease over repeated exposure.

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 [9] – a similar approach is by Omron with their NeCoRo robot system, and Michaud *et al.* who are designing robots for child-development studies [10]. Dautenhahn *et al.* has investigated since 1998 the role of robotic toys in therapy and education of children with autism [11] 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.

In the area of robot-assisted playing early research was done by Cook *et al.* [4]. In a series of experiments they analyzed how children with significant physical disabilities could use a robot arm to interact in a play and exploration activity. Smith and Topping [6] reported about commanding a robot for a playful scenario using single switch scanning. Howell *et al.* [7] presented a robotic system installed at an elementary school utilized for science instruction. Davies [8] described a prototype for a "playing robot" which aims to give assistance during either a painting or a building scenario. The common theme for all of these scenarios is to use the robot for improved interaction with and exploration of 3D objects. The robot assisted playing interaction with a standard toy presented in the present paper can be seen as further extension of that concept. As the main focus of the playing/ learning setup is on spatial ability, LEGO™ bricks were selected as toy.

III. ROBOT ASSISTED PLAYING

As mentioned earlier the main objective of the research described here is to open access to common toys for children with different kinds of physical disabilities by means of up-to-date (robot) technology. In the first phases of the project, commercially available toy systems were equipped with dedicated interfaces in order to allow various kinds of interaction with the real world. Another (coherent) approach was to use small commercial robotic (or robot-like) toy systems for playing action (e.g. LEGO MINDSTORMS™). Experiments have shown that with increasing functionality of the toy the child more and more took over a passive role during play, which actually was in contrast to the desired scenario.

Based on these results a remote controlled robot system finally was chosen to assist the child during play (Fig. 1). Such a 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 Playing" 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. 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 therapeutic needs.

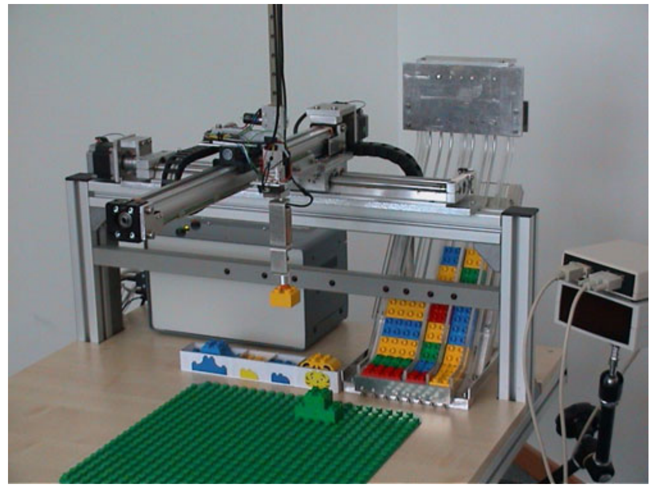

Fig. 1: First prototype of the remote controlled robot system [12]. The robot consists of three linear axes in Cartesian configuration. For supply with toys – i.e. LEGO™ bricks – a stacker system is being integrated to the system. Operation of the system is via standard input devices for AT – like special joystick, 5-key input device, mouth operated joystick or single switch – connected to a standard interface box.

A. *User trials and Results*

For user tests six children were invited to use the robot prototype. For first trials three able-bodied children (between 5 and 7 yrs old) were confronted with the system for three playing sessions each. Beside further evaluation of the system concept and the user interface there was also an evaluation of different playing setups (i.e. "free playing", reconstruction of pre-defined figures, etc.). In a second series, three disabled children (between 9 and 11 yrs old; child 1 – multiple disabilities; 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.

The user tests revealed that the chosen approach for a robot system can be an attractive device for children with physical disabilities. One child from the group of disabled users did not fully understand the link between using the input device and the control of the robot. In general, most of the children enjoyed playing with the system and the goal to make autonomous play for children with physical disabilities possible has been fully achieved.

IV. ROBOT SYSTEM PLAYROB

The very positive results from the first user trials have motivated to start a significant re-design and realization of a "near-to-market" solution. Main criteria for the re-design were reduction of the system costs compared to the first prototype as well as improvement of system safety.

A. Robot Hard- and Software

Similar to the first prototype, a 3DOF (degrees-of-freedom) Cartesian configuration was chosen for the robot. First of all, this setup supports the desired “low cost” approach by using standard components for the linear robot axes. In addition, the behavior of the kinematic chain during movement is easy understandable (compared to other kinematic types) which may increase safety and acceptance of the robot system. In order to allow maximal accessibility, the robot system only has one portal for the main axis and to other cantilever axes for positioning of the LEGO™ bricks. Thus, the entire system can be accessed from three sides which also allows cooperative playing. 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. 2). 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.

For the used gripper system, the main requirement – aside of robustness and “low-cost” - is that the footprint of the gripper system has to be smaller than the smallest brick used, in order to allow unrestricted inserting of bricks at any required position on the playground. Due to the observed problems with the original gripper design for the prototype, a new design was realized for PlayROB. This new gripper is based on a modified toy brick. A magnetic actuator is releasing the gripped LEGO™ brick after positioning on the playground.

The storage system for the toy bricks plays a decisive role as any disturbance during brick supply will stop playing immediately. Basically, the storage system consists of a set of supporting rails (made from aluminum) and center selvedge made from acrylic glass. As a consequence of the misalignments of bricks due to varying friction parameters for the prototype system, the new design of the storage device is not using gravity for brick feeding only but is now additionaly equipped with a servo-actuated loading mechanism for stable and accurate positioning of toy bricks at the loading position.

Finally, the control system for PlayROB was subject of redesign. Contrary to the first prototype described in [12], synchronisation of the three axis controllers as well as of the auxiliary devices is now accomplished by an on-board embedded PC (BSD operating system), which is also used for complete documentation of each playing session. Set-up of the playing session – i.e. administration/selection of user profiles, selection from pre-defined system settings, self-diagnosis function – is supported by a touch-screen device integrated into the housing of the robot.

Fig. 2: Robot system “PlayROB”. The system is mounted to a mobile rack; most of the moving parts are hidden behind a cover in order to improve system safety.

For later investigation of a possible learning effect, 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. Another new feature – also related to the above mentioned recording of the playing sequences – is the “Playback” function. If demanded, this feature allows fully automatic reconstruction of an earlier playing session.

Download of the recorded “log-files” as well as upload of system parameters (in order to configure the system to the particular needs of any new user) is accomplished by a TCP/IP connection. The user interface for these process steps is designed for any standard web browser – the “web” server is being installed on the on-board controller PC.

B. Playing Sequence

In order to evaluate any learning effects it is required to assign each recorded “log-file” to the responsible player. Thus, a basic study database is being implemented at the controller PC. When starting a new session, the player has to be identified by either selection from a list of existing players or specification of some key information (name, age, grade of disability). After initialisation of the robot axes (“Homing procedure” in order to set each robot axis to a defined starting position) the system is now ready for operation.

Using a dedicated input device (5-key switch, head switch, joystick, etc.) the user firstly can chose a particular brick type by moving the gripper to the desired magazine position. After confirmation of the storage tray the robot automatically moves down to the particular loading position and grasps the brick.

After automatic positioning of the robot to a predefined starting point, the robot can now be freely positioned on the playground by means of the four direction functions of the connected input device. After reaching the desired position the brick is inserted to the playground and released by the gripper by activating the confirmation function of the input device. Optionally, the contour of the brick is projected to the current position on the playground by means of a special designed laser projector in order to have better guidance during positioning of the brick.

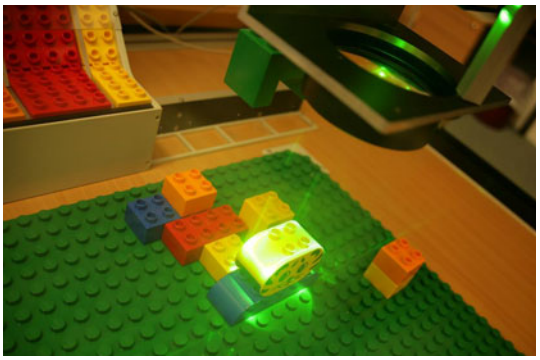

Fig. 3: Projection of the contour of the next brick in order to support the brick placement.

All robot movements are with constant speed and with predefined step size, i.e. the robot only moves to valid positions (loading position for each particular magazine, valid insertion points at the playground) in order to avoid time consuming fine positioning or misalignment. Using this pre-defined "motion primitives" allow operation of the robot by children which do not have the ability of setting fine motion commands.

After reaching the desired position the brick is inserted to the playground and released by the gripper by activating the confirmation function of the input device. Finally, after releasing the brick, the robot automatically returns to the position of the previously selected magazine and the next playing sequence can be started.

C. *Multi-Center Evaluation*

An important research question for the proposed "Robot Assisted Playing" setup is to investigate possible and estimated learning effects. A multi-center study should help to get reasonable answers to that question. Thus, six PlayROB systems were installed at selected schools and therapy institutions in winter semester 2004 and in summer semester 2005 respectively in order to introduce the system to as many children as possible. Playing with the robot should be included into the regular therapy plan in order to support the evaluation of learning effects.

For the desired evaluation of learning effects the following parameters are being 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/Wr. Neustadt, Institut Keil/Vienna, Vereinigung zu Gunsten körper- und mehrfachbehinderter Kinder und Jugendlicher/Vienna). At each of the three sites, about 5-10 children are using the PlayROB system on regular basis. All of the users are showing significant physical handicaps – 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 laser guidance during brick insertion is a very helpful tool for most of the children. The additional rack for the input device introduced for the second series of PlayROB systems shows a very positive impact to the sitting position of the children and thus contributes to an extended playing time. Also the other redesign measures for improvement of the robot speed (especially for the pre-positioning movements without brick) as well as of the setup procedures 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 (fig. 4). 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.

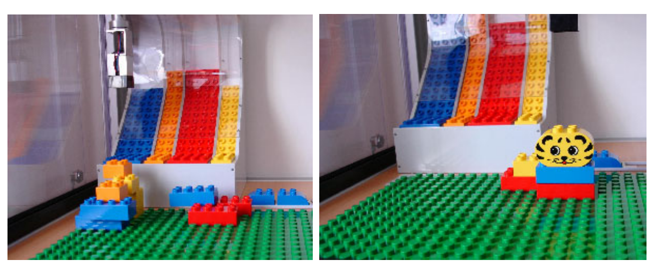

Fig. 4: Test recording over time for one particular player

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 results obtained during this stage of user trials are confirming the results of previous phases. Most of the children show significant advancement in terms of endurance and concentration, but also of spatial perception. Furthermore general improvement of motivation during the lectures is been identified as result of the work with PlayROB. The robot system also is turning out as optimal tool for training with input devices – children are learning different features of the particular input device in a playful environment and with high motivation.

In depth analysis shows a considerable improvement of the recorded parameters for many children. To give an example, figure 5 shows changing of parameters over time for one selected child (14 yrs; spastic tetra paresis). During the first phase of the test the subject was using one or two different brick types only, and also placement of the bricks was limited to a very small area. At later phases in this long term evaluation the child uses a bigger variation of brick types for the construction also covering a larger area on the playground. It is also evident from the recorded data that the duration of the playing sessions is increasing significantly over time. It is reported from the institution that the child had very much fun with PlayROB – he even claims to play with the robot as this is one of the rare opportunities for autonomous work.

Dauer	4,03	20,68	11,11	11	40,53	39,21	22,21	51,46
AZ B/S*	6	17	9	11	34	32	22	44
HV B1**	0	52,94	100	27,27	29,41	25	4,5	22,72
HV B2**	33,3	47,05	0	54,54	29,41	25	31,81	18,18
HV B3**	33,3	0	0	18,18	32,35	21,87	31,81	22,72
HV B4**	0	0	0	0	8,8	21,87	31,81	20,45
HV B5**	0	0	0	0	0	0	0	0
HV B6**	16,6	0	0	0	0	3,12	0	9,09
HV B7**	16,6	0	0	0	0	3,12	0	2,72
HV B8**	0	0	0	0	0	0	0	4,54
BG/min***	1,48	0,82	0,8	1	0,83	0,81	0,99	0,85
RS****	0	0	5,88	0	0	0	0	3,55
OS*****	0	0	5,88	0	0	0	5,88	4,14
ASP******	4,54	2,47	4,95	4,54	9,09	8,05	5,78	20,86

Fig. 4: Test record over time for one particular player.
"Dauer" = Session Duration; "AZ B/S" = Number of used bricks during one session; "HV B*i*" = Usage ration for brick type *i* [%]; "BG/min" = Construction speed in bricks per minute; "RS" = Step back [%]; "OS" = Orthogonal steps; "ASP" = covered area at playground [%]

Analysis of the recorded parameters for all involved children leads to the following results:

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

Aside of this quantitative analysis there is also a qualitative evaluation by the teachers/therapists from each involved institute. For example one institute reports that after a 6 month evaluation period – from 7 children playing regularly – one child finally is able to play without any manual or verbal intervention, one other child is able to play with only needing minor verbal intervention. One child is already using the entire playground area and creates rather complex constructions.

All three institutes are 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 is recognized as "learning with great fun".

Tests 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 our expectations. For further evaluation studies this has to be considered in more detail.

V. Future Work

Children with multiple impairments may have difficulties to understand this system, as the user-tests have showed. For this target group an easier handling of the robot has to be developed. For example they can freely choose bricks but put it onto default positions. Thus, the toy robot would get more automated and less autonomous play is possible. This of course raises the question: How much automating is useful and/or desired for this robot system? Finally the robustness and the fault tolerance will be continuously evaluated during the next test phases.

Another application of the knowledge obtained in the PlayROB project is for the EC funded project IROMEC started in fall 2006. 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 will be developed and evaluated by means of a dedicated robot setup in the context of therapy and education. The 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 behaviours and interaction modes. IROMEC will investigate how robotic toys can provide opportunities for learning and enjoyment. The developed robotic system will be 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 "plug&play" operation of the robot system are specially addressed.

VI. Conclusion

This paper reports on a new research topic dealing with "robot assisted playing" for severe physically disabled children. The robot should assist in manipulation of standard toys and thus allow autonomous playing. A first prototype system as well as a small series of six robots for playing with LEGO™ bricks was developed by the authors and successfully evaluated during a couple of user trials.

Concluding this paper it should be accentuated that physical 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 severe physical disabled children.

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