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Virtual robot and virtual environments for cognitive skills assessment*

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Abstract. Robots with adapted controllers have been used to assess cognitive skills of children with motor impairments who are sometimes difficult to assess with standardized tests that rely on verbal or motor responses.
Objective: Develop a virtual robot and virtual scenarios for cognitive skills assessment.
Main content: The paper describes the development of a virtual robot and virtual scenarios that mimic the physical robot and activities of a previous study. The goal is to use this virtual robot for comparing children's experiences using both the physical and the virtual robot, as measured by their performance executing the proposed activities. If experiences are equivalent, virtual robots, simulated environments, objects, and activities could be developed and widely shared and utilized without the need for a physical robot. The paper also reports a pilot study of the developed virtual robot involving three typically developing children, aged three, four and five years.
Results: Pilot test participants were able to perform the activities according to their cognitive age both with the virtual and with the physical robot, showing that the virtual robot and the virtual environments are close enough to their physical counterparts.
Conclusions: The developed system adequately mimics the physical robot and activities of a previous study. With minor adaptations, it will be used in the experimental part of an ongoing research project to assess if children's experiences using the virtual and the physical robots to perform the same activities are equivalent.

Keywords. Assistive Robots, Virtual Robots, Cognitive Development.

Introduction

Cognitive development of children with disabilities is often difficult to assess since standardized tests usually rely on verbal or motor responses [1, 2]. Even when children are only required to be able to point in some way, eye gaze included, making a choice among different options provided, standardized cognitive tests may not be reliable since children rapidly lose interest in answering questions that are meaningless to them. Children with disabilities may thus be perceived as being more developmentally delayed than they actually are, leading to reduced expectations on the part of teachers, clinicians and parents [3].

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To overcome these limitations, robotic systems and appropriate activities have been designed to assess cognitive skills of children [4, 5]. The underlying idea is to design play activities that require different cognitive skills using the flexibility of a fully programmable robotic system. Robots can be programmed to simply replay stored movements following a switch press, or be fully controlled by the user, using several switches for the different degrees of freedom. Different robot levels of autonomy require different user abilities, the less robot autonomy, the more demanding cognitive skills required. Observing children playing with the robots may thus provide a proxy measure of children's cognitive skills. Previous studies have demonstrated that even very young children are able to control the robots and that robot activities are more motivational than single-switch tasks with toys, appliances and computer-based activities [6, 7, 8].

However, the use of current physical robotic systems requires the involvement of a professional with technological skills to assemble and program the robots, the availability of the hardware, and the ability to deal with the limited reliability of current low-cost robots. Although the robots used in studies [4, 5] were low-cost compared to earlier studies [6, 7, 8], they are still expensive for some populations. This suggests the use of virtual robots and computer simulated environments since it would be easier to download and use a specific software package than to obtain, assemble and program a physical robot. Standard computers and commercial assistive technologies that provide access to the computer for children who have disabilities could then be used. Moreover, activities could be easily parameterized to match children's preferences (e.g., using different robot shapes or using different scenarios for cognitively equivalent tasks).

The major questions are: "Would children's experiences be the same with the virtual robots? And would the system be as appealing as the physical robot?" To answer these questions, a research project was set up involving the Faculty of Engineering of the Catholic University of Portugal, the Faculty of Rehabilitation Medicine of the University of Alberta, Canada, and the Portuguese company ANDITEC, Tecnologias de Reabilitação, L.da, with the collaboration of the Calouste Gulbenkian Rehabilitation Centre for Cerebral Palsy, and the funding of the Portuguese Science and Technology Foundation. Project COMPSAR – COmparison of Physical and Simulated Assistive Robots aims at comparing the experiences of children with and without disabilities using identical physical and virtual robots to perform the same tasks. Robot skills of typically developing children, aged three to five years old, when operating both the physical and the virtual robot, will be evaluated. If children's performance does not depend on the robot used, one can conclude that the physical and the virtual robots provide the same experiences in this context. The same skills will be evaluated with developmentally matched children with disabilities. A comparison between the two groups will also be made in order to investigate if the use of physical and/or simulated robots by children with disabilities is a feasible method to assess children's cognitive skills. All participants will be screened using the Pictorial Test of Intelligence (PTI-2) [9] to be assigned to the appropriate developmental age group. Participants with disabilities will be recruited among children with Cerebral Palsy within levels 1 to 3 of the Gross Motor Function Measure (GMFM-66) [10] and therefore all will be able to control up to three different switches.

This paper reports the development of the virtual robot and simulated environments for the COMPSAR project. The work builds on a feasibility study by Wang et al. [11] where it was shown that a virtual robot could be designed and controlled more easily than the physical robot. Ten adult participants without disabilities, four females and six males, participated in the feasibility test. The virtual robots and simulated environments were redesigned in the present work to match the physical robots reported in [5] more closely than in the feasibility study by Wang et al. [11]. A pilot test with three typically developing children, aged three, four, and five years, was conducted to assess children's perception of the developed system. This also served as a pilot test of the experimental protocol that will be used within the COMPSAR project.

1. Robot activities and cognitive skills

To the best of the authors' knowledge, Forman [12] was the first to study young children's cognitive skills required to control robots. He addressed five problem solving skills: causality, spatial relations, binary logic, the coordination of multiple variables, and reflectivity. The level of skill in these areas varied with the age of the children. Based on Forman, Cook et al. [4] developed a table that relates robot skills to the development of cognitive skills. From this table, it is possible to design activities to be performed using robots to test cognitive skills of children, meaning that children will only succeed in performing the given task if they have a specific cognitive skill. Activities for a truck-like Lego roverbot to access causality, negation, binary logic, sequencing, and reflectivity are reported in [5]. Eighteen typically developing children aged three, four and five years were observed in the study. The results showed that performance varied with developmental age, consistently with Forman's work [12].

The same activities in [5] were implemented in a computer simulation for the COMPSAR project. In Task 1 (cause and effect) the child is required to press and hold a switch to make the robot drive forward to knock over a stack of blocks (Figure 1a). Task 2 (negation) requires the child to drive the robot forward, stop to pick up blocks and then drive the robot to the location at which they were stacked for the first task, using the same switch as for Task 1 (Figure 1b). In Task 3 two stacks of blocks are located one to the left and one to the right of the original stack. The child is required to turn the robot left or right at a T-junction using one of two new switches and then press the original forward switch to drive the robot to knock over the stack of blocks (Figure 1c). This assesses binary logic and sequencing. Finally, each child was interviewed after using each robot to learn how they viewed the tasks. For example, participants were asked what are the functions of each switch and what might happen if one particular switch was disconnected (previous three year olds said it would work the same).

A Lego® Mindstorms® NXT 2.0 Tri Bot was used in this work. The robot (physical or virtual) was controlled through three standard Jelly Bean® switches connected to a laptop computer via a Sensory Software Joybox[2]. The forward switch made the robot move straight forward as long as it was pressed. Left and right switches made the robot turn exactly 90 degrees with each press. While turning, no other switch input was considered. Subsequent commands were only accepted after completion of the 90 degrees rotation. The robot control programs for the tasks were developed using the Visual Programming Language in a Windows-based environment of Microsoft Robotics Developer Studio 2008 R3 (MS-RDS) and Microsoft Visual Studio 2008 C#. The programs created can control both the physical (via a Bluetooth remote link) and the virtual robots.

[2] www.sensorysoftware.com

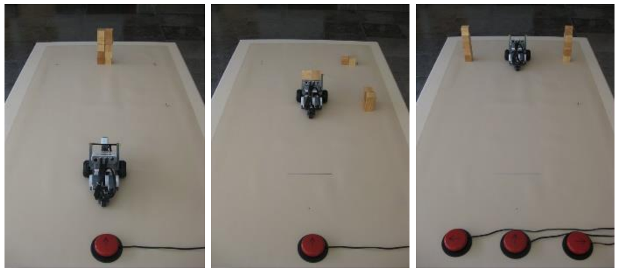

Figure 1. Physical Robot activities and cognitive skills: a) causality, b) negation, and c) binary logic and sequencing.

2. Virtual robot and simulated environments

A virtual environment simulating real-world physics, textures and sounds to match the physical environment was developed using DSS Manifest Editor and Virtual Simulation Environment of the MS-RDS. The Lego® Mindstorms® NXT 2.0 Tri Bot is already available in MS-RDS simulation environment and the NXT Intelligent Brick that controls the robot is also included in the package. A virtual table, covered with a mat with marks to facilitate replication of the experimental setup (used with the physical robot), and a set of blocks to be knocked over were created to closely resemble the physical scenario. The virtual setup was situated in a virtual classroom, a familiar scenario for children. Physics simulation provided by MS-RDS makes the manipulation of the virtual entities quite realistic. For example, a pile of blocks is only knocked over if the robot hits it hard enough. Or the robot drops off the table if one drives it past the edge of the table. Sounds can be associated to different events in the simulated world. The sound of the physical blocks falling down was recorded and associated with the event of blocks hitting other virtual objects, namely the table or floor.

Figure 2. Virtual robot activities: a) causality, b) negation, and c) binary logic and sequencing.

The three tasks described above were then implemented in the virtual environment (see Figure 2). An application to control each activity and record children's performance was also designed (see Figure 3). Within this application, the researcher can start each activity, virtually load and unload blocks onto the virtual Tri Bot if the child stops the robot close enough to the required positions in Task 2, and record if the child succeeds or not in performing each task. An Excel file is automatically created with information regarding participants' performance (see Table 1). Number of trials, number of successes, and number of switch hits to perform the tasks are recorded. Additionally, the average number of hits required per task is computed and saved into the Excel file. Since the physical robot is also controlled using the same switches connected to the computer, this control application is also used with the physical robot to keep track of children's performance. An external monitor is used for the experiments with the virtual robot so during tests participants only face a table with the switches and a monitor showing the virtual robot and simulated environment. The laptop that controls the virtual world displays the control application to be managed by the researcher. Figure 4 illustrates the experimental setup for the virtual robot. HyperCam™ was used to capture the Windows screen and a video of the participant's upper body for later analysis.

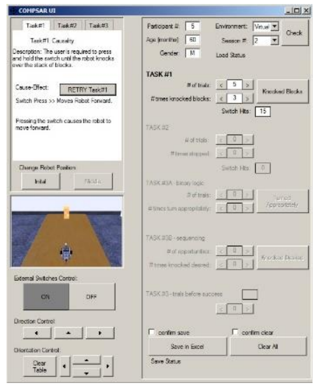

Figure 3. Control application after participant #5 has tried Task 1 five times with the virtual robot in the second session, having succeeded three times, using a total of 15 switch presses.

Figure 4. Virtual robot experimental setup.

3. Pilot test

A pilot test of the experimental setup was conducted involving three typically developing children aged 37, 47 and 62 months. The objective of the test was twofold: first to assess children's perspective of the experimental setup developed, second to test the experimental protocol to be used in the COMPSAR project.

The pilot test was conducted at the Calouste Gulbenkian Rehabilitation Centre for Cerebral Palsy. Participants were family members of collaborators of the Centre. Children were required to perform the three activities, both with the virtual and the physical robot, with a 15 to 20 minutes recess between sessions. The order of robot presentation was randomly selected. After each session, a questionnaire about the switch functions was administered:

Question 1: "When this switch [F] is touched, where does the robot go?"

Question 2: "If the robot is turned [90 degrees to the left] and I touch this switch [F], where will the robot go?"

Question 3: "If the robot is turned toward you [facing the child] and I touch this switch [F], where will the robot go?"

Question 4: "When this switch [<--] is touched, where does the robot go?"

Question 5: "When this switch [-->] is touched, where does the robot go?"

Question 6: "If the wire to the switch is disconnected and I touch this switch, what would happen?"

The test was conducted by a psychology research assistant with the collaboration of two engineering research assistants (to help in setting up the physical robot and blocks and operating the video camera). Other members of the COMPSAR team were also present, as well as two external observers (a psychologist and an augmentative and alternative communication specialist). A debriefing session took place after the pilot test for in depth discussion of the results.

4. Results

The virtual robot was randomly assigned for the first session with the youngest participant. He refused to play with the robot, not wanting to press the switch. The research assistant encouraged him to participate, even demonstrating the activity, but the child always refused to use the switch and eventually started to cry. The session was promptly suspended. After the recess, the physical robot was shown to the child in an attempt to engage him. However, he still didn't want to play with the robot.

Participants aged four and five years were more cooperative. The four years old child started with the physical robot, while the five years old started with the virtual robot. Tables 1 and 2 compile the results of their sessions. Question 2 was not asked to participant #3 after the virtual robot session.

Table 1. Participants #2 and #3 results performing the three tasks.

Participant #	2	2	3	3
Age [months]	47	47	62	62
Gender	M	M	F	F
Physical/Virtual	Physical	Virtual	Virtual	Physical
Session #	1	2	1	2
TASK 1 – CAUSALITY				
# times knocked over blocks	3	2	2	2
# of trials	3	2	2	2
Average # of hits required for task	1,67	2,00	2,00	2,50
TASK 2 – NEGATION				
# times stopped	3	5	4	4
# of trials	5	6	6	4
Average # of hits required for task	2,60	2,00	1,33	3,50
TASK 3A - BINARY CHOICE				
# times turn appropriately	3	2	3	2
# of trials	3	3	3	2
TASK 3B – SEQUENCING				
# times knocked over desired stack of blocks	2	2	2	2
# of trials	3	2	3	2
LEARNING PROCESS FOR TASK 3				
# of trials before success	0	0	1	0

Table 2. Participants #2 and #3 answers to the switch functions questionnaire. "0" codes a wrong answer, "1" codes a correct answer, n.a. stands for "not applicable".

	#2 Physical	#2 Virtual	#3 Virtual	#3 Physical
Question 1	1	1	1	1
Question 2	1	1	n.a.	1
Question 3	1	1	0	1
Question 4	0	0	0	0
Question 5	0	0	0	0
Question 6	1	1	1	1

5. Discussion and conclusions

The three year old participant refused to use the switch to control the robots, appearing to be afraid of what might happen if he touched the switch. The fact that the child was taken out of his family group to participate alone in the study might have influenced his behavior. Something similar occurred with one of the youngest participants of the study reported in [3], when his older sister had to demonstrate the activity before he would use the robot. Thereafter he was always happy to play with the robot. The experimental part with typically developing children of the COMPSAR project will take place in school settings to avoid shy behaviors induced by the presence of family members. A prompting hierarchy will be created so researchers can keep track of the amount of prompting necessary for each participant.

The results of participants #2 and #3 can only be qualitatively analyzed to conclude that children were able to perform the tasks both with the physical and the virtual robot, showing that the virtual environment was realistic enough so children managed to succeed at least twice in each task. They both looked engaged in the activities with the virtual and the physical robot. Answers to questions 4 and 5 regarding the turn switches were considered incorrect since participants pointed left or right as if the switches made the robot drive in those directions, when in fact the switches made the robot turn 90 degrees. Interestingly enough, the four year old participant looked under the table when the virtual robot dropped of the virtual table, in the virtual environment. The five year old child, after using the virtual robot, answered the question regarding what would happen if the switch was disconnected saying "the game wouldn't work". After using the physical robot, she said "the car wouldn't move" in response to the same question.

To visually support questions 1 to 5 following virtual robot use, virtual scenarios will be created with only the virtual robot on top of the table heading in the direction corresponding to each question.

The experimental protocol for the COMPSAR project proved in general to be appropriate and a script will be formally written to standardize the interaction with children when using the virtual or the physical robot as much as possible.

The experimental part of the COMPSAR project will begin with the observation of typically developing children. Their answers to the questionnaire will provide the vocabulary to be used in designing communication boards if any participant with disabilities requires an alternative communication system. Since all participants will be previously screened using the PTI-2, the researchers will know in advance if such alternative communication systems are needed or not.

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