Blending Robots and Full-body Interaction with Large Screens for Children with Intellectual Disability

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ABSTRACT

The core contribution of this paper lies in exploring new spaces of interaction for children with Intellectual Developmental Disorder (IDD). In the KROG (Kinect-RObot for Gaming) Project, we blend full-body interaction, virtual worlds on large screens, motion sensing technology, and mobile robots to support game-based interventions. This paper highlights the design challenges induced by this mix of technologies and interaction paradigms, presents the prototypes that have been iteratively designed and tested with 22 specialists, and discusses the lessons learned from our project.

Categories and Subject Descriptors

K.3.0 [**Computers and Education**]: General, H.5.2 [**Information Interfaces and Presentation Multimedia Systems**]: User Interfaces, 1.2.9 [**Robotics**]: Commercial robots and applications.

1. Introduction

In recent years, we have witnessed a rapid growth of interactive applications to support interventions for children with intellectual developmental disorder (IDD). Our research explores novel interactive learning technologies for this target group. We adopt a game-based approach and blend two interaction paradigms: *full-body interaction* and *interaction with mobile robots* (Figure 1). Full-body interaction is a general term for a wide set of technologies that enable the use of body as interaction device to control multimedia contents or digitally enriched physical artifacts. In our research, full-body interaction refers to the capability of interacting with virtual worlds on large screens using body movements or mid-air gestures at the distance. Mobile robots are motion-enabled objects instrumented with sensors and actuators. Sensors detect user's actions (e.g., speech, physical manipulation, movements), while actuators provide multisensory stimuli, e.g., light effects, vibrations, or movements.

Previous research have explored either full-body interaction [1][2] or human-robot interaction [3][5][9] for IDD subjects and have empirically proved that each of them, alone, has a huge learning potential for this target group. Full-body interaction can support kinesthetic and visual learning, and can bring benefits in terms of cognitive and social skills [1][2][3]. Mobile robots can act as social and emotional facilitators [4][6][7][8]. Still, the integration of these two paradigms has been seldom explored. It is largely unexplored how to blend them and which are the benefits of this combination for IDD children.

This paper sheds a light on this field and presents the work of the KROG (Kinect-Robot for Gaming) Project. We discuss the design challenges of integrating full-body and robotic interaction, and introduce our design process, which was performed in cooperation with 22 specialists. We outline the requirements and guidelines that emerged from this process, and describe the prototypes developed in KROG, which have been evaluated in a preliminary exploratory study involving 22 IDD children and 11 caregivers.

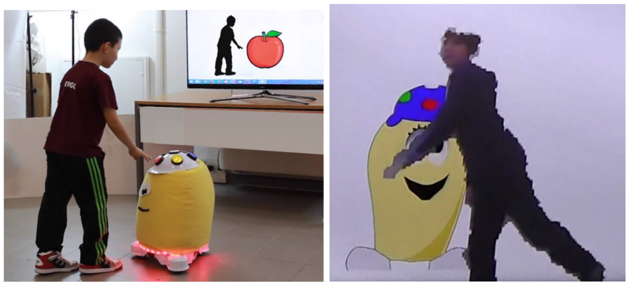

Figure 1: Interacting with robot and on-screen virtual world

2. DESIGN CHALLENGES

To integrate full-body and robotic interaction, the designer must orchestrate the behavior of different types of interactive actors: children, robots, and on screen digital elements – which behave and interact both in the real world and in virtual world, use different interaction modalities, and might be constrained by the characteristics of the physical world (Figure 2).

Figure 2: Example of physical space constraints

On screen digital elements are digital representations of the robot or the children, or characters of narratives, or virtual companions. Children interact with the robot using movements, touch, and physical manipulation, and interact with on-screen

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elements using mid-air gestures and movements in the physical space. The effects of children's interactions are actuated on the robot or in the virtual world. The robot behavior, affected by children's actions and by virtual world events, is expressed by movements, vibrations, sounds, or light effects, and can change the state of the virtual world. On-screen digital elements can react to the robot's and the children's behaviors, e.g., providing suggestions, instructions, and rewards.

Mastering this complexity is a design challenge per se, which increases when the UX must be conceived for IDD children, who have difficulty to process many simultaneous stimuli and may reject them.

3. REQUIREMENTS ELICITATION

To address the challenges discussed in the previous section, our design process has involved 22 specialists (psychologists, motor/psycho-therapists, special educators and neurological doctors) from 6 therapeutic centers in Italy. Within a period of 7 months, we organized 5 half-day focus groups (Figure 3) for small teams of specialists and 5 meetings with therapeutic center directors.

Figure 3: Focus groups with IDD specialists

The working materials used for these events comprise progressive design alternatives for the robot and the on-screen elements, rendered using paper-based sketches, digital images and animations, and physical prototypes. Wizard of Oz techniques were used to simulate the behavior of the robot and on-screen virtual worlds. Several questions were addressed in the sessions with specialists: “What is the profile of the IDD children who may benefit from our technology?” “What are the perceptual and cognitive affordances of the robot and the virtual worlds?” “Which stimuli should they provide to the children?” “What roles can the robot/virtual world elements play in the different moments of children's play? “What are the conventional educational and therapeutic practices and how can they be translated into, or integrated with, activities that make use of our technology?

According to our specialists, the target group for which our technology can be particularly appropriate comprises IDD children with low or medium cognitive level (IQ ranging between 35 and 60) who exhibit lacks in two or more specific areas of adaptive behavior (communication skills, interpersonal skills, or daily living skills).

To actively participate in any skill-oriented learning task and ultimately gain some benefits from this experience, a prerequisite for these children is to preliminarily achieve two emotional states – relaxation and affection. *Relaxation* is a state of low tension and absence of anger, anxiety, or fear. It is particularly important for IDD children because these subjects are typically scared of everything that breaks their routine or is unknown. Only after the child is relaxed, she may reach the state of willingness to participate in any skill-oriented learning activity. Still, this participatory state may not persist unless also a state of affection is reached. *Affection* denotes a positive feeling of fondness and affective attachment towards an entity [6]. In IDD children, affection toward an object can be reached by exploring, manipulating, and discovering it using all senses (touching, moving, eating, or smelling them) and is often expressed by manifesting pleasure from these actions.

From this general consideration, we elicited a *fundamental requirement*: The design of the robot and the virtual worlds, and the activities to be performed with children, should not be only functional to the improvement of specific skills in the cognitive, social, or motor sphere, but also to the achievement of relaxation and affection.

Distilling this general requirement and the whole amount of information emerged from the discussion with specialists; we identified a set of finer-grained functional and non-functional requirements on the behavior and sensory affordances of the robot and the virtual worlds.

Familiarity and Trust: Children should relax with the robot and the visual elements on screen, and believe that they are reliable, good, harmless, and inoffensive. This can be facilitated for example if the visual and physical characteristics of the digital elements and the robot evoke characters and objects that children have already experienced and enjoyed in other contexts, e.g., popular toys, or characters of well-known TV programs. In addition, the robot should be designed as a soft, comfortable and predictable object that can be touched, manipulated, hugged, and personalized.

Virtual ↔ Physical Transition: The robot should act as a bridge between the physical world and the virtual on screen world, helping the child to connect what happens in the two worlds. It must be clear for the children that the robot is the physical counterpart of a digital character on screen (its avatar).

Real → Imaginative World Transition: The robot, the child's avatar and the digital characters on screen should bridge the real world and the child's internal imaginative world. They should be designed to act as props to spark children's imagination and fantasy, helping the transition from sensory-motor (functional) play to symbolic play.

Imaginative → Real World Transition: The robot and its avatar should help children to “go back” to the real world when they fall in their own imaginary world for too long, e.g., drawing a child's attention to a physical object in the real space.

Social Mediation: The robot should encourage and facilitate social behavior by acting as a communication channel between children or among children and adults (caregivers). It should support the transition from non-social play (when the child plays alone with the robot) to social/non-interactive play (when two or more children play with the robot simultaneously, or in turn, but without communicating or interacting between them), to social interactive play (when children play with the robot simultaneously, or in turn, exchanging verbal or non-verbal messages, or performing collaborative tasks during play).

Feedback: The robot and the screen should provide a gamut of multisensory stimuli in response to child's actions that enforce affection, engagement, and promote various forms of learning (e.g., meaning making and cause-effect understanding). Still, stimuli must be clear, one-at-the time, well distinguishable, strictly functional to a specific learning goal. Children are distracted from feedbacks that are not strictly relevant for the current task, and may lose attention. Too many visual stimuli may induce anxiety as children may not be able to discriminate and interpret single elements within a group.

Prompt: Both the robot and the digital characters on screen should act as behavior-eliciting agents that attract attention, stimulate action and promote engagement.

Emulation: On screen avatars of the robot and the child should stimulate children's imitative capability. They should include both behaviors that replicate the movements and actions of the child and the robot in the physical space, and behaviors that must be emulated.

Facilitation: The robot and the on-screen multimedia content (e.g., video tutorials) should suggest how and when to do something, facilitating the execution of learning tasks.

Instruction: The virtual world should offer visual, verbal or textual instructions for the actions to be performed on the robot or in the real world. The robot should give verbal instructions for the children's interaction with the screen and for their movements in the physical world.

Reward: The robot and the on screen visual/audio contents should offer positive reinforcement to a child's successful action, and have no reaction in case of failure.

Restriction: Some movements of the robot should be used to "mark" the physical space; in this way, they help children to identify the spatial constrains for their movements during play.

4. THE PROTOTYPES

In our current prototypes, the whole set of perceptual and behavioral characteristics of the robot and the virtual world, and the set of activities that the children can perform with them, have been designed to meet the requirements discussed in the previous section.

4.1 Virtual world

On-screen multimedia contents range from very simple colored shapes integrated with sound or video elements, to 2D and 3D virtual environments and characters that create fantasy tales or communicate specific tasks for the children and the robot, to be performed in the physical world. The virtual representation of the child and the robot (avatars) are body silhouette, mirrored images, or fictitious characters, depending on the current game task. The children interact with multimedia contents on-screen using a very simple body language: raising or swiping arms, moving forward/ backward with respect to the screen or the robot, and moving to a specific area in the physical space.

4.2 The robot

Our robot is called Teo, a name that can be easily pronounced by children. We have calibrated its size and weight so that children can easily manipulate and hug it, and move it around, but at the same time, Teo can attract attention and cannot be ignored when on stage. Teo's body has a neutral egg-line shape, made of a soft fabric, to evoke the enjoyable, tactile experience that the children may have done with their own toys. Children can personalize Teo's neutral shape by sticking eyes, mouth, eyelids, and other components (Figure 4).

Figure 4: Personalizing Teo

Teo wears a hat equipped with a set of transparent buttons that can be customized to a specific task using either colored tags, PCSs (Picture Communication Symbols), or iconic images. Buttons are meant to enable children to express choices: in several games, they are requested to press the proper button in response to requests from the screen or the robot.

Teo offers a variety of visual, sensory, and spatial stimuli, providing feedbacks and instructions in many ways: using hidden speakers and light strips of colored LEDS placed at its bottom (Figure 1) it can speak or generate light effects; using its three omni-wheels it can vibrate, rotate, and move around. Teo's body is equipped with distance sensors that can sense children's distance and movements, while a force sensor strip enables the robot to detect manipulation (e.g., caresses, hugs, or punches).

All these sensors enabled us to implement a variety of states and behaviors for the robot: *Waiting* (when it to waits for someone to interact, Teo "looks around": it remains in the same position rotating itself); *Invitation to interact* (as soon as someone goes closer to Teo, it rotates towards her and verbally invites to play); *Happy* (when its body is softly caressed or touched, Teo "is pleased" and replies by vibrating, rotating itself cheerfully, and moving around, while a green colored light led strip blinks slowly); *Angry* (if the child slaps Teo with moderate force, the robot "becomes angry" and moves sharply towards the child); *Scared* (as soon as someone brutally hits it, Teo "becomes timorous" and slowly retreats itself).

Teo's behavior is automatically triggered according to children's interactions, movements, and the logic of the ongoing task. At any time the caregiver can take the control of the robot and trigger specific behaviors or feedbacks using a remote controller.

4.3 Children's activities

The tasks proposed to the children are of two types. A preliminary set of simple "familiarization" activities is devoted to help children understand the affordances of Teo and the onscreen elements, and to support the achievement of relaxation and affection. A set of structured learning tasks are devoted to promote cognitive and social skills; in these activities, multimedia contents, rewards, play time, body movements, and levels of complexity of tasks can be customized to the characteristics and preferences of each child.

4.3.1 Familiarization activities

During familiarization activities, Teo's behavior is largely controlled by the caregiver using the remote controller. After entering into the room, Teo keeps steady while the child is moving towards it. Then, the child is invited by the caregiver to stick face expressions, and Teo reacts by activating light, sound or movement feedbacks to express appreciation. Children are then invited to move in the space while Teo follows her. If the child is speaking to Teo, an operator can control the sound answer, either by editing the answer text and generating the corresponding synthesized voice on the fly, or by selecting the answer from a built-in set. Eventually, Teo's avatar appears on the screen, and invites the child to move towards it. When the child is close enough to be sensed by the motion-sensing device, its avatar appears near Teo's avatars and the child imitates it.

4.3.2 Structured learning activities

Structured learning activities are inspired by those frequently proposed to IDD children in therapeutic centers: simple choice-making and recognition tasks, well-known physical games, and storytelling. To promote the ability of making choices, often repressed in IDD children, children must express their willingness to play before each learning activity, by performing a specific gesture towards the screen. In addition, before leaving the room at the end of the entire play session, a final task is proposed: Teo and its avatar thank the child and greet him, and the child must respond with a similar gesture. This task has two goals. Firstly, it helps the child to learn a social convention (greeting when on leave); secondly, it smoothens the negative feeling that the departure may generate.

So far, four games have been designed and prototyped to support structured learning activities, two of which are briefly described in the rest of this section. In "Colors" game, a colored figure (e.g., a fruit, an animal) appears on the screen and the child must click the button of the corresponding color on Teo's hat to manifest her understanding of the color. "Witch says colors" game aims at developing concept understanding and spatial awareness. Six large images (colored circles or more complex monochrome figures) are physically placed on the floor of the play room. Teo's and the child's avatars appear on screen and move to one or two of the images (depending on the game level), calling the corresponding name(s). The child and the robot must do the same in the physical space. Three situations can take place: 1) both Teo and the child reach the correct position, and the activity ends with a reward. 2) Teo reaches the correct position while the child does not; Teo asks the child if that is the right place, giving feedbacks and suggestions until the child succeeds, and a reward appears on screen. 3) The child is in right place but Teo is not. The robot asks the child for help and the activity ends with a reward when the child, pushing the robot, places Teo on the right image on the floor.

5. CONCLUSIONS

The general goal of our research is to create new interactive spaces to promote relaxation, affection, and the development of social and cognitive skills in IDD children. Our approach blends mobile robots and virtual worlds on large screens, and implements multiple interaction paradigms to enable the communication among children, robots, and on-screen virtual world: motion-based interaction at the distance, voice interaction, and manipulation-based interaction.

In this paper, we have discussed the design challenges of this approach and have presented our current results, which we have achieved in collaboration with 22 therapists from 6 therapeutic and consist of: i) the identification of a set of general and detailed design requirements that take into account the affordances of our blend of technologies and the specific needs of IDD children; ii) the development of a set of prototypes (one robot and four games) that enable IDD children to perform a variety of familiarization activities and more structured learning tasks by interacting with the robot and on-screen multimedia contents.

An exploratory study has been performed at a local therapeutic center to test the effectiveness of our design solutions. The study involved 22 low and medium functioning IDD children and their 11 therapists. We are currently analyzing the results and we can only anticipate a general consideration. All therapists agree that the integration of robotic interaction and full-body interaction with large screen opens new extraordinary opportunities in the IDD context. It elicits operational behaviors, social interaction and emotional responses that normally do not occur using other methods, or that require a much longer time to be achieved. For example, an autistic child explicitly called a mate to play with Teo and the screen together: it was the first time he expressed the willingness to play in social mode. A girl with severe Hyperactivity Disorder relaxed in few minutes after meeting Teo, and she was able to concentrate on, and perform, a learning task (the "Colors" game) during the same session.

Our future work will revise our current prototypes in light of an accurate analysis of the results of this preliminary study, and will test more systematically the benefits of our approach in 2 additional therapeutic centers involved in the KROG project.

6. ACKNOWLEDGMENTS

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