Making playing robots for persons with disabilities

A framework and some experiences

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ABSTRACT

Play enables the development of skills and abilities in a way that brings satisfaction and enjoyment. Play is a right for everyone, but it is often negated to persons with disabilities both because their time is dedicated to other activities, such as therapies, and because of lack of appropriate tools and companions to play with. Robots have been proven as effective means to support development in persons with disabilities, since they provide unique opportunities and strong engagement. We present a framework to develop play situations based on robots and its application on some settings, with the aim of showing how effective, playful robots can be developed also using low-level technology at a relatively low cost. This may be a way to produce ad-hoc tools, adapted to specific situations, and, at the same time, to share experiences and ideas to foster the development of robots that can hardly reach a real market.

CCS CONCEPTS

• **Computer systems organization** → Embedded and cyber-physical systems; Robotics; • **Human-centered computing** → Human computer interaction (HCI); HCI design and evaluation methods; Interaction design; Interaction design process and methods; Activity centered design; • **Applied computing** → Life and medical sciences.

KEYWORDS

Interactive robot, Play, Disability, Robot development

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1 INTRODUCTION

Play is known to be a way people and animals use to explore the possibilities they have to act in the world and try to achieve goals in a protected environment; by doing so they safely develop abilities and skills that then could be used in the real life. "*Play is a range of voluntary, intrinsically motivated activities associated with recreational pleasure and enjoyment*" [12]. Self-motivated exploration comes from the natural tendence to discover new possibilities, in an environment that makes this activity possible and challenging at the same time, as stated by the *flow theory* [9].

The UNHRC Convention of the Rights of Child states "*the right of the child to rest and leisure, to engage in play and recreational activities.*" This should be guaranteed also to children with disability, often prevented to access play activities, both because their time is occupied by activities deemed more important, such as specific therapies, or because toys are not appropriate or accessible to them, or because the play activity has not been designed to consider their possibilities, or, finally, because they cannot play with companions.

Robots have been adopted in the last 30 years in many therapeutic and educational interventions dedicated to persons with disability [7, 13].

The design of a play experience with a robot should consider different aspects, starting from the needs and capabilities of the player(s), the shape and the capabilities of the robot, the context of play setting, the activities that can be suggested and their feasibility and playability. Robots available on the market often provide a set of constraints in the design of a play activity that may limit its playability. For instance, a fragile and expensive robot may not be considered as appropriate for a game involving physical contact, as well a robot that could hardly stand or walk cannot be used for a game involving free movement in space. In many situations, it may be possible to design robots and play activities to match the player's needs, and implement them by adopting simple technologies, as those developed within the makers community, that can be accessed at a low cost by everyone, including therapists and parents.

We present in the next Section a framework derived from the guidelines proposed within the LUDI project[1] [5] to guide the development of robots that can play with children with disabilities, compatible with the more general guidelines provided by the Human Activity Assistive Technology (HAAT) model [8], while in Section 3 we show how we have applied this framework to develop some robots and some of the play activities enabled by these. The experiences done with these robots showed that children enjoyed the play experience and often provided alternatives to the planned activity, as it happens with most toys, since the real play activity is inherently free. Despite this freedom, in many situations also unexpected, interesting, and desirable outcomes were obtained.

2 THE DEVELOPMENT FRAMEWORK

The role of the robot should be to stimulate the play activity, in a way that considers the specificity of the player(s) without requiring

[1]LUDI: Play for children with disabilities – http://ludi-network.eu

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any particular care to play due to the presence of the robot. Play is a free activity.

According to the definitions provided by ISO [14], a robot is "a drive mechanism programmed in two or more axes, having a certain degree of autonomy, moving inside its operating environment and performing tasks for its intended purpose". Therefore, a robot is not constrained to have any specific form, and its shape can be anything that could be functional to a satisfactory play experience. We are considering here only two types of robots, enabling different types of play:

- *Autonomous robots*, i.e., devices that can perceive some features of the world where they operate and can autonomously decide what actions should be produced, either in response to sensor inputs, or because of internal motivations, e.g., to stimulate activities.
- *Remote-controlled robots*, i.e., devices that are controlled to perform actions through an interface. These can be used both by operators, as avatars to take part in the play activity without directly involving themselves as persons with their role (so being able to take the role the play requires), or by the players, which may obtain possibilities (e.g., movement in space) that they cannot properly exhibit in person, and can play without direct involvement, which would be beneficial for some subjects, e.g., those with Autistic Spectrum Disorders (ASD).

The development framework we are proposing is based on user-centered design [15]: in all the steps, player, caregivers and designers interact to define the play activity. The principles of Universal Design [16] should also be considered, aiming at producing play experiences as much accessible by any player. The process starts with the identification of the potential *player's characteristics* (needs, abilities, preferences), potential *goals* of the play activity and the play *setting* (*Step 1*), given that the selected activity (first step of the HAAT model) has been already defined as "play". From these data, acquired with focus groups and interviews, requirements about the robot's characteristics may be derived. Since we are designing a robot, we should consider its *body* (dimension, material, appearance, shape), its *expression* potentialities (movement, sound, lights), and the channels through which the robot could perceive what may be relevant to play, i.e., its inputs (*Step 2*). In this definition of the robot characteristics, *safety* requirements must be satisfied. *Physical safety* is usually obtained by making intrinsically safe robots, so limiting speed, force, weight, and potentially harmful elements and shape, as it is done with traditional toys. *Perceived safety* is another aspect to consider: the robot should be perceived as harmless, according to the perception possibilities of the player. For instance, a player with ASD may be scared by too fast movements, or high pitch sounds, while a blind kid may be scared by a robot that hits her/him (needs abilities, preferences without making any noise. *Accessibility* by the specific player(s) should also be guaranteed, possibly considering specific input devices and output production. For instance, for a remote-controlled robot, input devices should enable the player to control naturally the robot, possibly adapting the actuators of the robot to the control abilities of the player (e.g., limiting the speed of a wheeled robot). For an autonomous robot, it should be able to perceive the signals that the player can produce. We should notice here that accessibility in the case of playing robots should include the possibility to use the robot for the purpose of playing.

The *design of the play activity* comes as *Step 3*: how the player can successfully interact with the robot to play? Given the principle of "*play for the sake of play*" [2], a first modality is "*free play*", where interaction is designed to enable the player to explore different possibilities with the robot and the environment (possibly through the robot); here, the aim of the play activity consists in discovering what it is possible to do with the robot and how to master the interaction, often obtained by repeating actions to consolidate what has been understood. The other type of play that we consider is the "*game*", where rules define how it is possible to reach a shared goal. Rules should be satisfied at any time by both the human player and the robot, and this calls for abilities in both to understand the rules and comply to them. Rules should be defined, and possibly adapted, to make this possible in the specific context.

The *implementation* (*Step 4*) brings then to a prototype. Notice that up to this step, the conceptual design proceeded without considering the feasibility of what was defined, but only a cascade of requirements. Implementation requires a creative effort to try to implement what was designed so far, and possibly suggest modifications to obtain a reliable prototype; this should often be tuned after appropriate tests (*Step 5*) with the player(s) to obtain the final robot suitable for the proper play activity. Test should check not only accessibility, but also *playfulness* [3], e.g., tested with tools like the one defined in [6]: the fact that the child is intrinsically motivated, in a state of suspension of reality, with internal locus of control and able to frame the play activity by giving and reading social cues [1].

It is evident that these steps interact with each other and are subject to backward loops to come to the final product.

3 ROBOTS AND EXPERIENCES

We have followed the proposed framework to implement more than 30 playing robots. A complete presentation of the elements to be considered in the design of this type of robots and play experiences, together with an in-depth analysis of play and its role with persons with disabilities is presented in [4]. Here, we present the development process adopted for four robots, belonging to different categories. We selected these robots as examples of the process, to present specific and general issues, as well as possible solutions to overcome them.

3.1 Yeti

Yeti was developed as a robot to support an association game. From interview with operators in different care centers, color association was identified as one possible goal for a game for children with ASD. Moreover, turn-taking was mentioned as another aspect to stimulate in a game that may involve different children, as well as the possibility to exploit at least a limited physical contact, and to explore emotion recognition (*Step 1*).

Influenced by ToFu, a robot developed in the past years [17], and by our research about emotional expression [11], we decided to design a body (*Step 2*) able to clearly show at least two expressions, associated to success and failure in achieving the game goal. This led to the design of a soft robot, able to compress and distend its body with motion patterns, soft and pleasurable to touch, and, at the same time, intrinsically safe. A pair of eyes and a mouth, implemented by LED patterns, were added to show emotions in addition to body movement. We decided to make a mobile robot to add the spatial movement dimension to the game.

Yeti plays the role of motivator for the game, which develops by putting the "sister" fur ball (see Figure 1) on the same color that it shows enlightening internal LEDs. Basic colors where selected: blue, red, and green. This is the object that should be manipulated, and that requires attention (another aspect to be exploited). Dimension, weight, skin, and transparency were designed considering that it had to be easily manipulated by kids up to 12 years old. A set of patches were provided, big enough to require some attention to be matched with the ball base where the color sensor is positioned, so that placing the ball requires only a small amount of care, but still some. The ball base is flat and large enough to ensure that, once placed, the ball stays firmly on the colored place. When the ball glows with a color, the player has a given amount of time to put it on the same color. This time can be tuned to match the ability of the player(s) (*Step 3*).

The implementation (*Step 4*) solved many practical issues among which the selection of appropriate materials to obtain a flexible and controllable body, the failsafe detection of colors, and a reliable wireless connection between the ball and the robot, needed for the game. Arduino[2] microprocessors were adopted to control the robot and to connect the color sensor in the ball with the robot. A set of sonars were added in front of the robot to prevent contact with walls and players: although the shape and consistency of the robot body make it intrinsically safe, going against people or objects would have not been coherent with the role of the robot as a good-tempered motivator. The first tests (*Step 5*) put in evidence that the robot was perceived as a good guy to be pleased with a correct action, and this was the metaphor motivating the interaction. When playing in a care center with medium to high level autistic children, it turned out that the physical object to be manipulated to play was a good way to obtain turn-taking: after three actions were done, the ball had to be left on the colored patch and the next in turn could take it. The pace given by the time between lighting up and the need to place the ball supported a quick shift of turn. The provided patches were placed not too far from each other on the floor. After a while, some kids understood that the patches were not really needed and that the reaction of the robot could have been triggered also by putting the ball on anything of the proper color, such as the shirt of companions; thus, the game evolved in a new one, where they tried to reach others and operators, somehow also facing the possibility of physical contact, mediated by the soft ball.

In this case, the robot did not play a direct role in game, but was a relevant element to control it, providing confirmations about the outcome of the performed actions that otherwise had to be given by operators. The role of the robot was recognized also thanks to the good quality of the global system, and its well-recognizable emotional expression, which naturally induced to perceive it as a rational agent showing coherent animacy.

[2]https://www.arduino.cc/

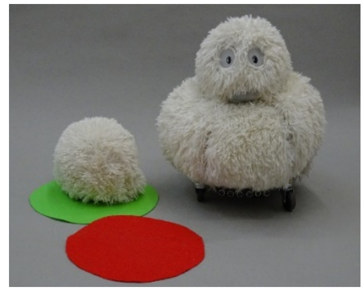

Figure 1: The robot Yeti, designed for a multi-player association game as a motivator.

Figure 2: The robot El Rizo, used for play for the sake of play to provide different emotional reactions to actions done with respect to it.

3.2 El Rizo

El Rizo was designed to express the five basic emotions defined by Ekman [10] in response to five actions done with respect to the robot. In this case, the basic requirement was only to be able to express the emotions while implementing a recognizable cause-effect relationship (*Step1*). No considerations were done with respect to issues related to specific subjects, since the original aim for this robot was only related to emotion expression.

Coming to the body shape (*Step 2* – see Figure 2), it was decided to make it robust enough to protect the internal hardware (based again on Arduino), but also pleasant to touch and caress, since caressing was one of the actions intended to activate an emotional reaction. The robot was designed to move on the floor, to exploit movement for emotional expression and, in principle, not to be held. LED matrices give the possibility to show emotional cues through "eyes", and a light bulb as nose could also participate to emotional expression. The most effective and attractive element is the tail, which moves according to emotional rhythms. Sounds recalling those of arcade games, simple and easy to produce even on Arduino, completed the set of tools for emotional expression. Input is related to the way people approaches the sonar sensor put on the front, to the amount of light sensed over the eyes, and to the caresses sensed by a capacitive sensor placed behind the "hairs".

The implementation followed an approach based on recycling and low-cost components. The body is made of a plastic colander, hairs are a mop, the program runs on Arduino-like card, the capacitive sensor is implemented by a simple copper wire, the nose is a plastic ball and the tail a plastic clamp covered by fabric and actuated by a small servomotor.

The robot was extensively tested in events with normally developed persons. It was attractive and kids spent time in discovering what it was possible to obtain and trying to obtain again and again what they discovered. Among general public, some kids with ASD approached the robot, together with others. In general, they were able to participate to the interactions and tried to caress the robot, the most evident and pleasant action to obtain a reaction. It was interesting to see that, since the activation of the consequent behavior was not immediate nor always triggered, kids that had seen the robot's reaction caressed its "head" for a relatively long time (up to 30 seconds). This delay may be considered, once the experience has been acquired and understood, to induce attention and repetition. In two cases, a child with ASD and a very young girl, the sound was perceived as disturbing and despite the invitation to participate by parents and other kids, they refused to interact with the robot, but still observed it while others where interacting. A different type of sound should be considered if the robot should be used with sensible children.

We had to face the issue of inadequate affordance and implementation with a very young kid who, attracted by the moving tail, suddenly grasped it, and detached it from its motor. This may happen when affordance for a gesture is present in the object. In regular toys, all parts with this type of affordance are connected to the motors or the passive joints through a spring that prevents breakage. The flexibility of the clamp-tail was not enough to prevent detachment and a better joint had to be implemented.

3.3 Mouse&Cheese

Mouse&Cheese was implemented as game to improve the ability to control a wheelchair by pursuing a goal. The subject should be able to move the wheelchair, either by hand or by using controls of an electric wheelchair, and to perceive the mouse and the target dish with the cheese (*Step 1*). The goal is to make the mouse reaching the cheese. The mouse is a sort of avatar and moves according to the movements of the wheelchair instead than driven by a joy-stick as common for many other toys. A secondary, but relevant effect of this is the need to manage the space for both the wheelchair and the mouse, which may call for some planning abilities, although these are not strictly needed.

Since the game is intended to be played by a single person on a wheelchair there is no need for considering manipulation of the robot body, which was implemented as a thermo-formed cover with a simple mouse shape (*Step 2*). To make the mouse visible also from distance, its length is about 30 cm, its color is bright white, with pink ears (see Figure 3). The only sensors on the mouse are metal whiskers to detect when reaching the metal bowl where the cheese is placed, which triggers a music and a reward dance. The movement of the mouse is remotely controlled by moving the wheelchair (*Step 3*).

The implementation (*Step 4*) is based on ESP[3] processors (a typical IoT device), which include hardware for WI-FI connection at a very low cost and can be programmed as easily as Arduino since

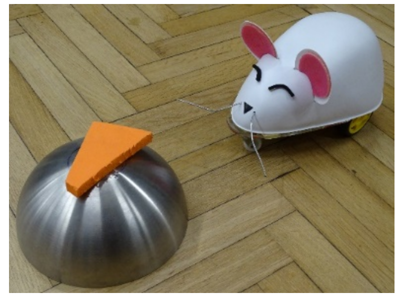

Figure 3: The mouse robot designed to play the Mouse&Cheese goal-directed game.

they may share the same programming interface. An ESP is controlling the mouse motors, the sound system, and the sensors aimed at detecting the goal achievement, implemented by two simple metal whiskers that close a circuit on the metal bowl holding the 'cheese'. Another ESP processor is connected to an accelerometer, and both are placed on the backrest of the wheelchair. This ESP sends the accelerometer signal to the robot's ESP, which maps it to commands for the motors.

As expected, (*Step 5*), the game was challenging and required to tune the mapping between the movement of the wheelchair and the control of the robot, to make the first not too sensible to produce undesired movements of the robot, nor too coarse to produce discrete robot movements that may make difficult to match the target. The issue of space management was relevant in constrained spaces like small rooms, while it was less relevant in large rooms and in gyms. In general, the environment where playing should be considered in the design of the activity. A critical situation occurs when the robot is against a wall and the player cannot move back to disentangle the robot. The shape of the robot helps to get out of most situations, but still cannot guarantee that external intervention is not needed. Of course, planning and a good skill about the relationship between the movement of the wheelchair and that of the robot make the game more enjoyable. It is always a matter of finding a trade-off that makes the activity challenging with respect to the players' abilities, so that they can reach the *flow* state [9], where enjoyment and engagement are at their optimal level.

3.4 Rosie, the monkey

Rosie was implemented upon suggestion of a psychologist working in a care center with adults with autism inspired by a gadget the author showed her. Rosie is one of the participants in a ring-around-the-rosey game. It can sing, only when all the participants to the game form a closed circle, the traditional song ("Girotondo" in Italian) that is associated to the round dance that most kids in many countries play in their life. The declared aim was to make persons with ASD participate in a collective action involving physical contact (*Step 1*).

The robot body could not be person-sized because of cost, logistics, complexity, and interaction management. We opted for a dimension that could be perceived in the circle and a shape that could have long arms so that it could be easy to make the robot part of the circle. A monkey plush from the market was selected (see

[3]https://www.espressif.com/

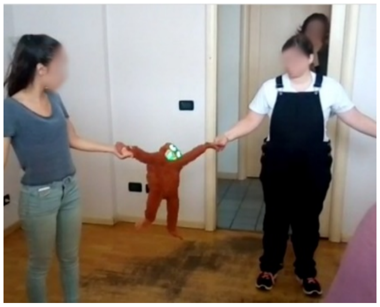

Figure 4: The robot Rosie in action in the round-the-rosey circle

Figure 4). It had to be improved by providing the ability to sense the closed circle, to sing, and to show some emotional reaction if mishandled (*Step 2*).

Interaction was soon defined (*Step 3*): when the closed circle is detected the monkey starts to sing the song. As soon as the circle opens it stops. Moreover, if it is subject to violent movements it shows with sound and lights that it is angry. To calm it, it should be caressed on the belly, the softer part of the body, so to obtain positive feedback implemented by sound and lights.

The implementation (*Step 4*) brought to put colored LEDs in the eyes, metallic contacts at the center of the hands, a capacitive sensor in the belly, and an accelerometer to sense violent actions, all managed by an Arduino.

The first tests (*Step 5*) put in evidence some issues, such as the need to have elastic electric connections between hands sensors and the processor because the arms were stretched when held, and to tune the sensibility to movements so that the monkey could play dancing with the others without becoming angry. Further tests with up to 20 people participating to the same play experience, showed that everyone accepted to make the monkey sing and paid attention to avoid strong movements. A kind of turn-taking game often emerged, where someone tried to open the circle, thus making its action evident, and then taking again the hand of the companion. At that point, if any others had left their hands, the monkey would not sing, so they should come to an agreement about who could break the circle, and who had to wait, to be the cause of making the robot sing or stop singing. Once again, a new way of playing emerged naturally, engaging and triggering interesting behaviors. It was also interesting to observe that adult persons could play this childish game without any problem, also because of the presence of the robot, which triggered interest and engagement. A questionnaire was administered directly to the participants in one of these sessions, but the experience was so pleasant that almost all of them put a cross to the highest score, even for the only question that was presented in negative form. This puts in evidence one of the criticalities that may emerge when trying to evaluate the effects of a trial directly with the subjects that may have cognitive disabilities.

4 CONCLUSIONS

We have introduced a framework to support the development of robots able to play with children with disabilities, and of the corresponding play activities. We have presented the development process that brought to the implementation of four of these robots, belonging to two different categories (autonomous or remote-controlled) and implementing different types of play, respectively: a structured game where the robot plays a support role, a free play where the robot offers a set of cause-effect relationships to be explored, a structured game where the robot is tele-controlled, and a structured game where the robot is active part of the game and is irreplaceable in its role.

All the presented robots have been implemented using or re-using cheap materials, integrated with low-cost sensors and processors that are widely supported on-line and can be accessed by everyone wishing to produce something useful for children with disabilities. All the presented robots have been implemented with costs in materials, at the shop, between 50 and 100 Euros. We expect that contributions like this one 1233.13.23.33.444] may stimulate and support a movement producing similar robots and sharing experiences and technologies to spread this approach, which may fill a need that could hardly be covered by the market, due to the need for specific devices, that should be adapted to the single needs, at a low cost.

REFERENCES

[1] Gregory Bateson. 1972. *A Theory of Play and Fantasy.* MIT Press. Boston,MA.

[2] Serenella Besio. 2016. The need for play for the sake of play. In: Besio, S., Bulgarelli, D., Stancheva-Popkostadinova, V. (eds.) *Play development in children with disabilities*, pp. 9–52. De Gruyter. Berlin, D.

[3] Serenella Besio, Daniela Bulgarelli, Vaska Stancheva-Popkostadinova. 2018. *Evaluation of children's play. Tools and methods.* De Gruyter., Berlin, D.

[4] Andrea Bonarini, Serenella Besio. 2022. *Robot play for all - Developing Toys and Games for Disability.* Springer Nature Switzerland AG, Cham, Switzerland.

[5] Andrea Bonarini. Rianne M. Jansens. 2020. Guidelines for parents, professionals, designers, makers and researchers on toys and technologies for play for children with disabilities: How to take usability and accessibility aspects into consideration? In: Bulgarelli, D. (ed.) *Perspectives and research on play for children with disabilities.* 106–145. Sciendo. Warsaw, Poland.

[6] Anita C. Bundy, Lori Nelson, Margaret Metzger, Kathleen Bingaman. 2001. Validity and reliability of a test of playfulness. *The Occupational Therapy Journal of Research.* 21(4), 276–292.

[7] John-John Cabibihan,,Hifza Javed, Ang Marcelo Jr, Sharifah Mariam Aljunied. 2013. Why robots? a survey on the roles and benefits of social robots in the therapy of children with autism. *International journal of social robotics.* 5(4), 593–618.

[8] Albert Cook, Pedro Encarnação 2020. *Assistive Technologies. Principles and Practice.* Elsevier. St Louis, Missouri.

[9] Mihaly Csikszentmihályi. 1997. *Finding flow: The psychology of engagement with everyday life.* Basic Books. New York, NY.

[10] Paul Ekman, Wallace V. Friesen, 1971. Constants across cultures in the face and emotion. *Journal of personality and social psychology,* 17(2), p.124.

[11] Julian M. Angel-Fernandez, Andrea Bonarini. 2016. Robots showing emotions - emotion representation with no bio-inspired body. *Interaction Studies* 17(3), pp. 408–437.

[12] Catherine Garvey. 1990. *Play.* Harvard University Press. Cambridge,MA.

[13] Renée J.F. van den Heuvel, Monique A.S. Lexis, Gert Jan Gelderblom, Rianne M. Jansens, Luc P. de Witte. 2016. Robots and ICT to support play in children with severe physical disabilities: a systematic review. *Disability and Rehabilitation: Assistive Technology* 11(2), 103–116.

[14] ISO - International Standards Organization 2012. ISO 8373:2012 – Robots and robotic devices — Vocabulary. ISO.

[15] Cara Shaw, Francesca Bernardi. Faraz Nickpour. 2022. "Child-centred framing through design research: a framework for analysing children's 'dream wheelchair' designs to elicit meaning and elevate their voice", *Disability and Rehabilitation: Assistive Technology*, Published Online, https://doi.org/10.1080/17483107.2022.2071487

[16] The Center for Universal Design. 1997. *The Principles of Universal Design*, Version 2.0. North Carolina State University. Raleigh, NC.

[17] Ryan Wistort, Cinthia Breazeal. 2009. Tofu: a socially expressive robot character for child interaction. *Proceedings of the 8th international conference on interaction design and children*, pp.292–293.