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A Robotic Toy for Children with special needs: From requirements to Design

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Abstract— This article presents the design process of Iromec, a modular robot companion tailored towards engaging in social exchanges with children with different disabilities with the aim to empower them to discover a wide rage of play styles from solitary to social and cooperative play. In particular this paper describes the design process from the elicitation of user requirements related to three main target users - Autistic children, Moderate Mentally Retarded children and Severe Motor Impaired children - to the robot design, highlighting problems and challenges encountered to meet and reconcile heterogeneous needs of disabled children. Modularity and configurability are the key features of the robot: the use of plug&play application modules, the coating components and add-on elements contribute to the flexibility of the system in creating rewarding games that can be easily understood by the child and can promote fun and learning. Other key features of the system are the combination of autonomous and user-controlled behaviour and a strong emphasis on identity and expressiveness that can be dynamically adapted during play. A main contribution of this work is that it does not just focus on the engineering aspects of robotic design, but it is primarily guided by learning and therapeutic issues and centred on the final user.

I. Introduction

THIS paper describes the design of a modular robotic platform, developed to engage disabled children in different kinds of play activities aimed to stimulate social relations and communication. The research presented has been carried out within the European project Iromec, a three year project started in November 2006, co-funded by the European Commission within the RTD activities of the Strategic Objective SO 2.6.1 "Advanced Robotics" of the 6th Framework Programme (Interactive Robotic Social Mediators as Companions, www.iromec.org). The project investigates how robotic toys can provide opportunities for learning, therapy and enjoyment. The main objective of the project is to develop a robot companion tailored towards becoming a social mediator, empowering children with disabilities to discover the range of play styles from solitary to social and cooperative play.

In particular the paper focuses on the design process, from the elicitation of user requirements related to three main target users - Autistic children (AUT), Moderate Mentally Retarded children (MMR) and Severe Motor Impaired children (SMI) - to the robot design. The paper highlights problems, challenges and solutions envisaged when designing for such an extremely heterogeneous user group as the one targeted in the Iromec project. Problems range from the difficulty of reconciling conflicting needs and different expectations about the final system and elicitation and interpretation of requirements expressed by the stakeholders in a non-technical language, to the minimization of the paucity of user skills necessary to engage in a meaningful way with the design team and the articulation and communication of their concepts to the design group. Challenges are related to the management of the design process. Indeed on one hand the adherence to tried and trusted protocols of play and therapeutic activities would appear to be mandatory and eminently desirable, but on the other hand, a research project aiming to develop innovative ideas and robotic technologies should remain open to leaving the whole "requirements" activity at a very general level, trusting in the competence of the experts to come up with solutions, leaving room for the definition of emerging scenarios and practices enabled by the use of the robot.

The solutions identified to the previously mentioned problems and challenges rely on the design approach: a modular and configurable robotic platform has been designed both to address the specific needs of each user group and to leave room for the experimentation of consolidated play and rehabilitation activities and the definition of new scenarios emerging from the use of the robot.

II. The Context: Play and Disability

The Iromec robot has been developed to address the needs of three main kinds of user groups - Autistic, Mild Mental Retarded and Severe Motor Impaired children.

Autism refers to the term Autistic Spectrum Disorder, a disability that can occur in different degrees of severity and in a variety of forms. Autism is a lifelong developmental disability, often accompanied by learning disabilities, that affects the way a person communicates and relates to the people around them. The exact cause(s) of autism are still unknown. The main impairments that are characteristic of people with autism are: impaired social interaction,

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impaired social communication, impaired social imagination (difficulty in the development of play) and having limited range of imaginative activities.

Children with mental retardation, also referred to as intellectual disabilities or learning disabilities (for example children with Down syndrome), might have trouble playing because of their intellectual limitations and cognitive disabilities. They have reduced ability to retain attention and might not understand the meaning of proposed play, and/or the meaning of the language used to play; some also have speech limitations.

Physical impairments often heavily affect activities such as mobility, communication, autonomous self-care, learning activities, interpersonal interactions, play and many participation areas, including social relationships, social life and education. Children with physical impairments may also present additional impairments such as sensory (deafness, blindness) and/or cognitive impairments. Physical impairment could affect both gross and fine motor skills. These children are limited in their ability to play due to the limitations of their movement, if they are able to move at all.

In the first year of the project a set of 20 play scenarios were defined in close collaboration with expert panels including therapists, care-givers, educators and parents [1] and [2]. These scenarios were grouped in more general typologies of activities that the Iromec robot should enable. Having both detailed scenarios and generic activities allowed us to bound the design to a set of specific play activities but also to leave a certain freedom to the user to try out different play activities within a wider framework of play possibilities. Three clusters of activities were identified: Imitation, Action and Coordination and Symbolic Play, each one playing a major role in the development of disabled children. Imitation game activities involve attention keeping and observation, the physical control to replicate and reciprocal coordination. Individuals engaged with Imitation games might be able to focus their attention on the behaviour of the other, creating a model of this behaviour to replicate with their own abilities. Action and Coordination game activities involve movement, spatial orientation and coordination. Individuals engaged with these activities might be able to navigate the surrounding space, detect the presence and the movement of objects and autonomously move, or ask to be moved through the space. Symbolic Play activities involve shared attention, imagination, pretending, and role-playing. Individuals engaged with Symbolic Play might be able to start or join playing with symbols and objects with symbolic values. They may also be able to follow a symbolic storytelling activity and take part with appropriate (coherent and meaningful) contributions.

III. Elicitation of Requirements

The Iromec project adopts a User-Centered design approach. Different kinds of users, therapists, care-givers, children and relatives have been iteratively involved in the design of the robot. Several workshops, panels, interviews and observations of children during play have been organized in order to elaborate user requirements. In the context of the Iromec project the definition of the user requirements was very complex activity that needed several iterations to address a wide population of disabled children and a variety of play scenarios. Requirements are not simply "out there" awaiting collection [3], but are themselves constructions, jointly and dually produced by a range of actors, including users and analysts and developers in specific contexts. This collaborative and participatory approach required paying close attention to the ways in which we investigated the use situation, taking into account a number of factors including functional, emotional, social, organisational and cultural factors involved in the requirements process.

The approach we adopted to attempt to adequately represent user requirements has led to an opening within requirements engineering for ethnographic and participatory approaches to understanding the setting and user needs. Since the children's disability turned out to be a significant inhibitor for their direct involvement in the design process, other stakeholders like teachers, special educators, parents and experts were involved by means of interviews and focus groups, researchers probing them about their understanding of several specific concepts, asking them to explore the concepts, comparing abstract representations and real events, defining together scenarios of play and encouraging them to develop ideas about the future system, and trying out mock-ups and low-fidelity prototypes. Requirements have been progressively defined and organized with respect the following robot features: Shape and Structure (requirements of the general physical structure and the general appearance of the robot), Identity and Expression (requirements of the face and the body structure, appearance and sensorial feedback and expressiveness), Interaction (user sensing, user interaction, object manipulation and user controlled interaction vs. autonomous behaviour) and Behavioral Patterns (sensing, orientation and space navigation).

The main problems we met during the design process range from the difficulty of reconciling conflicting needs and different expectations about the final system and eliciting and interpreting requirements expressed by the stakeholders in a non-technical language, to minimizing the paucity of user skills necessary to engage in a meaningful way with the design team and articulating and communicating their concepts to the design group. As an example of conflicting requirements we can mention the ones related to the robot's expressiveness and the appearance of the robot. While Autistic children require a very simplified cartoon-like “mechanical” face without too many details, Moderate Mentally Retarded and Severe Motor Impaired children require a more expressive face, able to show basic facial expressions aiding in sustaining imagination in symbolic play. Furthermore, while Autistic children require a robot face with physically embedded parts like eyelids that can be manually opened or closed during play; Moderate Mentally Retarded and Severe Motor Impaired children require a wide range of facial expressions, and more specifically, the personalization of facial expressions. This means that to be used by Autistic children the robot should physically have a 3D face whilst to allow dynamic expressiveness and personalization (necessary for MMR and SMI children) a digital screen-based face is necessary. Regarding the play activities, imitation games are easier with a vertically orientated stationary robot with a human body-like appearance so that the child can focus on basic behaviours to imitate (e.g. arm movements), while action and coordination games require a moving platform with a clear front and rear to indicate the orientation and direction of the movement.

What these requirements and play scenarios brought to the design of the Iromec robot will be described in the following section.

IV. The Robot Design

A. Main Components

Iromec is a modular robot that can assume different configurations. The main components of the robot (Figure 1) are: the *mobile platform*, an *interaction module* and some *control buttons*. The *interaction module* consists of: a *body* whose semitransparent *skin* can display different visual effects by way of a projection, thus supporting identity, expression and feedback; a *head* with a digital display for both expression and orientation; and *arms*, to guarantee basic manipulation features. The *head* rotates along the vertical axis simulating right to left (and vice versa) movements, or/and to emphasize situations in which the attention of the robot is attracted towards a specific direction. Some *add-on components* and a *coating surface* provide the means for a personalization and customization of the robot. The mobile platform contains all the technological components for managing the robot's spatial movement, including wheels, sensors and bumpers.

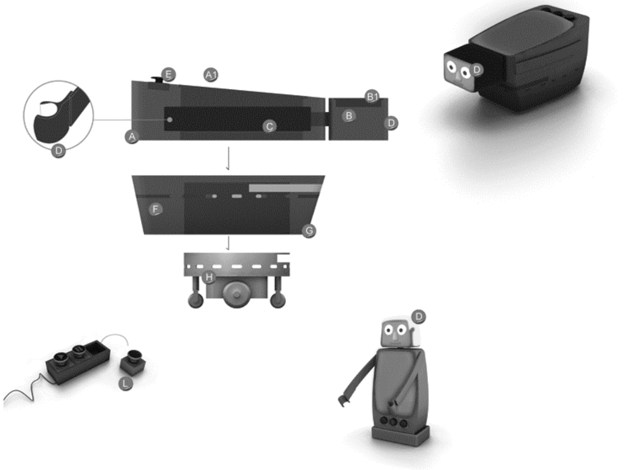

Figure 1: The robot 's components. Interaction Module: Body (A), Skin/Screen (A1), Head (B)m Head Screen (B1), Arm (C), Add-Ons (D), Control Button (E). Mobile Platform: Base (F), Coating (G), Movement Engine (H). Accessories : Dock (I), Remote Control (L)

B. Configurability

The robot has two main configurations: horizontal and vertical (Fig 2). In both configurations, the body of the robot has a bilateral symmetry. Furthermore, in both configurations, the position of the head clearly shows the front of the robot. Bilateral symmetry and directionality (the clear understanding of the front/rear of the robot) were two important requirements shared by all target user groups.

Figure 2: robot configurations

In the vertical configuration, the interaction module can be used in a stand-alone mode. When needed, the module can be connected to a dedicated docking station that provides stability and allows for recharging. In this configuration the robot resembles the shape of the human form. This configuration supports imitation scenarios that require the children to reproduce basic movements, e.g.

raising an arm or rotating the head. The application module can be also used in a horizontal configuration attached to the mobile platform in order to support a complete set of activities requiring a wider mobility and dynamism of the robot. In this configuration the robot has a vehicle-like appearance that suits the requirements of Action and Coordination games. With the horizontal configuration we have been deliberately using a mobile, non-humanoid robot that allows for unconstrained interactions. This solution is suited also to children with autism who have difficulty interpreting facial expressions and other social cues in social interaction. Consequently, they often avoid social interactions since people appear unpredictable and confusing. In contrast to other children, who enjoy a lively, dynamic and even ‘messy’ playground, children with autism prefer a predictable, structured and, in this way, ‘safe’ environment [4]. A child with autism prefers to be in ‘control’ of the interaction. For this reason, a simple, non-humanoid, machine-like robot seems therefore very suitable as a starting point for therapeutic interventions.

To sustain a full range of play scenarios, the interaction module and the mobile platform can be used also independently from one another. The surface of the mobile platform, when used without the interaction module, can be covered with a passive skin (Fig. 3) that can be constituted of various materials, providing in this way different visual and tactile experiences. One further possibility, applicable to thin and/or semitransparent materials such as textiles or plastic, is to have LED lights applied below the surface that can provide an additional dynamic and luminous visual feedback when/if needed.

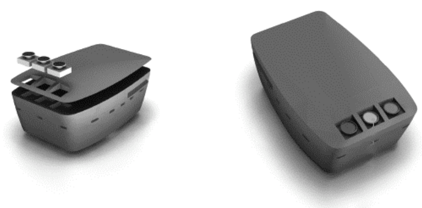

Figure 3: passive skin

However, in this case the range of activities supported by the horizontal configuration is reduced due to the absence of the display/projection, head and arms. The possibility of using both the application module and the platform stand-alone constitutes an important opportunity for the therapist: the robot can be used continuously, without having to dedicate period of time to recharging the battery; the robot can be eventually used in two activities at the same time: it can be used in activities that require the application module in the vertical configuration for imitation games and, simultaneously, in an activity that requires the use of the mobile platform with the passive skin for Action and Coordination games. The possibility of having such flexibility in relation to the use of the robot allows the therapist to better plan therapeutic sessions and to optimize the use of the robot. This was a fundamental requirement that several experts from different institutions have identified. As institutions that provide therapeutic interventions for children with special needs have a very tight schedule, having the robot not working for even short periods could have a critical impact on the execution of therapeutic plans.

C. Identity and expression

Another important design issue was related to the robot's identity and expressivity. The design of the robot attempts to harmonize the requirements of the different user groups with heterogeneous and sometimes conflicting needs (from low expressiveness for Autistic children to high expressiveness for the MMR and SMI children), by adopting a hybrid solution that integrates the use of digital and physical elements.

As it is possible to observe in figure 4, the robot's physical appearance resembles an abstract figure composed of three main elements: a head, a body and two arms without any specific human-like or pet-like appearance. The physical design of the robot is as abstract as possible, but when it is used by MMR or SMI children, two surfaces (a 7 inch screen for the face and a pico-projector for the body) are used to display different kinds of visual cues that could stimulate fairly complex levels of symbolic play.

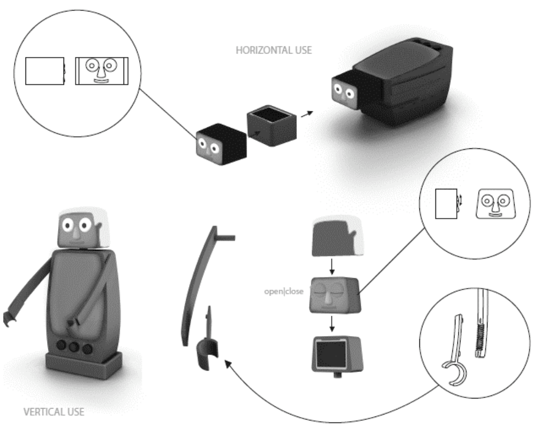

Figure 4: face and expressiveness

For example, the screens can be used to visualize different kinds of textures: some of them can represent the fur or skin of a specific pet; others are more abstract by displaying glowing colours or moving surfaces. In other words, these embedded screens allow the modification of the appearance of the robot, matching the needs of different children and the requirements of different activities. Furthermore, a number of add-ons and skin components can be used to further transform the robot's appearance. A set of “coating materials” can be applied to the robot’s body in order to obtain different tactile and visual effects.

Coating materials will be interactive and are composed of smart- memory alloys in combination with embedded textile sensors that contribute creating interactive surfaces.

A specific issue arose in relation to the expressivity of the face. Although Autistic children do indeed require a very simplified face without too many details that should resemble a cartoon-like “mechanical” face; MMR and SMI require a more expressive face, able to show basic facial expression, in order to appropriately support imagination in Symbolic games. To solve these conflicting requirements a small screen has been used to show the robot face. The small screen can visualize two different facial models. Both of them include mouth, nose, eyes and eyebrows organized according to the basic structure of the human face.

While one face model addresses the needs of SMI and MMR, the second one has been specifically designed for Autistic children. Differently from the face for Autistic children, the faces for SMI and MMR have a higher level of expressiveness: colours and visual cues (shadow and shades) have been used to provide a 3D impression. The behaviour of the face elements is more complex in this case, including a higher number of possible transformations and smooth transitions (Fig. 5, left). The face model for SMI and MMR allow the expression of seven different emotional states. The second face model is designed for Autistic children with a more simple appearance; each element has been designed using a basic geometric shape. The behaviour of each element (eyes, mouth and eyebrows) is limited to few variations. This second model can express three basic emotional states (Fig. 5, right).

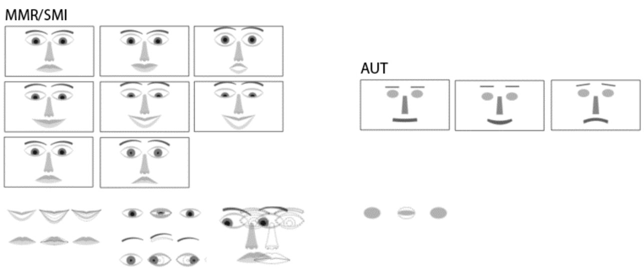

Figure 5: robot expressions

However, the level of competence and preferences of Autistic children can vary considerably. For example, high-functioning Autistic children can recognize a digital face on a , while the Autistic children with a severe impairment are more likely to recognise a physical face. In order to support both cases, the head display can be also hidden using a physical mask to modify the physical appearance of the robot and reduce the expressiveness (Fig. 4, bottom right). These masks can have different transparency levels in order to partly or completely show the eyes or the mouth movements (Fig. 6).

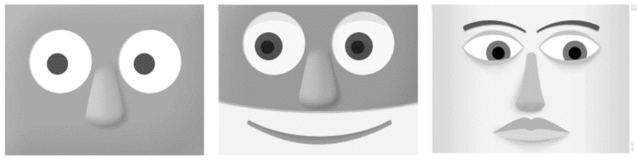

Figure 6: masks

The combination of a digital and a physical face allows the therapist to experiment with several configurations, in order to find the solution that better fits the needs of the children.

D. Control

Control plays a fundamental role in interaction with robots. For example, François Michaud and his team at Université de Sherbrooke [5] have investigated different designs of autonomous robots, using a variety of modalities for interaction, from interactive to remote controlled robots, to explore the design space of autonomous robots in autism therapy. Since the Iromec project addresses the needs of a wider population of disabled children, we organized a number of panels composed of both experts and parents to explore the issue of control. The panels signaled the importance of experimenting on both the autonomous and user-controlled behaviour of the robot and providing the therapist or the child with the possibility of maintaining the control over the robot’s behavior during the play activity. In particular, in the case of SMI, it is important to allow a remote control of the robot’s behavior using either standard assistive interface devices like joysticks, switches and scanning interfaces, or remote control units tailored to different physical abilities. On the contrary, for Autistic children it is important to interact with and control the robot using physical buttons.

For this reason a set of *wireless control buttons* have been integrated into the robot design (Fig. 7).

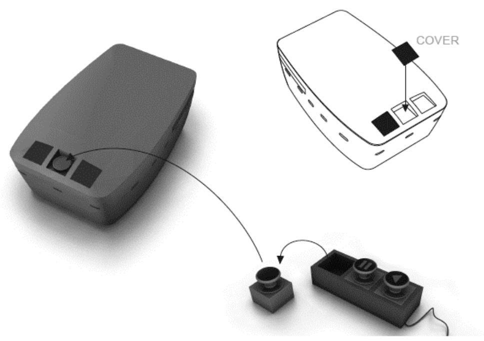

Figure 7: buttons and controls

On the top of each button a small LED display can visualize an intuitive icon or a palette of colors to represent the associated function or to provide a visual feedback to the performed action.

Control buttons can be used one by one, i.e. one for each child, or grouped and placed into an appropriate case to create a modular remote control (Fig. 7). They can also be plugged into the robot’s body.

V. AN EXAMPLE OF PLAY SCENARIO: GET IN CONTACT

In order to exemplify the types of interaction that can occur with Iromec, we shall now provide a narrative account of one particular SMI child interacting with the robot in the horizontal/mobile configuration. The scenario shows different interaction style during Symbolic play.

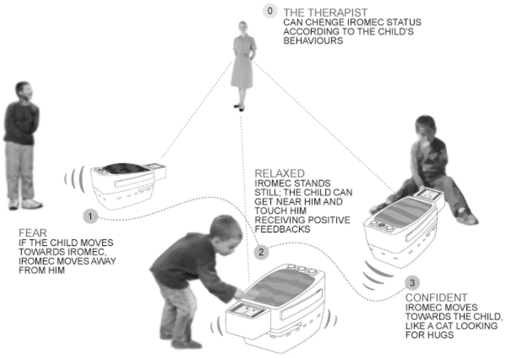

Figure 8: symbolic play scenario

At the outset the adult selects the robot’s behavioural pattern (i.e. a configuration of robot movement, colour patterns and shape transformation) expressing a ‘ feeling of fear’. The robot does not approach the child and tries to maintain a pre-defined (‘safe’) and significant distance from him/her. Then when the child tries to approach the robot, it retreats, and changes its appearance to “fear appearance” (e.g. its colour gets darker, its skin becomes rough). Such a pattern creates a context that encourages the child to interpret the robot’s behaviour, and then change his/her approach/behaviour towards the robot accordingly (e.g. to approach the robot slowly). When the child gently approaches the robot, the adult modifies the behavioural pattern into ‘communicative’ mode: the robot now approaches the child (trying to maintain a small pre-defined distance, the robot displays warm colours as an invitation to a more intimate interaction). The adult can now select a tactile exploration mode. In this mode, the robot does not move, but as it is positioned next to the child, the child may touch and explore the robot’s surface. The robot responds by vibrating as if it was purring and by getting smoother and smoother.

The scenario depicts a simple Symbolic play scenario where the child can exercise his or her imagination and learn to comprehend others' minds by seeing things through the point of view of the robot. The activity is unlimited and can continue as long as the child is interested. Some key values of the robot are highlighted by this scenario: tactile exploration, expressivity, acting to change the state of the robot, the expressive potentialities of the robot through the use of colours and visual patterns, shape and movement, the sense of touch in combination with proximity and the use of the remote control to modify the robot’s behaviour.

VI. CONCLUSIONS

Using a modular robot as a remedial toy for children with different disabilities meets the challenge of bridging heterogeneous needs and expectations [4]. The first Iromec prototype has been developed with the aim of being used for the beginning of January 2009. The robot will be experimented on in different schools and rehabilitation institutions in Italy, Austria, Spain, UK and The Netherlands starting in February 2009. For the user testing we hypothesise that the robot can meet the requirements of MMR, SMI e AUT children and that all of them are sufficiently interested in the play scenarios as described in the Iromec project. Furthermore we hypothesise that the robot can engage the child in interactions which demonstrate important aspects of human-human interaction (e.g. touch and eye contact, action and coordination, turn-taking, Imitation games, Symbolic and Construction play), and that by slowly increasing the robot’s behaviour repertoire and the unpredictability of its actions and reactions, the robot can be used to guide the children towards more ‘complex’ forms of interaction, as found in social human-human interactions.

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