2010 IEEE International Conference on Robotics and Automation
Anchorage Convention District
May 3-8, 2010, Anchorage, Alaska, USA

A Robot Companion for Inclusive Games: a user-centred design perspective

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***Abstract*— This article presents the design 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 focuses on the user-centred design approach taken to develop a robot able to engage in meaningful interaction with different typologies of disable children - Autistic children, Moderate Mentally Retarded children and Severe Motor Impaired children. Modularity and configurability 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 the lessons learned in applying a user-centred perspective in designing the robot: from user requirements to concept design, from the initial prototype evaluation to the redesign and the final testing.**

I. Introduction and Related Work

Human-machine interaction has only recently welcomed human-robot interaction within its disciplinary scope. Until 2004 key phrases like “robot” and “human-robot interaction” were not included in the areas of interest listed by CHI (Computer-Human Interaction), one of the most influential conferences of the sector: robotics was not one of its conference topics. The reason is simple: robotics had been mainly the object of industrial applications that produced programmable machines capable of carrying out physical tasks, an area of interest far from that of interaction designers [1].

Human-robot interaction has received in the past five years a significant and growing interest that led to the development of a number of so-called *robots companions*, a term that emphasizes a constant interaction and co-operation between human beings and robotic machines.

The robotic companions serve and support the human beings but they do not do this just executing tasks. A continuous and natural dialogue holds between the human being and the robot companion, a high quality modality of interaction occurs that is not merely functional (press a button so that the robot can execute the command) but emotional (“is the robot or the human angry?”), aesthetically gratifying (“my cute robot companion”), social (robots as mediators of social exchanges).

Within the area of the robot companions, some of these have been specifically designed to stimulate social exchanges and to support the cognitive development and maturation of children with socio-relational disturbances, from slight linguistic retardations to Down Syndrome [2]; from developmental retardations to relational deficit problems such as autism [3]; from light to severe motor impairment to stimulate the execution of coordinated movements [4] and explorative behaviour. Other studies have been performed on autistic children [5], to study the therapeutic role of robots in the treatment of autism [6], [7], [8].

In this paper we present Iromec, a robot that engages in social exchanges with children with different disabilities.

It has been developed 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 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.

II. The User-Centred Design Approach

The Iromec project adopts a User-Centered design approach [9] where users are not simply viewed as *objects* of study, but as *active agents* within the design process itself. Thus, user involvement is not simply required to increase the effectiveness of the resulting system, but also to develop a cooperative setting where people who will use the system can have a true impact by re-inventing the technology while

Manuscript received September 15, 2009. This work was supported by the IROMEC project - a Specific Targeted Research Project (contract number IST-FP6-045356) 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.

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they try out its features, can tweak concepts and functionality so they better answer their needs, can come up with different ways to use the technology, and develop new social practices around the possibilities open by new technological system.

Another fundamental tenet of this approach is the iterative nature of the design process. In the IROMEC project design concepts and working prototypes underwent different design iterations. Each evaluation informed the redesign of the next prototype, and the user requirements that were progressively refined and elicited in a continuous user research.

The involvement of different stakeholders, including children , teachers, carers and therapists, was fundamental in all the design phases. The user-centred design process conducted in the Iromec project was articulated in different phases described below. Even if the user-centred design process described in this paper cannot be applied *hic et nunc* to any other design process without adaptations, however the lessons learnt can be generalized and re-used to produce flexible design solutions that promptly address a variety of user needs. The user-centred design process in Iromec has been organized according to the following phases:

- Problem setting: identification of the user community, definition of activity scenarios, user requirement elicitation.
- Robot design and implementation
- Field trials
- Re-design

III. Problem Setting

A. *Identification of the user community*

Different kinds of users, therapists, care-givers, children and relatives have been iteratively involved in the project. Several workshops, panels, interviews and observations of children during play have been organized in order to elaborate user requirements.

From this preliminary phase a set of primary users of the system was identified: Autistic, Mild Mental Retarded and Severe Motor Impaired children. All of them have difficulties in playing alone or with others and for this reason they are ideal candidates of the Iromec project.

In particular autism affects the way a child communicates and relates to the people around them. The main impairments that are characteristic of children with autism are impaired social interaction, 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. These children are limited in their ability to play due to the limitations of their movements, if they are able to move at all.

B. *Definition of activity scenarios*

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 [10].

The educational and therapeutic objectives of the scenarios have been discussed with the user panels for each of the user groups, and have been classified with reference to the ICF-CY, the International Classification of Functioning – version for Children and Youth. The scenarios ranged from turn taking and imitation games to construction and pretend play. Examples of play scenarios are: Turn taking, Imitation Game, Make it Moves (a cause and effect game), Follow-me (coordination game), Dance with me (composition game), Build a Tower (a solitary constructive game), Bring me the ball (cause and effect game), Get in contact (Sensory stimulation game), Pretending to be a character (a pretend play game).

Each scenario has a number of specific educational and therapeutic objectives. For example the Turn Taking scenario has the objective to improve understanding cause and effect connections, to improve perceptual functions like auditory, visual, tactile, visuospatial perception and proprioception, to improve attention and judgement, mobility and basic interpersonal interaction.

C. *User requirement elicitation*

The definition of the user requirements was a very complex activity that needed several iterations to address a wide population of disabled children and a variety of play scenarios. In Iromec the requirements were jointly and dually produced by a range of actors, including teachers, parents, care givers and designers.

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. 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.

One of the most critical set of requirements was the one 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.

IV. ROBOT DESIGN

A. The modular components

Iromec is a modular robot that can assume different configurations. The main components of the robot (Fig. 1) are: the *mobile platform*, an *interaction module* and some *control buttons*.

For the mobile platform the Faulhaber DC-micromotor 2342, 17W, the planetary gearbox with 14:1 ratio and the magnetic encoder were selected as main components (35x55x18 cm). This set motor/gearbox/encoder will allow a very fine control of robot motion even at low speed in a reduced size (the whole set fits in a cylinder with 23mm of diameter and 80mm length for 90g). The spatial movement of the platform is also regulated by ultrasound sensors (Devantech SRF08) providing 3D information about obstacle presence and infrared sensors (Sharp gp2y0a02). The combined use of 12 ultrasound sensors located every 30° around the robot platform and 16 infrared sensors located every 22,5° allows the complete coverage of the robot surrounding with obstacle detection, reactive navigation and presence detection whatever the position of child regarding the robot position. Furthermore the platform is equipped with a CmuCam3 integrated video camera and a laser scanner (eyes safe and small dimension) giving a very rich source of information about the environment, delivering 660 measures per scan (240° field of view and one measure each 0,36° every 100ms).

The mobile platform is controlled by a software architecture based on the generic control software robuBOX from Robosoft (www.robosoft.fr). The robuBOX allows the integration and the communication with the interaction module plugged on top of the mobile platform. The interaction module can be easily plugged/-unplugged on/from the mobile platform following a "plug and play" philosophy. A connector interface between the two main IROMEC robot components serves as mechanical locking system and allows power and data transmission.

The interaction module is featured with high level control system that provides editing of "play scripts" through the GUI, by means of XML-description. The high level control system also provides with the functionality to execute the selected script. It 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 interaction module measures 35x55x17 cm.

The head (22x12x17 cm) 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 robot has two main configurations: horizontal and vertical (Fig 1). 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 1. the final Iromec robot.

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. 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. 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

B. The visual interface

The IROMEC visual interface is defined by two main elements: the Head (visualized in the 8-inch display) and the Body (visualized in the 13-inch display).

The Head interface can be configured selecting between two different models of Face: a model addressing the needs of SMI and MMR and a model addressing the needs of AUT. Both of them include mouth, nose, eyes and eyebrows; these elements are organized according to the basic structure of the human face. However, differently from to the face for AUT, the faces for SMI and MMR have a higher level of expressiveness (seven different emotional states): colors, visual cues (shadow and shades) and smooth transitions have been used to provide a life-like impression. The face model for AUT has a more simple appearance; each element has been designed using a basic geometric shape and the behaviour of each element (eyes, mouth and eyebrows) is limited to few variations.

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 screen, while the Autistic children with a severe impairment are more likely to recognize 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. 3).

Figure 3: 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.

The Body interface has been designed with the main purpose of driving the interaction, stimulating specific actions and communicating the robot status in a clear and unambiguous way. The choice to have a neutral interface, without any level of expressivity, has been done to allow all the three target user groups to interact with the robot (figure 4).

V. FIELD TRIALS

Field trials were conducted at the primary school G. Pascoli and S. Martini in Siena [11]. The testing focused on different aspects, from usability, to suitability with respect to learning objectives and user acceptability. The trials involved 5 children (3 female and 2 male) with different disabilities, from 6 to 11 years of age with different disabilities (global cognitive retardation, developmental disorder, epilepsy, and language retardation). The experimental plan and the entire project were submitted to the Educational Board and the parents and approved by all members. Parents of the children involved in the trials undersigned a written consent. Teachers and experts discussed the methodology, proposed a specific protocol for conducting the experiment and sampling the subjects. They later followed all the phases of the experiment and collaborate in the final interpretation and communication of the results. Also the parents were involved in the conception of the experiment and were constantly informed about the evolution of the experiment. The tests were organized in individual and group sessions, i.e. two sessions per child, one individual and one in group (from 2 to 4 classmates). Each session was about 40 minutes. Two teachers attended the trials, one was directly involved in the activity while the other observed the session. Both of them filled in a questionnaire at the end of the session and participated to a debriefing to share comments and discuss what happened during the activity. At the beginning of the session the teacher introduced the robot to the child and then proposed a game. She let the child explore the robot and when the game started she supervised the activity. From time to time she tried to attract the attention of the child on the robot behaviour by asking specific questions and encouraging the exploration.

Figure 4: body interface of the first prototype

VI. EVALUATION RESULTS

As a general consideration, the children were interested in the robot and in the play activity regardless of their different disabilities. Children were engaged in the activity from the very beginning of the session: the scenarios have been clearly understood and the child properly interacted with the robot respecting the game rules. Some scenarios worked better than others; in particular Turn-taking and Follow Me when played in group. In these situations the robot played the role of mediator of different social behaviours like collaborative exploration of the robot, reciprocal support during play, speech production, coordination. A fundamental drawback of the activity was that the robot was barely perceived as an agent but mostly as a machine without an inner emotional state. The interaction was mainly "functional" (stop and go) rather than emotional ("does it stops because it is tired or angry?"). The children paid attention to the facial expression of the head mainly when stimulated by the teacher. Only in few occasions the child interacted with the robot as it was an agent. This happened mainly during the *Follow Me* scenario. During this scenario, an experimenter operated the robot using a remote control in the Wizard of Oz modality. In this condition, the behaviour of the robot was more believable and the movement more expressive. When the game started the robot moved around as it was looking for someone. This was sufficient to stimulate a spontaneous collaborative behaviour, like moving toward the robot and waving or saying "hello" to be recognized and play together.

These preliminary observations show that the robot appearance and behavior do not seem to evoke an agent with own inner states and intentionality and this radically reduce the potential of the robot as mediator of social exchanges. The main issues of the current prototype of the Iromec robot are mainly related to the functional aspect of the visual interface that does not adequately support a life-like metaphor and meaning attribution processes. Another problem is related to the design of the physical appearance of the robot: children perceived the two screen displays (that one used for the face and the other one located on top of the main body) as separated components that do not constitute a whole. Most of the child attention was focused on the body screen where the commands of the game are entered. The face disappears in the background as well as most of the robot expressiveness. This negatively impacts the interpretation process thus forbidding the emergence of the role of social mediator.

VII. RE-DESIGN

The results of the evaluation brought to a fundamental change in the design metaphor and the interactions styles of the robot.

We redesigned the robot using a different approach, a metaphorical design to help the child in developing a mental model of what the robot can do, in order to support understanding and learning during play.

We involved the children in brainstorming sessions where we invited them to "draw" the robot companion they would like to play with. Some of them focused on the vertical configuration (human-like robot), some others on the horizontal one (zoomorphic robot), but all their robots were caricatures with an extremely vivid impression of life-likeness. Learning from the children, the current prototype conveys a new metaphor, the caricature of a zoomorphic creature, less functional and more expressive that shows clear agentivity cues related to life-like appearance and behaviour (Fig. 5).

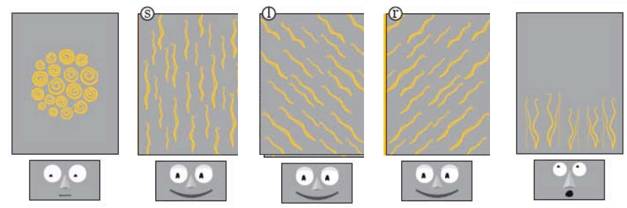

Fig. 5: The redesign of the visual interface

The robot is currently a zoomorphic creature with a (digital) fur on its back. When the child touches the fur knots, these develop in a soft fur and the robot starts moving. The fur moves dynamically following the direction of the robot. In some play scenarios lady birds appears on the top of the fur. The robot emits sound that reinforce the different feedback and improve the expressiveness of the robot.

Also the physical appearance of the robot has been modified. The head as a different inclination to allow a face to face interaction.

The new prototype (fig.1) is currently being tested in different European schools and institutions in Italy, Spain, United Kingdom, The Netherlands, Austria. A pilot experiment in Italy has been conducted in two different schools of Siena ("G. Pascoli" and "Sclavo), over two months, with four children (three females and one male) with different disabilities: Global retardation with impaired of cognitive – language functions (MMR), 10 years; Attention-Deficit/Hyperactivity Disorder (ADHD) (MMR), 10 years; Sclerosi Tuberosa and global retardation (MMR, SMI), 10 years; Pierre Robin Sequence (PRS) and Mental Retardation (MMR), 6 years.

The trials have been organized in individual and group sessions, i.e. four sessions per child, two individual and two in-group. Group sessions included from four to five classmates including the disabled child. One teacher per child assisted the sessions and completed a questionnaire before the trials (as pre- test) and at the end of trials (as post – test). The questionnaire contained items addressing the objectives of the play scenarios run during the test.

The sessions were observed by three experts who compiled observation grids (one for the individual sessions and one for group sessions) independently.

The data analysis is still undergoing and the results of the first pilot experiment cannot be discussed properly. Anyhow we can report some of the teachers' comments collected during a focus group held at the end of the experiment.

The first remark was related to the effectiveness of the design process: the teachers were pleased to see that most of the suggestions for improvement identified from the previous cycle of trials were incorporated in the new robot design. The robot was able to catalyze the children's attention and in this respect it could be used as a valid support for introducing new activities and reach educational objectives. Qualitative observations of the children involved in the trials revealed the following attitudes and behaviours.

The child affected by Sclerosi Tuberosa and global retardation showed a clear change in her behaviour during the sessions. At the beginning she was scared and refused to interact but during the following sessions she slowly started to accept the robot, touching it and playing some scenarios. This is a quite remarkable result since she usually gets tired soon of any kind of game. She was fascinated about the sound. When the robot walked around she clearly enjoyed the music, clapping hands, smiling and pretending to dance.

The child with global retardation and impaired cognitive and linguistic competences was fascinated by the expressions of the robot and the use of the lights. She spent a lot of time just exploring the robot, touching the surface, following its forms. The activity was more successful when played individually. During the group activity sometimes she showed aggressiveness and the teachers highlighted that they never observed such kind of behaviour in the past. In this respect Iromec could be used also to identify and anticipate disturbances at the social and interpersonal level.

The hyperactive child surprisingly showed a calm and reflective behaviour in presence of the robot. He tried to understand how it works, how it can move, why it doesn't do what expected (in case of breakdowns). He was also extremely patient when the robot didn't move at an acceptable speed due low battery. The teachers highlighted that when playing with video games he doesn't calm down really and keep changing games after a while.

VIII. Conclusions

As said above, the user testing is still undergoing. For the final 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 also hope to discover in a principled way which robotic features are most significant and effective for developing robot companions.

The user-centred design approach was fundamental to address the needs of disabled children and to learn from initial faults.

In the project children and teachers were constantly involved in the process e.g., definition of pedagogical objectives, observation of practices in the school, definition of user requirements, development of scenarios, mock-ups and testing.

The concept development was the prerogative of professional designers who worked in constant collaboration with stakeholders. Children were involved later in the process to explore and test the first prototype and to try to imagine a new one. This method allowed user requirements and design concepts to be explored at an early stage in the design process. Teachers and children performed play scenarios using the first prototype in iterative sessions and the testing results were used to improve the robot until the final system was developed. In sum, we see a fundamental advantage in using user-centred design in the Iromec project: the different users/informants had an active role in shaping the design at different stages: at the beginning to help designers problematize the domain, in the middle to test out and reflect on assumptions, and at the end to evaluate the robot in real-world contexts.

IX. Acknowledgments

We would like to thank Iromec partners, the experts, the children with their parents who collaborated with us and supported the work..

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