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Expressiveness in human-robot interaction

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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 expressiveness as a fundamental feature of the robot for engaging in meaningful interaction with different typologies of disable children - Autistic children, Moderate Mentally Retarded children and Severe Motor Impaired children. Modularity and configurability of expressive traits 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 the robot's expressiveness is achieved through different channels (facial expression, gesture, pose, body language -appearance, shape, movement-) and realised through the use of both digital and mechanical components but also of smart materials and textiles.

Categories and Subject Descriptors
H.5.2 [**User Interfaces**]: User-centered design, Screen design, prototyping, Input devices and strategies.

General Terms
Design, Human Factors.

Keywords
Human Robot Interaction, Play, Assistive Technologies, Robot Expression.

1.MOTIVATION
The design of expressive robots is a fundamental challenge in Human-Robot Interaction. With a robot's behavior that conforms to human social expectations, it is more likely that people will find interactions enjoyable, intriguing and meaningful [1].
However, in order to engage in interaction with a robot, the level of robot's autonomy and expressiveness (life-likeness, anthropomorphism, zoomorphism etc.) need to be carefully designed [2]. By "expressiveness" we refer here to the ability of the robot of manifesting and communicating its status and its behaviours in a way to effectively sustain the interaction with the user.
Expressiveness can be conveyed through many channels: speech, facial expression, gesture, pose and body language (appearance, shape, movement).
In this paper we present Iromec, a robot that takes advantage of many of these modalities in order to engage in social exchanges with children with different disabilities. In this specific application domain, the way the robot can express its own status and manifest its behavioural features profoundly affects the experience of interaction.
The research 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 this paper focuses on the design exploration of the expressive traits that can be configured and adapted in order to respond to the specific needs of the three main target users - Autistic children (AUT), Moderate Mentally Retarded children (MMR) and Severe Motor Impaired children (SMI). 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.

2.RELATED WORK
Attempts to create a robot capable of showing social behavior and interacting with human beings by expressing internal states have been very popular in the recent history of robotics. Research in this sector has rapidly expanded to the design of social robots inspired by the way human relationships and communication are carried out.
In the design of *lifelike robots* different perspectives coexist and are articulated by the robots through emotional, physical-perceptive and behavioural expressions. In general, artificial emotions in robots are used to increase the "credibility" of

interaction, to provide the user with feedback on the robot's internal state and intentions, to act as a control mechanism when activating a specific type of behaviour, or to understand how certain environmental factors influence the robot's behaviour.
Even the way expressions are showed can vary a lot. There are robots that can simply turn on or off LEDs to express excitement, and others like Kismet, a robotic head that can control the movement of its eyebrows, ears, eyes, eyelashes, lips and neck to produce a wide variety of emotional expressions. Kismet's design [3], produces emotional expressions by interpolating the three values that make up the robot's "emotional space": intensity, valence and position. There are many other examples of social robots aimed at expressing and controlling emotions and internal states: from those that use facial expressions and spoken language, to those that use body language and gestures [4]. Robins et al. focus on kinesics that is the study of the role and timing of nonverbal behaviour, including body movements, in communicative and interaction dynamics in human-robot interaction [5]. Yoshikawa et al. highlight the role of responsive gaze in human-humanoid interaction [6]. Yamamoto and Watanabe found differences in people's preferences concerning the timing of utterances in human-robot greeting interactions [7]. Robins et al. explored interaction kinesics in child-robot interaction in a play context involving a robotic dog [8].
However, our goal in this paper is not to provide a phenomenology of artificial emotions and their expression by robotic creatures, but rather determine when the emotional expression of a robot is the goal of interaction (although in this case the design becomes a replica and an imitation) and when it is intended to mediate human activity like in the case of the Iromec robot.

3.THE IROMEC PROJECT

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, 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 movements, 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 [9] and [10]. 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.

4.THE REQUIREMENTS ELICITATION

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 a 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 [11], 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 to 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.

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.

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

5. ROBOT DESIGN

4.1 Iromec robot

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*. 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.

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.

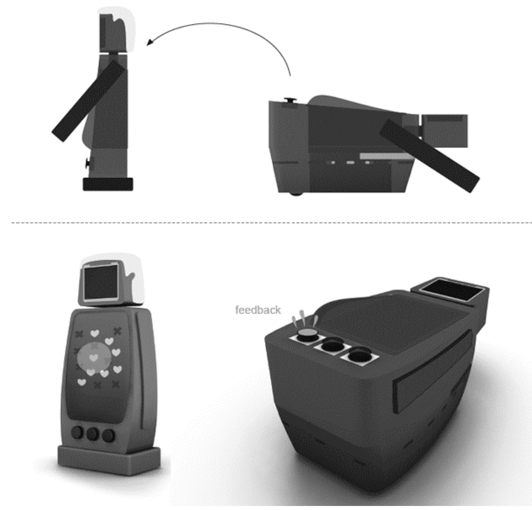

Figure 1. the Iromec robot.

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 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 [12]. 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. 2) 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. These design solutions have been purposely investigated in order to support the robot's identity and expressiveness. Also these solutions can be differently combined to support the specific needs of the different users group.

Being conceived as a modular robot Iromec allows to use the expressive traits of the robot and to create ad hoc configurations.

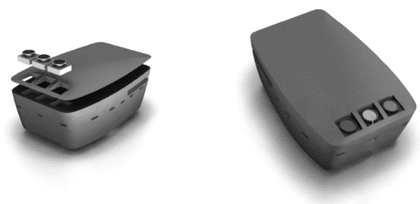

Figure 2. passive skin

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.

At this stage of development of the prototype the expressive traits that have been explored are related to the following dimensions:

•the robot Face

•and the Coating.

4.2 Face and expressiveness

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. 3, 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. 3, right).

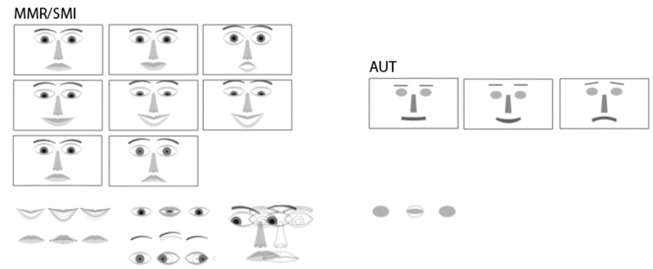

Figure 3: robot expressions

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 screen, 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. 3, bottom right). These masks can have different transparency levels in order to partly or completely show the eyes or the mouth movements (Fig. 4).

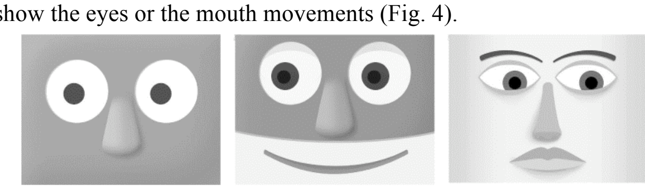

Figure 4: masks

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.

4.3 Coating

A set of "coating materials" can be mounted on the robot's body in order to obtain different tactile and visual effects. Coating materials are interactive and provide the meaning for personalization and customization of the robot, especially as regard the expressiveness of the robot.

Different kinds of smart materials and their application have been experimented as Coating elements. Colour changing / thermochromic inks, luminescent fabric, pressure sensitive textile and shape memory alloys, i.e. flexinol and nitinol wires have been experimented in order to improve the expressiveness of the robot. Smart materials embedded in the coating module can provide the robot with unusual visual and tactile feedback resulting from material transformations.

Three prototypes of the Coating module are currently under development: Luminescent Fabric, Pressure Sensitive Textile and SMA Textile. The prototypes explore the use of different smart materials. In particular the use of smart memory alloy materials in combination with textile embedded sensors are used to create interactive surfaces able to show minimal shape transformations.

The following coating prototypes are 150 x 20 cm and are thought to be placed around the application module. In their preliminary version the two prototypes are equipped with velcro stripes through which they can be fixed to the application module.

4.3.1 Luminiscent Fabric

The prototype is made of coloured polyester and luminescent fibers. Three groups of lumiscent fibers are inserted into the textile following the orientation of the textile with 4 cm distance in between. The electroluminescent fibers can have different colours ranging from purple to yellow and blue. The groups adopted in the prototype have three different colours that can be managed independently being controlled by one inverter each.

4.3.2 Pressure Sensitive Textiles

The textile is made of two external metallic and conductive layers with one isolating layer in the middle. The conductive layers are made of inox wires and the isolating layer could alternatively made of coloured polyester or transparent PA6 monofilament with relation to the required commutation. The choice is made in order to completely separate the conductive layers. The colour of the polyester textile can be chosen within a large range.

4.3.3 SMA Textiles

The prototype is made of coloured polyester and one selected Shape Memory Alloy (SMA), i.e. Nitinol and Flexinol inserted into the textile. The SMA are opportunely modeled into wave-like shape through the austenitic phase. The SMA wires are connected to power supply in order to provoke changes of temperature (from 60°C and up). Power is transformed into temperature causing the SMA modelling until the predefined shape is reached. Giving power to the wires many load cycles can take place after each other changing the shape of the SMA. They get warm and cold alternatively with the relation to the administered current. In particular the memory metals require low power supply and could improve the interaction with the robot by supporting physical modifications. The smart materials currently under investigation, the memory metals and the thermochromic ink represent an innovative feature of the design of the Iromec robot. These also represent different coating modules that can be used to enrich the expressiveness of the robot supporting the interaction with the users.

6. A PLAY SCENARIO

In order to exemplify the types of interaction that can occur with Iromec, we will 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.

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 therapist can create ad hoc configuration of the robot components to tailor its appearance to the specific needs of each single child. In the case of an autistic child, the therapist can use the mask sketched in figure 4 to have a physical representation of the robot face or use the simplified version of the digital face. This can be decided on the basis of child preferences, attitudes and specific therapeutic objectives. Furthermore, the therapist can decide to switch off the big screen since digital images can annoy autistic children. Fear, communication and tactile status can be expressed by specific patterns of movements and by using coating modules, such as smart textiles that encourage the tactile exploration of the robot. In the case of moderate mental impaired children, the robot can be configured to create richer interaction experience: more complex digital version of the face can be used in order to show different kinds of emotional expressions; the big screen can be used to show graphical patterns for engaging the child in interpreting the different robot attitudes. Figure 5 shows different kinds of graphical patterns. The content of the big screen can be developed in several ways, each one being a set of three different graphic images based on a common visual language. The therapist can choose among different alternatives to meet children preferences and attitudes.

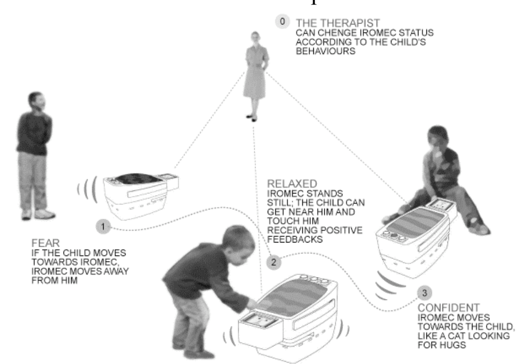

Figure 5: symbolic play scenario

7.DISCUSSION AND CONCLUSIONS

The design of the Iromec platform is still in progress. However some key values of the robot can be clearly identified:

• A strong emphasis on modularity, which is realised not only at the hardware level but at the behavioural level: plug-in modules and coating elements can define and change the behaviour of the robot.

• The robot's expressiveness is achieved through different channels (facial expression, gesture, pose, body language - appearance, shape, movement-) and realised through the use of both digital and mechanical components but also of smart materials and textiles.

• Adaptiveness to the needs of very different categories of users. This is undoubtedly a key value of the Iromec system. The same robotic platform can be configured to meet the needs of very different typologies of users with different physical and cognitive abilities.

User testing sessions of the first Iromec prototype are currently underway in different schools and rehabilitation insitutions in Italy, Spain, UK, The Netherland and Austria. 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 also hope to discover in a principled way which channels for conveying expressiveness are most significant and effective for human-robot interaction in the application domain of the project.

8.ACKNOWLEDGMENTS

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