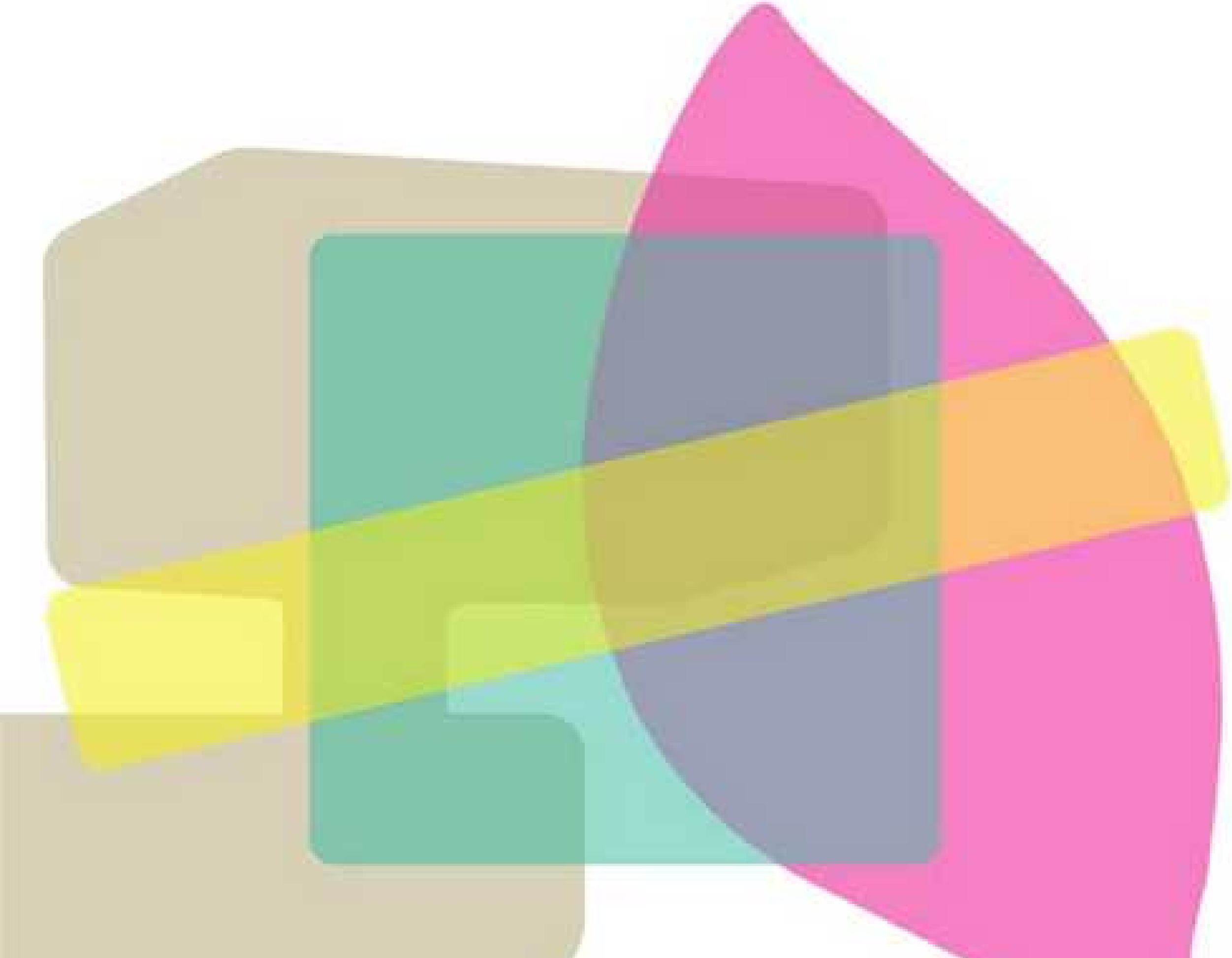
Patrizia Marti

Enabling through design:

explorations of aesthetic interaction in therapy and care



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Ena

explora

Graphic design concept developed together with Alessandro Dei and Lisa Tavarnesi, studio21.it

A catalogue record is available from the Eindhoven University of Technology Library

ISBN: 978-90-386-3089-2

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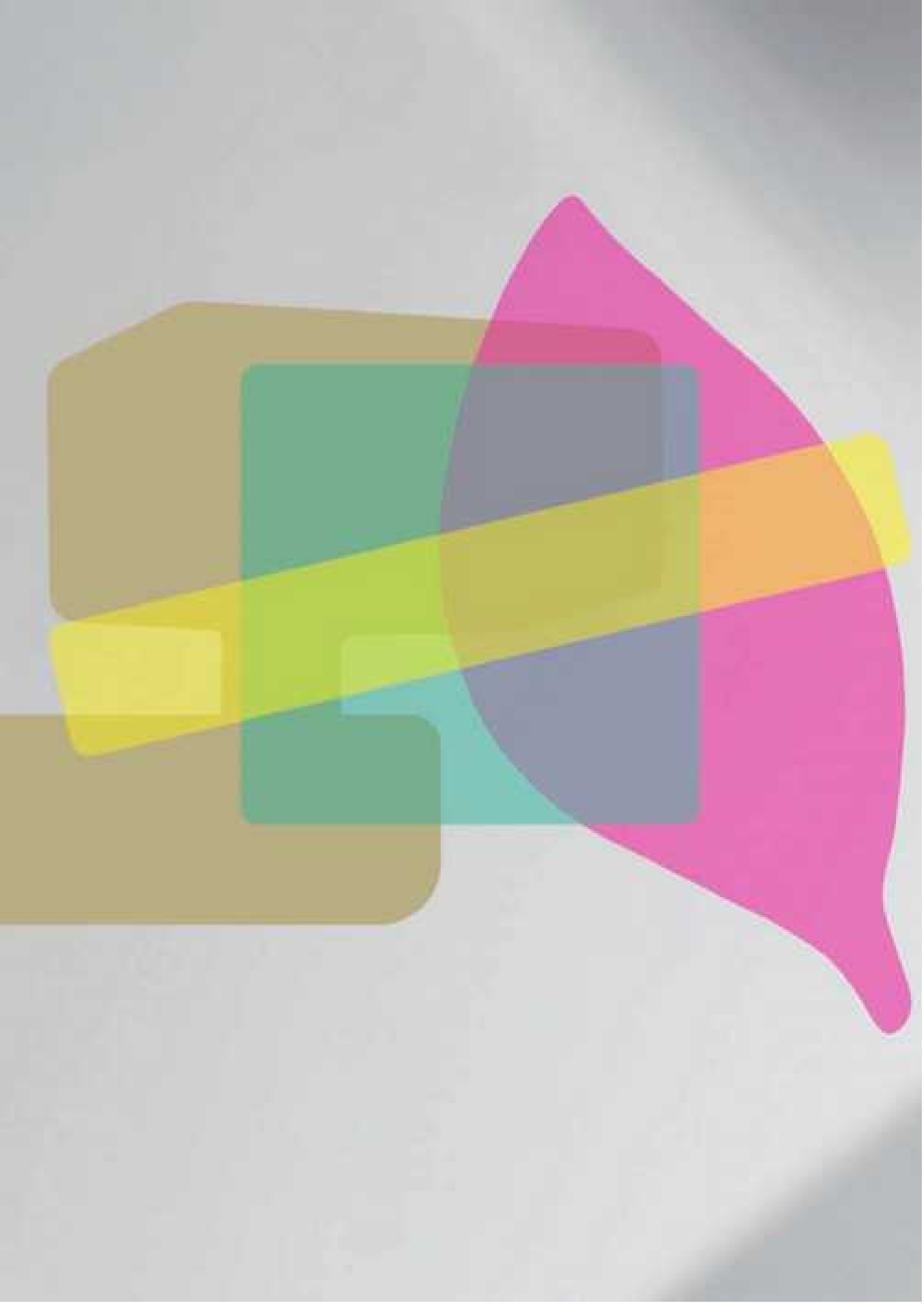
Proefschrift

Ter verkrijging van de graad van doctor aan de Technische Universiteit
Eindhoven, op gezag van de rector magnificus, prof.dr.ir. C.J. van Duijn,
voor een commissie aangewezen door het College voor Promoties in het
openbaar te verdedigen op dinsdag 28 februari 2012 om 16.00 uur

door

Patrizia Marti geboren te Rome, Italië



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Prof.dr.ir. C.C.M. Hummels vervangt
wijlen prof.dr. C.J. Overbeeke als
eerste promotor

In loving memory of Kees Overbeeke

You gave me the faith that my ideas were worthwhile expressing. You penetrated deeply in my life showing the way to strive for brilliance and beauty. Your ideas will live on in my mind, heart and work. They are your breathtaking legacy.
"We gaan mooie dingen doen Patrizia".
Abbiamo fatto cose bellissime, avrei voluto che fosse per sempre.

Caroline Hummels

I'm indebted to Caroline, a talented, generous and openhanded woman. She unrelentingly supported me with dedication and sharpness. She brought a smile to my lips in the midst of the sadness for the loss of Kees. Her critical observations and the continuous encouragement to reflect on my own work from different angles and viewpoints were a fundamental point of reference. It was a pleasure to work with you and to spend time together also in the rainy Siena… Hope the closing of this chapter can make room for working and enjoying together again in the future.

Miguel Bruns

It was a last second call… Thank you for responding and for being so open and committed. Your kindness and thoughtfulness reassured me. I'm grateful for your comments and your precious support despite the physical distance and the short notice.

Emile Aarts

We didn't know each other very well by the time I presented the idea of my thesis. You listened at my presentation and made the questions I hoped to hear from you. You strengthen my intuitions and made me feel on the right track. It was a tremendous starting point.

Colleagues and friends at TU/e

I did my sabbatical at the DQI, an extraordinary group of world-class people. Your energy, friendliness, creativity, sharpness, professionalism were a wonderful source for discovery and learning. I'm grateful for making me feel part of the "magic", for sharing dreams and the overwhelming grief for the loos of Kees. Hope the magic will continue for the years to come.

Henny Van Alphen

I didn't thank you enough for the warmth and tenderness you showed towards me in the painful moment of Kees' decease. I admired your energy and serenity when everything seemed gloomy and sad. I'm sincerely grateful.

Giorgio Soderi
Ho concluso questo un lavoro soffrendo per la perdita di Kees e cercando di colmare la sua mancanza. Ho combattuto contro il tempo e centellinato le energie. Mi sei stato sempre accanto, rinunciando al tuo tempo per raddoppiare il mio. La meravigliosa alchimia di serenità, cura, sostegno e amore che hai saputo darmi, mi ha accompagnato giorno dopo giorno. Sei un dono prezioso… ma anche Biaggetto.

A **Graziella**, **Mauro**, **Elena** e **Adriano**. Per tutte le volte che ho dato forfait quando ero troppo stanca, per aver riso con me ed avermi dato energia quando non ne avevo più. Vi sono grata dal profondo del cuore per aver dato una famiglia a Kees e per averne fatto un contradaiolo orgoglioso (grazie Adri). Con voi è stato felice, insieme a voi ha trovato la voglia di cambiare, di venire a vivere a Siena, la città che ha tanto amato. So che lo avreste reso felice, e so che lo porterete con voi nei vostri ricordi con lo straordinario affetto che gli avete sempre riservato. Ci mancherà nei nostri bomboloni party!

Ai miei genitori che sapranno cogliere dalle immagini, la passione e l’impegno con cui ho affrontato questo lavoro. Grazie per aver creduto in me e per aver sostenuto i miei sogni.

Grazie a quanti hanno collaborato con me in questi anni, ai partner di progetto e agli studenti di dottorato di allora. E' stato un buon tempo, abbiamo fatto grandi cose insieme.

Grazie agli anziani e alla loro meravigliosa pazienza. Grazie ai bambini, ai loro occhi e alla loro voglia di giocare. Grazie alle famiglie e alla loro grandissima umanità. Avete reso il mio lavoro una straordinaria avventura per la mente e per il cuore.

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1

STRUCTURE

My research explores the role that design could play in reducing the stigma associated with the use of rehabilitation aids that inherently manifest impairment and the inconvenience of the disability condition. The Design Cases described hereafter show that rehabilitation tools can be both engaging and useful, reflecting the inherent beauty and satisfaction of recovery.

The dissertation is structured around the presentation and discussion of four Design Cases. The introduction summarises my research agenda. The theoretical and methodological approaches clarify the conceptual framework of my research. A collection of eight peer reviewed journal or conference papers forms the core and gives full details about the Cases. Four videos are associated to the Design Cases to illustrate the context of the research and show the prototypes in use. Conclusions and reflections complete the dissertation.

Each Design Case is structured as follows:

Domain context: it describes the application domain, its problems and peculiarities, challenges and potentials. Dementia care, physical and cognitive rehabilitation with aqua therapy, neonatal intensive care and learning and play in disabled children are the main contexts addressed by the Design Cases.

Research context: it provides information about the project in which the Design Cases were developed. All projects are the result of international collaborations, some of them were co-financed by the European Union, in one case by an Italian private institution. This section specifies the time duration of the project and my role.

Inspiration: It explains where the concepts come from, how they have been defined and the main sources of inspiration for design. It describes the very early phases of the design process which was not necessarily intended to solve problems but mainly to create opportunity for use.

Focus on aesthetic and embodied interaction: it clarifies the nature of the aesthetic and embodied experience explored with the designed systems. Each Design Case provides the context to define, elaborate, experiment with a specific variation of design focus: empathic tuning (Case 1), play and autonomy (Case 2), intimacy, fragility and (in)visibility (Case 3), perceptual crossing (Case 4).

Prototype: Each prototype is described highlighting its formal, material and technical qualities.

Testing: Each prototype has been tested in the real context of use with disabled people and care givers. Experimental design, methodology and the data analysis are reported and discussed with respect to initial hypotheses and challenges.

Papers: Each Design Case is accompanied by one or more peer-reviewed journal or conference papers, providing full details of the subject matter.

Videos: Each Design Case is illustrated by a video that introduces the context and shows the prototypes in use. The videos can be accessed via QR code or URL.

2

INTRODUCTION

Can therapeutic and rehabilitation aids be pleasurable and gratifying to use? Can disability be seen in terms of aesthetically-minded design rather than only in terms of accessibility legislation? Can we set up an agenda with the seemingly reasonable goal of making therapeutic devices beautiful to use and pleasurable?

There is a huge potential for innovation in the rehabilitation practice and care of disabled people. Nowadays technology offers a full range of possibilities, from innovative prostheses to monitoring systems, from e-health care to augmented rehabilitation. Most of these technologies find a place under the big umbrella of accessible and assistive technologies (LoPresti et al., 2004). A fundamental issue for the development of such technologies is to design for both accessibility to impaired people and effectiveness of the therapy. These technologies work as compensatory strategies that alter the patient's environment and are directed exclusively to an individual's functional skills (Kirsh et al., 1988).

This work aims to contribute to "change stigmas into desirables" (Donald Norman - http://www.jnd.org/dn.mss/design_meets_disability.html) in the design of rehabilitation and health care aids.

In my research, I refer to "beauty" as the experience of use that may lead to feelings of engagement, emotional well-being and comfort during the therapy. In this context the experience of beauty is enabled by therapeutic tools or systems that may engender a positive reflection and confidence of recovery. Throughout the dissertation, beauty is not seen as an isolated modality or property of an object/tool. It is related to the way in which the system behaves and responds over time in interplay with the person (Löwgren, 2008) and to the engagement and positive feeling of people during the therapy. It is what resonates with personal meaning and hopes of well-being.

Four Design Cases were developed to emphasize beauty of interaction, loveliness of use, engagement and gratification in therapy with the goal of making therapeutic devices pleasurable and meaningful to use while maintaining their value and usefulness as therapeutic aids.

The Cases show that design can balance the tension between a functional approach to accessibility and a more playful and aesthetic exploration of technologies supporting disabilities.

The idea that design sensibilities can be applied to therapeutic aids and that in return disability can provoke radical new directions in mainstream design is witnessed by recent design research projects and by famous and outstanding design cases.

In Design Meets Disability, Graham Pullin (2009) shows how design and disability can inspire each other. By discussing insightful design cases, he states that disability can force some new questions onto the agenda that can actually open up new ways of thinking from subjective viewpoint, and not just in terms of better accessibility. If the eyeglasses design made it possible the switch from disgraceful medical appliances to fashion accessories, why does design not make any rehabilitation or assistive technology more dignifying and respectful of the person?

On the same subject, even if from a different disciplinary viewpoint, Cairns and Thimbleby (2003) argue that disability in Human-Computer Interaction (HCI) is a source of richness.

Harper et al. (2008) make the point that human values, in all their diversity, can be better understood and charted in relation to how they are supported, augmented or constrained by technological developments.

Other examples come from furniture and fashion design. For instance over the last 40 years Graham Cutler and Tony Gross have guided the revolution that turned eyewear from a medical necessity into a key fashion accessory (www.cutlerandgross.com).

Charles and Ray Eames's iconic furniture was inspired by a moulded plywood leg splint that they designed for injured and disabled servicemen (Fig. 1). The materials and the form of their chairs were prompted by the leg splints they designed beforehand. The example serves the purpose to show that design and disability can effectively inspire each other.

Figure 1: Sketches of Charles and Ray Eames's leg splint and chair

Damian O'Sullivan redesigned medical prosthesis in the hope of arriving at more dignified solutions for disabled people (www.damianosullivan.com). His ProAesthetics collection of porcelain prosthetic devices is an exploration of innovative forms and materials for prosthetic devices like the porcelain eye patch, both hygienic to use and elegant to wear(www.damianosullivan.com).

In her master thesis project 'ProAesthetics Supports', Francesca Lanzavecchia explored the perception of disability by re-designing medical garments like neck braces, back braces, canes and crutches, that are normally designed for functional purposes (www.lanzavecchia-wai.com). She transformed these accessories making them elegant and smart to wear and use, so to minimize the social stigma.

Figure 2: ProAesthetics Supports by Francesca Lanzavecchia (courtesy of ©Davide Farabegoli)

Nevertheless the aesthetic experience is not just correlated to the appeal of an objects as the examples above illustrate. The Design Cases presented in this thesis shift the focus of the aesthetic appearance to the context for experience and the rich and meaningful interaction with therapeutic devices which make the therapy worth to endure (Wensveen, Overbeeke, Djajadiningrat, 2002).

"People are in search of a positive experience. Therefore the designer needs to create a context for experience, rather than just a product. He offers the user a context in which he may enjoy a film, dinner, cleaning, playing, working ... with all his senses. It is his task to make the product's function accessible to the user whilst allowing for interaction with the product in a beautiful way. Aesthetics of interaction is his goal. The user should experience the access to the product's function as aesthetically pleasing as possible". (Overbeeke et al.,1999).

Following the quote by Overbeeke et al. (1999), also the interaction with therapeutic devices should contribute to make the experience of recovery as pleasurable and meaningful as possible. A prerequisite for this is that the disabled person should at the very least not be frustrated or bored during the therapy. Therapeutic tools should be surprising, playful, smart, rewarding, tempting to use and the activity itself should exalt a positive feeling of recovery and improvement. Most of the therapeutic practices and tools nowadays focus on the impairment of the person rather than providing a context for a rich and meaningful experience of care. For example, the physical rehabilitation is based on the repetition and training of physical exercises.

But why should the activity focus on impaired perceptual-motor skills rather than combining them with other skills like the emotional, social or cognitive ones which are still intact?

Why do therapeutic tools not imply the combination of different skills which makes the therapy more natural, interesting and intriguing?

The Design Cases explore the challenges of Aesthetic Interaction in the context of rehabilitation and care.

They show an interpretation of the aesthetic experience that lies primarily in embodied interactions with devices involving different senses and abilities (see chapter 3.2).

They also show that the aesthetic experience in this context critically depends on the way in which the device behaves and responds over time in interplay with the persons.

Four Design Cases of health care and rehabilitation systems are presented with a different focus on aesthetic and embodied interaction. They cover a time span ranging from 2004 to 2011 and are presented in chronological order.

The Cases show how my view of aesthetic interaction evolved and refined along time, from the initial cases mainly focusing on embodied interaction modalities to the more recent cases including the experimentation of smart materials and expressive, intentional behaviours with robotic devices.

Design Case 1: Rolling Pins

The Rolling Pins (RPs) are semi-transparent plastic tubes capable of measuring their orientation and the speed of their rotation and to produce three types of feedback: RGB light, sound and vibration (Fig. 3). They are able to communicate with each other and the local feedback of a RP can be set depending not only on its own speed and orientation, but also on the speed and the orientation of the peer RP. The system is used as facilitator and mediator of social dynamics during therapy to counteract social isolation that can result in dementia through the loss of social skills.

The system combines the use of different abilities from sensory-motor skills (they enable coordinated movements between the patient and the therapist), perceptual skills (they generate aural, visual and tactile feedback), cognitive skills (the patient and the therapist have to imitate each other movements and therefore "to read the other's mind"), and social skills (the activity consists in a non verbal dialogue between the patient and the therapist). The system provides the context for a social experience where the actors empathically tune their movements to create a choreography of light, sounds and tactile perceptions. The therapy consists of a playful, engaging and stimulating experience where people can experiment social exchanges using all their senses in an emotional and creative way.

Therefore the aesthetic focus of Design Case 1 is on emotional tuning experienced through a wide range of action possibilities offered by the RPs.

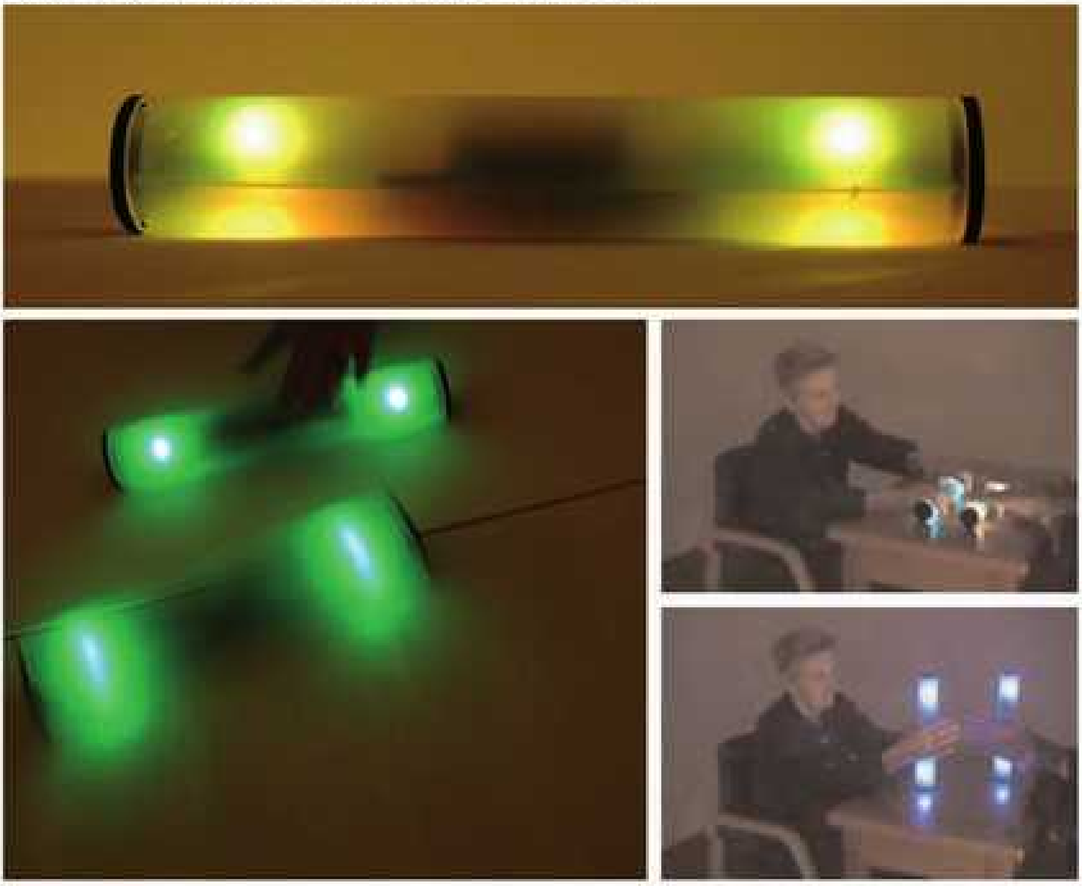


Figure 3: Rolling Pins

Design Case 2: Active surfaces

Active Surfaces (Fig. 4) is a system of position-aware floating tiles able to communicate with each other in the water. Each tile communicates with the others via the six sides using only a low bandwidth short-range infrared link. The output is a set of light emitting diodes which provide feedback during the game and reward at the game completion. The tiles are used in the swimming pool to combine physical and cognitive rehabilitation activities and to offer a play experience in complete autonomy.

In fact children with physical impairment such as multiple sclerosis, cystic fibrosis, spinal cord injury, arthritis, orthopedic impairments, can move autonomously only in water. On the other hand, children with cognitive impairments like autistic children can benefit from aqua therapy in many respects. Water activities provide them with proprioceptive and tactile input. Usually children with cognitive disability have sensory difficulties and are very distractible. The warm water provides a safe and supported environment, which not only sustains the children, but also provides them with hydrostatic pressure that surrounds their body in the water. This pressure actually soothes and calms the children, providing the necessary sensory input they crave. Using Active Surfaces, children with physical or cognitive disability have to assemble the tiles into meaningful configurations like forming words out of letters (scrabble game), or putting in a sequence tiles with images of increasing size, or matching colours (sequence game).

Aquatic activities are a fun and enjoyable experience that have many physical, psycho-social, cognitive, and recreational benefits. Aquatic therapy with Active Surfaces can focus on therapeutic play-based activities, improving the range of autonomous motion, helping to facilitate body awareness and sensory integration, but also stimulating cognitive and social skills associated to the different games, and most importantly, having fun.

Therefore the aesthetic focus of Design Case 2 is on play and autonomy.

Figure 4: Active Surfaces in the swimming pool

Design Case 3: Premature baby care

Design Case 3 is a monitoring system addressing the need of intimacy and closeness between mother and the premature child through unobtrusive monitoring. The system is composed of a mat that takes its form in a soft layer of gel, which is sensitized and capable of analyzing the micro-movements of the child and the vital parameters (Fig. 5a,b,c). The second component is the Bio-belt (Fig. 5d), a sensitized band that permits the monitoring of the cardiac frequency, the respiratory frequency, the respiratory movements and the temperature. Redundancy of the monitoring system improves the accuracy of the monitoring. The system is conceived as a soft and protective environment composed of foldable and sensitised components that gently embraces the baby to favour intimacy and emotional bond.

The neonatal intensive care setting is both a delicate and highly specialised environment. It offers an opportunity to reflect on how different actors (parents, neonatal doctors, nurses) perceive, interpret and take part in the premature baby's care. This Design Case shows the role that design can play in envisaging technologies that respect and harmonise different views and needs, making the unlucky event of a premature birth a more sustainable experience.

Design Case 3 provides a context for experience where the medical treatment, often regarded as invasive and intrusive for a fragile baby, is reconciled with parents' needs for information, communication and emotional bond with their child. Issues of visibility, intimacy and fragility are as important as monitoring and control.

Therefore the aesthetic focus of Design Case 3 is on intimacy, fragility, (in)visibility.

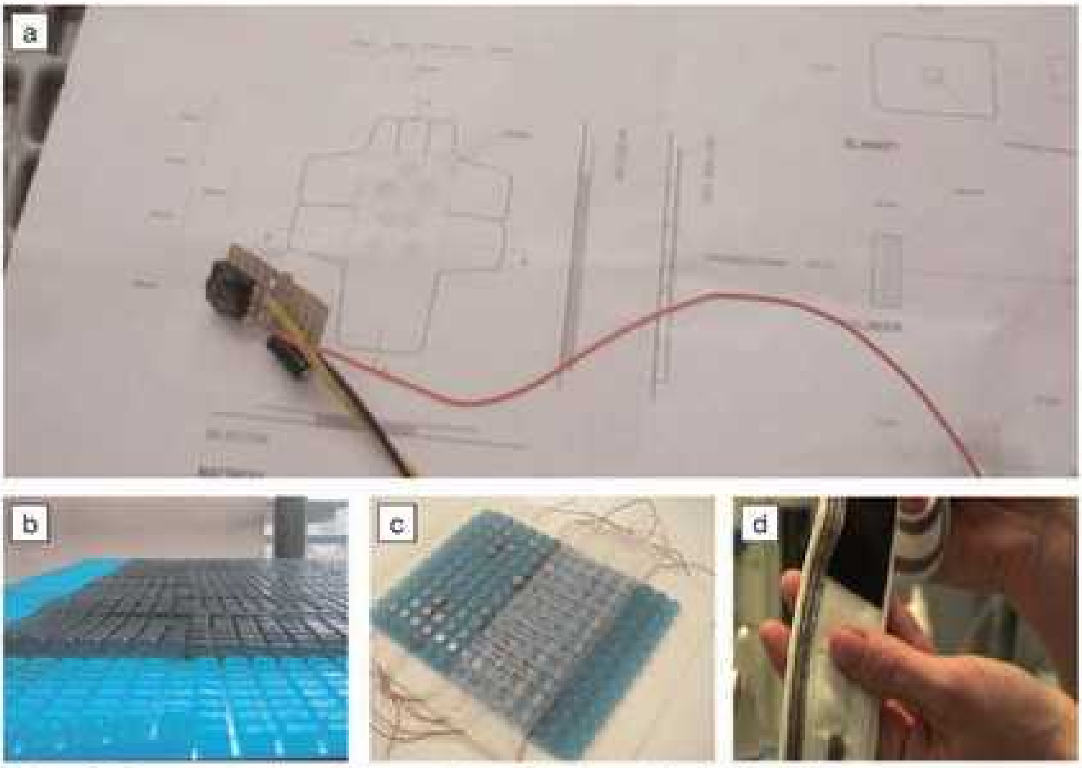


Figure 5: The construction of the mattress (a-b-c) and the Bio-belt (d)

Design Case 4: Robot for kids

Children with a disability do not only experience the physical and psychological consequences of their impairment in the short time but the disability will profoundly affect the harmonic development of their social skills all along their life. Communication and social interaction are fundamental in child development. Both these skills can be acquired during play in the childhood. Robot toys can play a main role in supporting the development of such skills. Iromec (Fig. 6) is a robot tailored towards engaging in social exchanges with children with different disabilities with the aim to empower them to discover a wide range of play styles from solitary to social play (Robins et al., in press).

In interacting with the robot, children are not passive agents, all their cognitive, sensorial and emotional abilities come at stake, and a supervised exposure by the adult can reinforce a positive effect of learning. Robots are designed to be patient, predictable, able to play many games, both intellectual and physical, and in this respect they can open unexplored opportunity for learning.

Design Case 4 explores rich interaction modalities with a robot companion of play. Intentionality and shared perception are fundamental characteristics for a robot playmate. Its credibility as autonomous entity is given by the ability to show intentions, and to express, pursue and share them with the child. Design Case 4 investigates the possibility of achieving by design a shared perception with the robot in order to enrich the experience of learning through play.

In exploring shared perception the concept of "perceptual crossing" (Auvray, Lenay, and Stewart, 2008) is taken as a main source of inspiration for design. Perceptual crossing is the perception of how the behaviour of the object and its perception relate to our own.

Deckers et al. (2011) investigated perceptual crossing with artefacts. They designed and built PeP, "Perception Pillar", with different perceptive behaviours realised in form of a dynamic light design. PeP is able to detect the presence, perceptive action and expressivity of a person. It allows for the reciprocity, where the subject is able to perceive the perceptive activity of the artefact. It is able to detect the presence of an external event and to show perceptive activity relating to the event (e.g. music).

PeP was experimented under the hypothesis is that if perceptual crossing between the subject and object happens, the feeling of involvement of the subject increases.

The experiment shows that it is possible to design perceptive activity in an object to allow for perceptual crossing between subject and object and for sharing the perception of an event. This positively influences the feeling of involvement of the user.

The aesthetic focus of Design Case 4 is perceptual crossing.

Figure 6: Iromec (a-b) and a drawing by a child (c)

3

AESTHETIC AND EMBODIED INTERACTION

In our everyday living we inhabit complex technological spheres of life that require a novel and more 'ecological' understanding of our relationship to technology. New kinds of pervasive sensor-based and embedded technologies entail a very different understanding than traditional user interface design activities.

People are confronted with new demands and increasingly complex technological infrastructures and ecologies. They need to make sense of them on the logical level (what can be done with them and for what purpose), on the functional level (how to use them), on the physical level (how to manipulate them), on the emotional and experiential level (how to enjoy and get involved), on the social level (how to be part of a community, to share and learn together).

As designers we strive to manage such complexity and to develop systems that seduce our senses. As ordinary people we would like to get rid of such complexity and interact in the digital world with rich interaction possibilities as we do so well in the physical world, using our intuition, motivation and enchantment towards objects.

The challenge is how to exploit this complexity and new possibilities for novel applications and experiences, which are inviting, witty and playful, original and fascinating, and last but not least, improve life and people on an individual or societal basis.

This vision requires societal and aesthetic sensitivity to be achieved. Such a deeply informed ethical and aesthetical perspective is indispensable if we hope to design more sustainable technologies for the future.

3.1 Aesthetics of interaction

The aesthetics of digital artefacts has recently received considerable attention, not only as regards the appearance of the product but also with respect to the design of the interaction modalities. This area of research is referred to as Aesthetics of Interaction.

In the last years, the field of Aesthetics of Interaction has reached a maturity. It consolidates the idea that, in response to a change in the use of computers and interactive technologies, traditional HCI concepts of usability, efficiency, productivity have to be enriched with other values such as curiosity, intimacy, emotion and affection (Marti, Overbeeke 2010).

Given that there seems to be near consensus on the importance of designing interactive systems beyond rational and functional requirements, the ways in which this can be achieved are not so straightforward, and the notion of Aesthetics of Interaction is still ambiguous and sometimes controversial.

In fact, different views have emerged. A first view is connected to the notion of aesthetics as a result of the properties of form as perceived visually (Fogarty, Forlizzi, Hudson 2001), as the use of exquisite materials, and as "an added bonus" pertaining to the object per se isolated from the context of use. According to this view, the judgment of beauty is a conceptual construct which is independent of actual product-usage experience. Satisfaction and pleasure are emotional consequences of goal-directed product usage.

Some views consider aesthetics with a socio-cultural connotation, as a result of the human appropriation of the object, a socio-historical appreciation of different components (materials, forms) and properties that do not inherently pertain to the object itself (Petersen et al., 2004).

Wright et al (2008) conceptualise a framework for aesthetic accounts of HCI and interaction design through the themes of: 1) a holistic approach to human experience including feelings, emotions, and thoughts; 2) co-construction of meaning and personal engagement in making sense of experience; 3) a "relational or dialogical approach" considering self, object, and setting as centres of value with multiple perspectives and voices. This framework recognises an active role to the user who brings as much to the interaction as the designer does. The focus on sense-making and the acknowledgement that it concerns not just the cognitive but also the sensual and emotional threads of experience provides means to interpret interaction as aesthetic engagement.

On a similar viewpoint, Löwgren (2008) stresses the need for holistic, interpretive approaches to dealing with aesthetics in interaction design.

Wallace and Press (2004) explore the notion of enchantment by arguing that beauty can play a fundamental role in facilitating our experience with digital technologies. Beauty is a form of enchantment that develops in craft practice: "Craft finds beauty, and design puts that beauty to work" [Wallace and Press 2004, p. 4].

The beauty of a product can elicit positive emotions and these can alter the way we think and behave. Interacting with an attractive product "the behaviour seems to go along more smoothly, more easily, and better. Attractive things work better" (Norman, 2002) and therefore valued aesthetics can lead to a positive response and feeling.

Inspired by the theories mentioned above, the perspective of Aesthetics of Interaction adopted in this dissertation is multifaceted. It focuses on the following assumptions which are explored in the domain of therapy and care:

- Appreciated aesthetics engenders positive feelings which are fundamental to face difficult situations like the ordeal of a therapeutic path.
- Societal and aesthetic sensitivity is fundamental when designing for disability support. Technologies should be experiential and respectful (Overbeeke et al. (1999).
- The aesthetic interaction is a dialogue that is released in interaction and that is dynamic. It is enabled by the presence of rich action-possibilities (Wensveen, Overbeeke, Djajadiningrat, 2002) (Frens, 2006) involving perceptual-motor and emotional skills, instead of focusing only on cognitive skills.
- The designer needs to create a context for experience, rather than just a beautiful product (Hummels, 2000). The context should be authentic and not simulated.
- The aesthetic experience lies in narrative experiences (Dunne, 2005), and more in particular in playful narrative experiences as exemplified in Design Case 2 and Design Case 4.

3.2 Embodied Interaction

Over the last ten years research in HCI and Interaction design has put emphasis on the concept of embodiment and the fundamental role the physical body plays in shaping our experience and understanding of computation in the world we live in.

However the concept of embodiment has been interpreted in very different ways depending on the particular disciplinary view-point and realm of application.

Rohrer (2006) surveys twelve different uses of the term in the cognitive science literature.

Starting from a criticism to the functionalist paradigm that deliberately theorized the body away, cognitive scientists argue that the specific details of how the brain and body embody the mind do matter to cognition. This view has inspired diverse fields of research ranging from neurobiology and linguistics to robotics and philosophy.

Among the different connotations of the term "embodiment", some of them are specially relevant for the purposes of this thesis.

In particular the phenomenological dimension of "embodiment" emphasises the role of our body in shaping our self-identity and our culture through actions and reflection on the lived structures of our experience. Action is the preferred link between the subjective and the objective. The distinction between the knower and the known is a distinction for the sake of analysis.

Experience is intrinsically meaningful: through action, action possibilities (affordances) are opened in the world on the scale of our body and perceptual modalities (Gibson, 1979). Perception thus becomes action, and vice versa. We cannot separate ourselves from the world as we are always contextualized (Merleau-Ponty 1962). The socio-cultural dimension of "embodiment" emphasises the situated nature of the social and cultural practices within which the body, cognition and language are shaped (Hutchins, 1995).

Another fascinating connotation of "embodiment" is the embodied viewpoint. Here "embodiment" refers to the particular subjective vantage point from which a particular perspective is taken, as opposed to the objective tradition of the all-seeing, all-knowing (Roher, 2006). An intuitive example of embodied viewpoint is the spatial orientation: when we give directions, we ordinarily assume that one is facing in the direction of the travel and we provide information accordingly (deictic utterances). Embodied viewpoint may have huge implications for design in the mutual sharing of experiences and meanings.

The term "embodiment" is also widely used in robotics to mean that the work done by the robot depends on the particular morphological characteristics of the robot body (Pfeifer & Scheier 1999).

The different nuances of the concept of "embodiment" can be reflected also in several usages and interpretations in the HCI and interaction design literature.

Multiple streams of research and design see "embodiment" as the bridge between the physical and digital. Ubiquitous computing, tangible interactions, and computational materiality represent strategies for accomplishing full integration of the digital and the physical.

Sensibilities to the theme of "embodiment" can be found in Vallgårda and Sokoler (2010) who consider the computer as a material, analyze the substances from which it is made and then utilise these properties as computational materials to create new functionality, forms and expressions of computational devices.

Different sensibilities emerge in the field of Tangible Interaction in its strategies for design. This approach has given rise to strands of researches like graspable media (Fitzmaurice et al., 1995) and tangible bits (Ishii, Ullmer, 1997), to mention a few, for bridging the divide between the physical and the digital world. However, both computational materials and tangible interaction often rely on metaphors and representations for mapping the digital and the physical.

Sometimes this results in interaction requiring cognitive effort in interpreting the relation between the digital and the physical, inadvertently maintaining the separation rather than bridging the divide.

For the purposes of this thesis we will refer to the concept of Embodied Interaction as formulated by Dourish (2001) that does not only imply physical embodiment of digital components, but also extends to other aspects of our everyday world such as participation in action, perception and understanding. In this sense interaction is an embodied phenomenon that happens in the world, being it a physical or a social world.

The world shapes substance and meaning to the interaction.

In this dissertation, the fields of Aesthetics of Interaction and Embodied Interaction are investigated in a barely unexplored field of application: disability. This is done by tackling problems and opportunities related to four application domains by taking each time a different focus on aesthetic and embodied interaction in the design of technological solutions.

Despite their specificity, these application domains share a vision of aesthetic and embodied Interaction that goes beyond the formal properties of an object/system.

Embodiment, bodily skills, cultural context, social practices and contextual aspects are all essential for the aesthetic experience that is considered as a potential that is released in dialogue as we perceive and act in the world.

The aesthetic experience is a key property of the embodied interaction. This experience is dynamic and implies the exploration of the world with our perceptual-motor and emotional skills, our cognitive capabilities, and our value-related personal and social system.

4

RESEARCH
THROUGH
DESIGN

My research along the four Design Cases can be regarded as an example of Research-through-design, since I spent time exploring experienceable prototypes in the real context of use, reflected back on the design process and the achieved results, developed a set of research questions that guided the development of the next iteration of prototypes or projects. The iterative design cycles were conducted in a diachronic, retrospective way, by reflecting on how the Cases evolved in time and which new topics and challenges emerged from practice in the field.

In the Interaction Design community, the term Research-through-design has been used with different emphasis and nuances (Stolterman, 2008). Donald Schön introduced the idea of design as a reflective practice where the act of reflecting-on-action enables designers to develop a useful repertoire of design ideas and concepts to be used in future projects (Schön, 1983). Bruce Archer (1995) defines Research-through-design as a "systematic enquiry conducted through the medium of practical action, calculated to generate or test new, or newly imported, information, ideas, forms or procedures and to generate communicable knowledge" (Archer, 2004, p.15). This kind of research must be knowledge-directed, that is it must produce new knowledge through testing and concretely acting in the context of application. Furthermore it must be systematic and situation-specific, that is it must be pursued through action in and on the real world, in all its complexity. However findings that are limited to a specific situation or context can only be generalisable to a limited degree but this does not mean that they are not valid. When the Research-through-design activity is well documented, it can advance design with valuable insights, and generate new research questions and exemplar solutions.

An excellent example of project conducted in the field of disability using a Research-through-design approach is LinguaBytes (Hengeveld et al., 2008, Hengeveld, 2011). LinguaBytes is a play-and-learning system that stimulates the language development of non- or hardly speaking children between 1 and 4 years old. It is a modular system in which language is experimented with a physical, playful form. Linguistic exercises can be tried out constructing interactive stories together with a caregiver. As for the Design Cases described in this thesis, LinguaBytes does not only address the child's linguistic development, but also his social and emotional development. The project was conducted through different Research-through-Design cycles to improve the design, reflect on the decision taken and improve the knowledge on the domain problem.

In the development of the Design Cases, Research-through-Design cycles were combined with a user-centred design approach. I needed to constantly confront with potential users to understand problems and highlight opportunities to explore in the design. Users were involved in iterative design processes (Markopoulos, et a., 2008) even if the forms of participation were sometimes questioned and varied from that presented as the prototypical UCD approach (Marti, Bannon, 2009). Nevertheless users concretely experienced with prototypes contributing to a better understanding of the problems and also stimulating different viewpoints. Iterative design processes were inspired by the idea of "designing in context", since all intermediate steps in the design process including inspiration, content review, technology exploration, concept design, prototyping and testing, were developed in the real contexts and situations of use.

This approach is inspired by the phenomenological tradition of considering human action and perception as situated in the world and not abstracted from it. Social facts emerge from acting in the world and therefore are properties of interactions.

Design in context aims at exploring the whole complexity of the target domain and to intentionally promote reflection and expression of personal point-of-view and meanings in the use of digital technologies. The notion of context has largely been used in the realm of computational design, mainly by taking the form of technological challenges such as sensor fusion, contextual information management, ubiquitous computing, pervasive technologies and so forth. By considering contextual elements, engineers strive to develop technologies that are more sensitive to people expectations and natural to use. Dey, A. K., Abowd, G. D. (2000) stated the importance of better understanding and modelling the context to make it possible to produce more useful computational services. They defined a framework for the development of context-aware applications to help designers select contexts to use and orient the choice on the features to implement. Psychologists and social scientists (Suchman, 2007) have often criticised the engineering approach arguing that a technology-oriented interpretation does not properly address the full richness of socio-cultural, emotional and situated components of a context. On the other hand, designers know that the successful introduction of new technologies in everyday life contexts critically depends on meeting people expectations and interpreting their dreams. In this respect, collecting explicit demands and expectations from people and existing practice of use may limit imagination rather being inspirational for design.

The definition of context is therefore slippery. Dourish (2004) surveys a dual origin in the notion of context as used in computational design: the technical connotation and the socio-psychological connotation. The technical connotation offers engineers new ways to conceptualise human action and its relationship with interactive systems grounded to defined settings. This notion can be ascribed to positivist theories that try to reduce social phenomena to simplified and abstract models (Dourish, 2004).

On the contrary, the socio-psychological connotation emphasises the improvisational and situated aspects of human behaviour and de-emphasises apriori plans that the person executes (Suchman, 1987, Abowd et al., 2002). This notion can be endorsed to phenomenological theories that are subjective and qualitative in orientation. These theories refuse the idea of an objective reality beyond the ability of individuals and groups to recognise and perceive occurring phenomena. Social facts are not pre-given but negotiated and continuously interpreted. Phenomenology (Merleau-Ponty, 1962) stresses the unity between human beings and environment, and sees action as the preferred link between the subjective and the objective. Therefore the phenomenological orientation urges us to confront the complexity of life not through a classical Cartesian building blocks dissection, but as a whole in context (Marti, Overbeeke, 2011).

The methodological approach taken in the Design Cases presented below is inspired by the phenomenological orientation toward considering the human activity in context and confronting the whole complexity of the situation at hand. Designing in context is put into practice in the Design Cases as a detailed exploration of the mundane reality of everyday life of disabled people, their careers and the related socio-cultural milieu. The real and concrete settings are therefore used as living laboratories to experiment ideas, share reflections and negotiate meanings with people who are the main actors of the designed system. Dynamic, creative and engaging methodological techniques were tried out in the Design Cases, (in particular Design Cases 1, 2, 3) which provide examples of how methodologies can be pushed, moulded and experimented with (Paper 2, 3, 5, 6).

Mainstream design methods such as observational research, iterative prototyping and storytelling, alongside more unconventional techniques, have been applied together with design sensitivities to create value and meaning. Design sensitivities consist of the ability to tap into intuitive qualities such as delight, beauty, personal meaning, cultural resonance, empathy, autonomy, intimacy, playfulness, not only to guide design decisions, but also to influence how people experience the resulting product or system.

For this reason, rather than suggest a complete overthrow of established methodologies, the Design Cases were developed creating a dialogue between conventional methods, novel approaches and design sensitivities. As Alan Latham (2003) states "We simply do not have the methodological resources to undertake research that takes the sensuous, embodied, creativeness of social practice seriously." Therefore designers have to call upon sensitivities to imagine and create a product and people will tap into their sensitivities to enjoy and make sense of it.

The approach adopted in the Design Cases consists in the integration of different techniques and design sensitivities articulated in three fundamental steps.

Opening sensitivities

It focused on opening designer's sensitivities in the first place through a sensorial exploration of the space and an observation of the context of use. The aim was to get inspired about the different qualities of the space where the activity took place, the existing practices and the socio-cultural milieu.

Ethnomethodology (Garfinkel, 1967) was widely used in this phase for its inspiration to the phenomenological tradition and for being directly related to the study of the ordinary character of everyday activity. Some ethical issues were raised by the Design Cases when observing people in sensitive contexts like hospitals, home cares, rehabilitation centres and schools. Participative or even non-participative observations in these contexts can be regarded as inappropriate, intrusive or unethical (Marti & Bannon, 2009). The impairments of the people sometimes limit the degree to which they can be involved, and external intervention, unless very carefully and sensitively managed, can produce frustration. Paper 2 and Paper 3 provide concrete examples of such difficulties. In addition to interviews and observations, facts related to the hosting institution, the therapeutic practice and medical records were collected and shared with experts and locals.

Design sensitivities were stimulated using different techniques like:

Data sessions: Interdisciplinary review of ethnographic data, selection and analysis of significant pieces of data.

User Workshops: workshops organised to develop and evaluate a joint understanding of the work, the potential impact of socio-technical innovations, activity models, scenarios and prototypes for future uses, focus groups and experiments in situ.

Fieldstorms (Büscher et al. 2004): Brainstorming sessions grounded in analysis of ethnographic data and experience, where ideas were documented as sketches, video prototypes, animations and mock-ups.

Travelling Architects (Amhoff, 2009): A group of architects/engineers participated in some fieldwork and played a key role in connecting problems in use with technological solutions.

Reflections corner: A whiteboard located in the hospital/home care/school to collect data, document the activity, capture ideas in situ using post-its and photographs, collect probes and "vote" for ideas.

Diary probe: A shared diary was designed to document best practices, activity breakdowns, problems encountered and not solved, and ideas for improving the activity. A disposable camera was made available to take pictures of places, tools or situations, to exemplify what was reported in the diary. An 'object collector' (a large envelope) was used to collect small objects or tools representing meaningful events or situations. The diary was designed to be used collectively and anonymously by all the actors in the target institution.

Contextual enquiries (Beyer, H. and Holtzblatt, K., (1997) with children/elderly with different (dis)abilities and their parents/relatives to document the use of tools and the "hacking" practices necessary to adapt them to the abilities of the person.

Workflow and scenarios of the current and imagined therapeutic/educational activities. Scenarios illustrated the context of use of rehabilitation aids, the educational/therapeutic objectives of the activity, artefacts (both material artefacts as devices, tools, ambient and spaces, and conceptual artefacts as procedures, practices, ethics, etc.) and social relationships. Role playing, acting out, story telling, simulations were also used to generate ideas and experiment with them.

Making

The second methodological step of the design process was making. Through physicality and thinking with our hands, we can actually transform the world and create the radically different. The radically different exploits to the fullest culture and technology (Marti, Overbeeke, 2011). Making was grounded in technology exploration and building using different materials. Mock-ups and prototypes were developed not simply to increase the effectiveness of the final system, but also to tweak concepts and functionality to better answer people expectations, come up with different ways to use the technology, and develop new social practices around the possibilities opened up by the new technological system.

Experimenting and reflecting

All prototypes developed in the Design Cases were tested with people in the real contexts of use. Sometimes testing took the form of qualitative data collection from unstructured and spontaneous activities (Paper 4). In some projects, technology was tested through measured experiments (Paper 1), in other projects qualitative data were combined to pre-clinical trials to test the accuracy of the technology in the real setting (Paper 5).

Testing was not used only for assessing the impact of the new technology on the application domain but also for reflecting on doing and get a deeper, felt-through understanding of how these systems can become part of our lived world. Reflection was always conducted in a " performance" way sharing the experience with people in context.

5

DESIGN CASE 1:
Rolling Pins

5.1 Domain context

People with dementia suffer from an acquired permanent neurodegenerative disorder that affects the global functioning of the individual, progressively impairing cognition, personality and behaviour. Dementia is strongly characterised by social isolation and difficulties in communication. Speech becomes increasingly inefficient and progressive short-term memory difficulties and problems with new learning make conversations and other social interactions problematic. The social sphere of the individual is jeopardized not only by the impairment of social abilities resulting from global functional impairment , but also by the patients withdrawal from social interaction due to a number of contextual factors ranging from aural and visual ability impairment, institutionalization, interpersonal disorientation, lack of self-esteem and low motivation.

5.2 Research context: The RPs were developed in the context of a research project carried out from 2005 until 2007 by a multidisciplinary European consortium: University of Siena responsible for the user studies, design and field experiments, University of Southern Denmark in charge for technology development, and the home care Casa Protetta Albesani, the test site. The project was sponsored by Fondazione Piacenza-Vigevano and Targetti Sankey Spa. I was the principal investigator of the project and coordinated an international team including PhD students from the University of Siena. I was involved in the user studies, design and field experiments. The overall deliverable of the project was a therapeutic environment called "the sensory room" composed of interactive tools including the RPs, and a non pharmacological therapeutic protocol to use the tools for the treatment of people with dementia (Marti, et al. 2007). The RPs are still in use at the nursing home Casa Protetta Albesani.

5.3 Inspiration

The clinical research, which in the past has focused its attention almost exclusively on cognitive and neurobiological aspects of dementia, has recently placed increasing attention to "non-cognitive symptoms" of the disease. These symptoms are heterogeneous, intermittent and influenced by different variables. An example of non-cognitive symptoms is the aimless bustle characterised by busy, frantic and repetitive motor activity. The most frequent sensory-motor patterns characterizing bustle, are rolling, grasping and shaking objects.

This simple observation was inspiring to design graspable objects that can be rolled and shaken to support non-verbal, empathic dialogues based on visual, aural, tactile and sensory-motor interaction modalities.

5.4 Focus on aesthetic and embodied interaction: Empathic tuning

Empathy is a construct comprising affective and cognitive aspects. It is the emotional response that moves people to interact with others as they share their emotions. It can grow out of the perception of expressive behaviour that transfers emotional states from one individual to another (emotional contagion) (Enz et al., 2009). Such process helps to establish a shared experience, and, in the human-human interaction context, create intersubjectivity. Evidence from psychology indicates that perceived empathy has beneficial effects on attitudes and social behaviour (Eisenberg, 1986) since it implies the apprehension of another's inner world and a joint understanding of emotions. People with dementia progressively lose social competences including empathic behaviours. Social competences are fundamental to prevent cognitive and behavioural decline in elderly people and therefore they have to be exercised and preserved as long as possible.

5.5 The prototype

The Rolling Pins (RPs) are interactive objects designed to scaffold dialogic exchanges between therapist and elderly people with relational disturbances. They are semi-transparent cylinders capable of measuring their orientation and the speed of their rotation. At a local level they have three types of feedback: RGB light, sound and vibration. The peculiarity of the RPs is that they are able to communicate with each other. They are used in pairs by two actors (typically the therapist and the patient), and the local feedback of the single RP can be set depending not only on its own speed and orientation, but also on the speed and the orientation of the peer RP.

The RPs embed by design a concept of reciprocity and empathic tuning: the local feedback of each RP depends on the operations synchronously performed on the two pins. Therefore, we used the RPs in which the local feedback of each RP is a function of the sum of the speed rotation of both RPs. Potentially, it can be a function of any other operation on the speed rotations and orientations of two RPs.

Paper 1 describes the technological features of the system.

Paper 2 contains details of the design process.

Video 1 shows an overview of the system and some experimental sessions at the home care Casa Protetta Albesani.

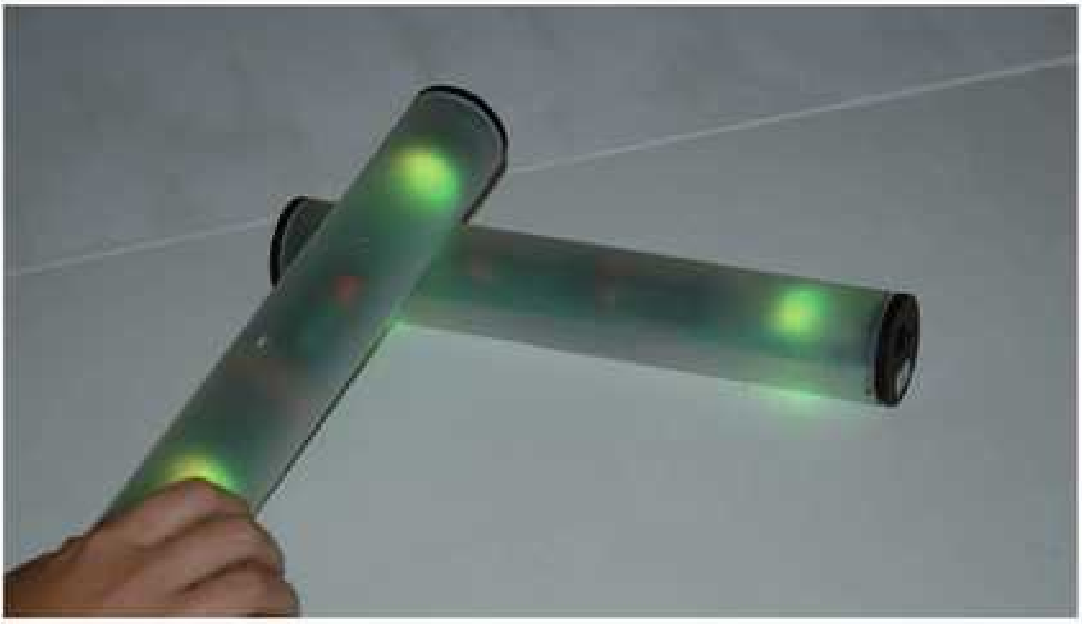
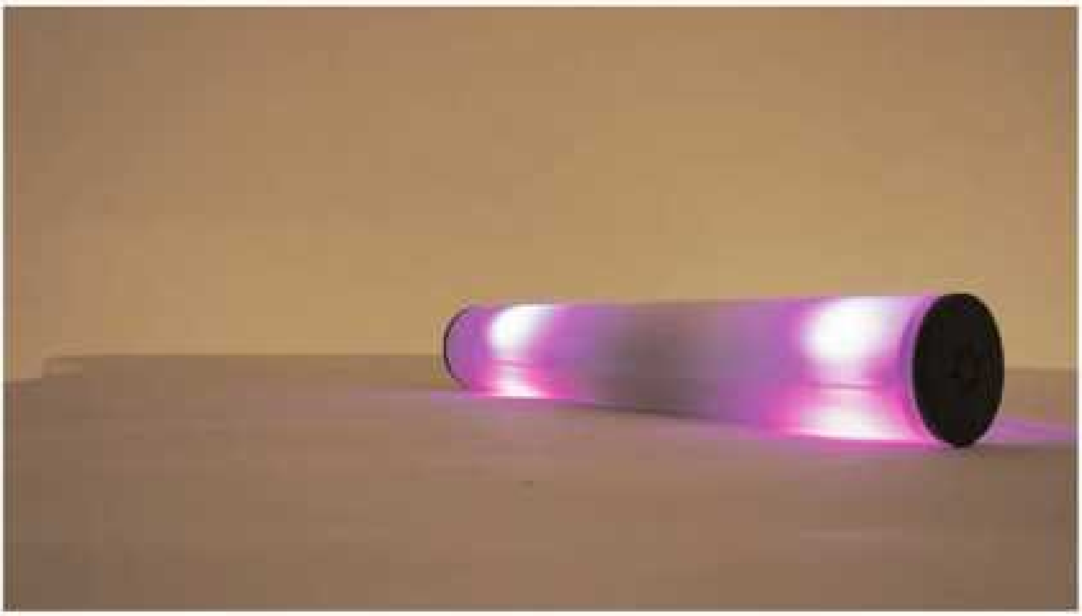


Figure 7 - Rolling Pins



5.6 Testing

The RPs were tested for several months in exploratory field trials. A measured experiment was designed involving 12 patients of the home care Casa Protetta Albesani (Castel S. Giovanni, Piacenza, Italy). The patients' performance was assessed using "in between group" experimental conditions.

All details related to the experiment are reported in Paper 1.

Paper 3 discusses caveats in involving in the design process people who present a rather special set of circumstances-namely when working with children and with people affected by dementia.

Design Case 1: Papers

Paper 1
Marti, P., Giusti, L., Lund, H.H., The Role of Modular Robotics in Mediating Non-verbal Social Exchanges, *IEEE Transaction on Robotics*, June 2009, pp 602-613, ISSN: 1552-3098, vol. 25, n. 3

The authors equally contributed to the paper working in close collaboration. More in detail, Patrizia Marti edited the introduction, the state-of-the-art, part of the research context, the design process and the conclusions. Henrik Hautop Lund wrote the technology design part. Leonardo Giusti edited part of the research context, the field trials and the experimental results.

Paper 2
Marti, P. Giusti, L. Bringing aesthetically minded design to devices for disabilities. *Proceedings of 5th International conference on Designing Pleasurable Products and Interfaces*, DPPI, 22-25 June 2011, Milan, Italy.

The authors equally contributed to the paper. Patrizia Marti edited the introduction, the theoretical approach, part of the design process, the presentation and discussion of the experimental results and the conclusions. Leonardo Giusti edited part of the design process, produced the graphics illustrating the models used in the design process, introduced the field trials.

Paper 3
Marti, P. Bannon, J.L. Exploring User-Centred Design in practice: Some caveats. *Knowledge, Technology & Policy*: Volume 22, Issue1 (2009), Page 7-15, DOI: 10.1007/s12130-009-9062-3.

The authors equally contributed to the paper, conceiving together the structure and the contents. In particular Liam Bannon introduced the paper and the UCD approach and Patrizia Marti edited the case studies.

Video 1: The Rolling Pins: overview and field trials
www.vimeo.com/patriziamarti/rollingpins

The Role of Modular Robotics in Mediating Non-verbal Social Exchanges

Patrizia Marti, Leonardo Giusti, Henrik Hautop Lund

Abstract— This paper outlines the use of modular robotics to encourage and facilitate non-verbal communication during therapeutic intervention in dementia care. A set of new socially interactive modular robotic devices called Rolling Pins (RPs) have been designed and developed to assist the therapist in interacting with dementia affected patients. The RPs are semi-transparent plastic tubes capable of measuring their orientation and the speed of their rotation; at a local level they have three types of feedback: RGB light, sound and vibration. The peculiarity of the RPs is that they are able to communicate with each other or with other devices equipped with the same radio communication technology. The RPs are usually used in pairs, as the local feedback of an RP can be set depending not only on its own speed and orientation, but also on the speed and the orientation of the peer RP. The system is not used as a therapeutic tool *per se* but as facilitator and mediator of social dynamics during normal therapy to counteract social isolation that can result in dementia through the loss of social skills. An experiment is reported showing that using the RPs the patients participated in the activity, coordinating their behaviour with the therapist and imitating the same interaction patterns generated by the therapist.

Index Terms—Modular robotics, dementia, social exchanges, imitation, gesture-based interaction, tangible media.

I. INTRODUCTION

THIS paper describes an early experiment using modular robotic devices to mediate social exchanges between the therapist and dementia affected patients with the objective to facilitate the development of ordinary therapeutic intervention. One of the problems of current therapeutic practice is the difficulty for the therapist to establish and maintain a sufficient level of communication with the patient during therapy. Dementia affected subjects suffer from an acquired permanent neurodegenerative disorder that affects the global functioning of the individual progressively impairing cognition, personality and behaviour. In particular, dementia is strongly characterised by social isolation and difficulties with communication. Speech becomes increasingly inefficient and progressive short-term memory difficulties and problems with new learning make conversations and other social interactions increasingly problematic [1]. The social sphere of the individual is jeopardized not only by the impairment of social abilities resulting from the global functional impairment of the subject but also by the voluntary withdrawal from relational exchanges due to a number of contextual factors ranging from aural and visual ability impairment, institutionalization, interpersonal disorientation and lack of self esteem and motivation.

Furthermore, in a longitudinal study lasting 12 years involving 2812 non-institutionalized elderly persons, Bassuk and colleagues [2] showed how social disengagement is a risk factor for cognitive impairment among elderly persons. These results have a direct implication on the definition of care interventions: if elderly persons are actively provided with opportunities for communicating, exchanging, collaborating and being engaged, their cognitive and behavioural abilities will remain more intact and their quality of life could be improved.

II. RELATED WORK

Assistive technologies usually refer to the concept of "cognitive prosthetics", that is, compensatory strategies that alter the patient's environment, directed to an individual's functional skills. However, the notion of "cognitive prosthetics" mostly neglects a number of fundamental factors like motivation, personal involvement and engagement, all extremely important in the treatment of people affected by dementia. In this respect, a different perspective is opened up by socially assistive robots, defined [3] as robots designed to provide assistance by means of social interaction.

These robots' main purpose is to engage people in failure-free activities, stimulating the expression of inner emotional states, social relations and processes of meaning negotiation. For example, some projects seek to include robots as part of the therapeutic regimen for individuals with autism [4,5]. These studies have demonstrated that robots generate a high degree of motivation and engagement in subjects, including those unlikely or unwilling to interact socially with human therapists.

A number of studies [6,7,8,9,10] have recently reported encouraging results regarding the use of these robots in the domain of dementia care. As dementia affected subjects suffer from a progressive cognitive and behavioural disease which contributes to an early deterioration of the ability to interact socially, the continuous stimulation of social skills constitutes a critical issue in every therapeutic intervention in order to avoid social isolation, which is important in terms of the emergence of behavioural disorders.

III. MODULAR ROBOTICS: THE ROLLING PINS

Our work draws on the recent results, partly presented above, of the use of robotics in dementia care exploiting the opportunity offered by modular robotics [11,12,13].

Modular robots consist of a number of independent parts which can be connected in many different ways. Each unit has its own power supply and intelligence, and can communicate with the others. Furthermore, each unit is able to process and communicate with its surrounding environment either through communication to neighbouring robotic modules and/or through sensing or actuation [14].

Recently we have witnessed a growing interest in modular robotics. The reason is that a robot is usually designed for one particular activity, or at best a few closely related activities. This of course is not the ideal situation when the context of use requires supporting a large number of activities and meeting the needs of a heterogeneous target user group, like in the case of dementia care. In such cases it is necessary either to design several different robots, or a very complicated one.

The modular robotics approach we have adopted is to some extent inspired by the behaviour-based robotics approach [15], although the modular robotics approach builds on the belief that behaviour-based systems can include not only the coordination of primitive behaviours in terms of control units, but also coordination of primitive behaviours in terms of physical control units [14,16]. We can imagine a physical module being a sort of primitive behaviour. Therefore, the physical organisation of primitive behaviours will (together with the interaction with the environment) decide the overall behaviour of the system. Hence, in a way similar to the control of robot behaviours by the coordination of primitive behaviours, we can imagine the overall behaviour of a robotic artefact to emerge from the coordination of a number of physical robotic modules, each one representing a primitive behaviour.

The RPs (Fig.1) described in this paper were designed according to this same concept of modular robotics [9,10].

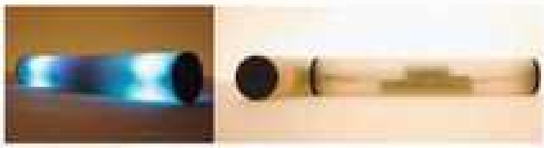


Fig.1. Rolling Pins.

The design of the RPs has been based on the following three main characteristics.

Gesture-based interaction.

Each time an RP is manipulated, it produces an output (visual, auditory or tactile) both locally and remotely on the peer device, thus influencing its behaviour. The therapist and the patient can therefore communicate by showing and imitating specific gestures with the RP and simultaneously influencing the behaviour of the peer device: synchronization and coordination are key objectives of the activities supported by the RP.

Engagement.

Patients affected with dementia refrain from exploring novel situations since they perceive their competence as not sufficient. Using the RPs, the patients are stimulated to start the exploration of the system on a "safe" and familiar base, manipulating simple objects with familiar affordances (rolling imaginary objects is one of the most frequent representation of stereotypic behaviour in dementia).

Flexibility.

Different applications of the RPs have been designed. In the "mirror" application, for example, an RP can vibrate whenever it moves at a different speed than its peer. The task of the patient is to match the therapist's rotation speed to stop the vibration. However, the therapist can choose vibration as a single feedback or to reinforce the output with a visual or aural feedback. The particularity of this task rests in its dynamic nature: the therapist can decide to slow down the rotation speed in order to help the patient in the task of synchronization or can decide to make the task more difficult to execute by deliberately challenging the synchronization or moving the pin at different speeds and rotation patterns; in other words, the therapist can adapt the task complexity during the task itself. The opportunity to continuously adapt the difficulty of the task to the skill of the patient is fundamental to the creation of an optimal experience, and to the maintenance the patient's attention.

In conclusion, the RPs were specifically designed to support collaborative and non-verbal exchanges between the therapist and the patient, providing them with the opportunity to establish a "pragmatic dialogue" based on visual, aural and tactile feedbacks and sensory-motor interaction modalities. They embody by design a dialogic component supporting non-verbal communication between therapist and patient. They can be manipulated (e.g. grasped, rolled and shaken), and each of these actions can produce feedback. But the very essence of the RPs is the collaborative activity they embed. The tools communicate with each other, and by doing this they influence each other. Each time an RP is manipulated, it produces an output (visual, auditory or tactile) both locally and remotely on the peer device, influencing its behaviour.

A. The design process

In dementia care, the use of non-verbal communication is widely adopted. For example, physical contact is used in the home care ward: nurses are trained to use affective touch to sustain and reinforce verbal instructions, especially in the case of the manifestation of behavioural disorders. In music therapy, the therapist tries to establish a dialogue by playing rhythmical instruments together with the patient or by listening to music while maintaining physical contact. Studies in music therapy [17] show a positive effect of this therapy on promoting the dialogue between therapist and patient, by re-integrating the person within a communicative ecology preventing isolation, regulating emotional arousal in terms of expression and inhibition, with positive implications for sufferers and caregivers, and motivating communication and participation without being speech dependent.

These effects are achieved utilising the ability to gesture and hand-eye coordination to establish a dialogue. Different studies [18] have demonstrated the importance of sensory-motor imitation in facilitating the establishment and maintenance of social relations in people with communication problems (in particular regarding people affected with autism and dementia).

The RPs are tangible tools that can be easily manipulated just by shaking, rolling or grasping the units. Since people suffering from dementia have several limitations in processing and understanding symbolic languages, the use of physical objects define more natural interaction modalities that can be easily understood.

In order to design interaction modalities that are meaningful for a patient suffering from dementia, a user-centred approach was adopted including both direct observation of patients during their daily activities in the ward and extensive discussions and interaction with the people surrounding the patients – namely therapists, geriatrics, care-givers and, on occasion, family members and associates. We tried to perform a non-intrusive observation of their everyday life practices, with a very naturalistic approach using only our senses and intuition, respecting of the privacy of the Home Care guests. After each observational session, a written report was prepared and shared with doctors and care givers in order to correctly interpret the data.

Findings of the observations revealed dementia affected people are unmotivated to participate in social activities; social interactions are very few and they spend most of their time isolated from the others. Quite soon we were struck by the behavioural response of these people to simple external stimuli. Very basic sensory-motor patterns like grasping, rolling and pulling recurred in most of their activity. We observed some people spending hours repeating the same basic movements such as rolling a bottle or folding a sheet of paper. In particular, patients were generally attracted to very simple objects that show simple sensory-motor affordances and allow very basic manipulation.

In parallel with the observation of the elderly people in the ward, an extensive analysis of their residual abilities was conducted to define a conceptual framework for understanding the progressive manifestation of cognitive and behavioural symptoms. Even if the degree and the temporal manifestation of the impairment are different for each individual patient, some features can be commonly observed. For example, the first symptoms to appear are episodic memory deficits and the related difficulties in remembering recent events. Furthermore, since dementia affected patients lose the ability to retain and process complex stimuli, they experience increasing difficulty in making sense of the external world. Any system/technology/support, to be successfully integrated in the treatment of dementia, should strictly address the following requirements. Firstly, the gross-motor physical limitations of these patients suggest the need for interaction with objects whose dimensions and weights are suitable for an easy manipulation (technical details on weight and dimensions of the RPs are provided in section B below). Because of their difficulties in making sense of novel and complex situations, it is fundamental to design very simple and clear interaction modalities based on physical and sensorial manipulation (rolling and shaking are the main interaction modalities with the RPs). Next, in order to exploit residual abilities related to procedural knowledge, the system should be able to stimulate familiar sensory-motor patterns (e.g. rolling is a very familiar sensory-motor pattern for these subjects). Also, other stimuli should be reduced in order to avoid the dispersion of the limited attention span of patients (stimuli are selected and controlled by the therapist). Finally, due to the difficulties that patients affected by dementia have with verbal communication, the system should sustain non-verbal dialogues [18] (the RPs sustain a gesture-based dialogue).

The results of the observations and studies of clinical cases and therapeutic practices were used as design guidelines for the new system. The process generated a number of concepts that were continuously assessed by therapists and physicians, resulting in the selection of one concept, the Rolling Pins, for its potential to evoke consolidated sensory-motor patterns, to enable coordination and communication without verbal exchanges and to generate an intrinsic motivation to actively participate in a social exchange.

B. Technology design

An RP consists of a semi-transparent plastic tube (Fig. 2) with solid end caps (Fig. 3, Fig. 4). All the electronic components are placed on one large PCB inside the tube (Fig. 5). The total weight of an RP is 350 grams including batteries.

The RP has three types of feedback: RGB light, sound and vibration. Furthermore, RPs are able to communicate with each other or with similar devices equipped with the same radio communication technology. The RPs are capable of measuring their orientation and the speed of their rotation [19].

The outer tube of the RP (Fig.2) has the following dimensions: Outer diameter: 50 mm, Inner diameter: 44 mm, Length: 290 mm, Weight: 150 grams.

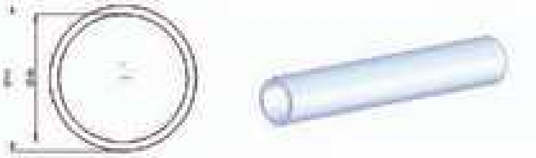


Fig. 2. CAD drawing of tube

The right end of the tube is equipped with three holes with small screws for holding the right end cap in place. The left end cap is glued to the tube. The end caps (Fig. 3, Fig.4) have the following properties: Outer diameter: 50 mm, Length: 11 mm, Weight (each): 22 grams, Material: Sandblasted black plastic.

The left end cap is equipped with six holes (ø 4 mm) for the sound to travel through, and a countersink for holding the loudspeaker (see Fig. 4). The right end cap is equipped with 3 holes for holding the charge connector, JTAG programming interface and the On/Off switch (see Fig. 4). Furthermore, the right end cap carries the vibrator. The caps are also equipped with countersinks for holding the PCB in place (Fig. 3, Fig. 4).

Fig. 3. Drawing of right end cap (seen from PCB mounting side)

Fig. 4. The end caps (seen from the outside (left) and inside (right))

Fig. 5. The PCB seen from the top, the bottom, the side, and an assembled RP

The electronic parts of the RP consist of one large PCB (Fig. 5, Fig. 6) and an internally connected loud speaker which is mounted in the left end cap. The weight of the PCB is 78 grams or 156 grams with batteries installed.

Fig.6. Top: dimensions of the PCB (thickness 1.6 mm) and bottom: PCB layout (top layer in front).

Besides standard components such as resistors, capacitors and diodes, the PCB carries the following electronic components.

Computing
- The RP is controlled by a microcontroller from Atmel (ATmega128 running at 4 MHz).

Sensors
- A gyroscope from Analog devices (ADXRS300EB) is used for measuring the speed and direction of the rotation (Fig. 7).
- Two 2 axis accelerometers from Analog devices (ADXL320) are used for measuring the orientation of the RP. One of the accelerometers is mounted vertically on the PCB, so all three axes can be measured (see Fig. 7).

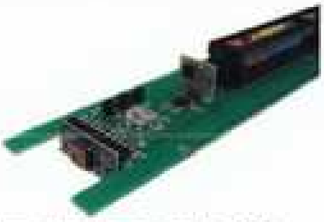


Fig. 7. Picture of gyro and accelerometer end of the PCB.

Actuators
- Four RGB LEDs from Dotlight (SRGB7130 Superflux LED 130 degrees) are used for visual user feedback. The four LEDs are divided into two pairs (one pair in each end) that are individually controllable (see Fig. 5). It is possible to generate any color due to the nature of the RGB LEDs.
- One vibrator (from a Mobile phone vibrator unit) is used for sense of touch user feedback. The vibrator is not shown in the pictures.
- One loudspeaker (ELFA 30-204-84 20 mm 100 ohm) is used for audible user feedback. Any hearable sound can be generated or combined to form short melodies. The loudspeaker is not shown in the pictures.
- One digital volume adjuster (Dallas DS1666-010) for the adjustment of the volume of the loudspeaker. (This device is not installed in the RPs used in the experiments presented here due to limitations in the control of the volume).

Communication
- One communication module (RadioMetrix SP2 433 160) used for communication with other RPs or similar devices equipped with the same communication technology (Fig. 5).

Power
- Three AA rechargeable batteries (GP NiMH 1800 mAh).
- One regulated 5V 300mA charge pump (TI TPS60130 3 x AA to 5V)
- One low power shutdown circuit (MAX834) for shutting down the power supply to the electronic circuitry when the battery supply voltage goes below a fixed voltage level.

External connectors
- On/Off switch (see Fig. 8, right).
- JTAG programming interface (for programming of the microcontroller) (see Fig. 8, left).
- Charge connector (for use with customized external charger). When a charge plug is placed the charge connector, the circuitry is disabled and only the connection to the batteries is maintained (Fig. 8, center).

Fig. 8. Picture of the connector and of the PCB

The RPs use rechargeable batteries. Each unit is equipped with 3 AA NiMH rechargeable batteries. The batteries are manufactured by GP batteries, and the nominal voltage of each battery is 1.2 V and the capacity is 1800 mAh. The batteries have no memory effect and have up to 1000 recharge cycles. The batteries are charged while in the units, so an external constant current charger is used to charge the batteries. The charger can charge 15 units at a time and each unit is charged with a constant current of approximately 177 mA. The relatively low charge current results in a recharging time of approximately 10 hours when the batteries are totally drained, but the typical charge time is less than that. Note that the charger is specialized for charging of 3 NiMH rechargeable batteries in series and not for common use. The charge voltage is adjusted to approximately 4.36V where the maximum allowable charge voltage is 4.5V.

The reason for choosing a relatively slow constant current charger instead of an intelligent fast charger is a tradeoff between complexity and charging time. An intelligent fast charger requires rather complex circuitry and often requires additional cooling. A constant current charger only requires simple circuitry and for safety reasons, such as overheating, the charge current should be 1/10 C. The schematics of one charger and photo of the 15 unit charger are shown in Fig. 9.

Fig. 9. Left: Schematics of 1 unit charger. Right: 15 unit charger.

The charger is supplied by a 7.5V DC 3.25A power supply, but the charger only uses approximately 1.5 A when all 15 charging units are in use. For safety reasons the 15 unit charger has a 2.5 A fast fuse installed. A small green LED installed in the lid indicates whether or not the charger is supplied from its external power supply or whether or not the fuse is intact (3 mm green LED with 270 ohm resistor in series).

The output of each charger goes to a 2.1 mm DC Jack connector (note that GND is connected to the inner part of the pin).

A Base unit is connected to an ordinary PC via a serial (RS232) connection. It is used for the control and settings of the adjustable parameters of the entire system. It can be used for run-time control of the RPs, but in the work presented here it is used only a priori for downloading application parameters to the RPs. Furthermore, the Base unit can control a specialized external dimmer to control the surrounding environment via PWM (adjustment of the light intensity of externally connected coloured light lamps). This option is not used in the experiments presented here. The Base unit contains a standard main PCB and a radio module. The radio module communicates with the corresponding radio module in the RPs.

C. Software design for the RPs

The RPs are generally used in pairs, since the local feedback of each RP can be dynamically set depending not only on its own speed and orientation, but also on the speed and the orientation of the peer RP. For example, the local feedback of each RP can be a function of the sum of the rotation speed of both RPs; potentially, it can be a function of any other operation between the speed of the rotations (and orientations) of two RPs. Furthermore, since each RP runs its own software, each of them can generate its own feedback in relation to rules that are different from the rules of the other one.

The software framework for the RPs allows the applications to run autonomously in the objects, while also providing the possibility for communication with a host PC. The PC software is responsible for the control of the application selection, thus allowing the therapist to select an application for usage. Hence there is a PC software and an embedded RP software, as shown in Fig. 10.

Since the PC is used for application selection only, this implies that the application itself is controlled in a distributed manner by the objects. Each object contains no identification thus enabling maximum freedom in the assembly – each RP can be replaced by another RP. The advantages of this are that a program can run without the presence of the PC, the same program code can be loaded into all RPs, the program can be made independent of the number of pins, less wireless radio communication is needed and there will be faster information flow.

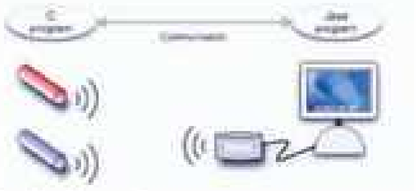


Fig. 10. The software framework.

For the ease of the application development, a framework was constructed on the PC side in JAVA. Thereby, the developer only adds his/her program by respecting a contract settled by the framework. In the objects (cylinders and pins) a C library was constructed to provide access points to the different hardware functionalities of the objects.

The software architecture on the PC side is shown in Fig. 11.

Fig 11. PC software architecture.

The application developer inherits from the *Program* interface and implements all the necessary methods. The application must then be implemented on the RP. This is done by implementing the application logic in the RP on top of the library, which is illustrated in the fig. 12.

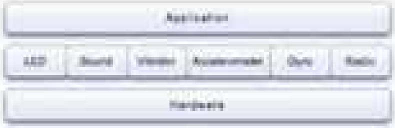


Fig. 12. RP control layers.

The library consists of a driver layer that provides ease of use for the underlying hardware. At the current hardware state an RP can communicate through two different channels – RS232 (standard serial) or wireless. The communication protocol for each of them is described in the following paragraphs.

The transmission package structure is illustrated in Fig. 13. The first byte is always the length of the package and the rest (max. 254 bytes) are data fields. This implies that the application layers must agree on a common communication protocol. Fig. 13 illustrates that the first data field could be used as a program ID and the rest as parameters.

The PC side of the application consists of an easy to use graphical user interface (GUI) which has the capability of plugging in the different applications that respect the *Program* interface.

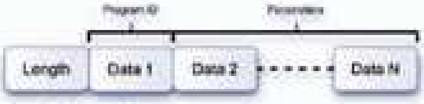


Fig. 13. Transmission package structure.

A simple example could be a program that changes the colour intensity for red, green and blue. This example of a simple GUI is illustrated in Fig. 14. The GUI was designed to enable the therapist to modify the sensorial stimuli by selecting different combinations of visual, aural, and tactile feedback. The tactile stimulation can be produced either by the physical surface of the RP (on which different types of covers can be placed) or generated by the vibration actuator.

Furthermore, the therapist can also select different communication rules between the RPs. In sum, the therapist can adapt the complexity of the interaction to the specific needs of each patient, the therapeutic objectives and the specific therapeutic protocol.

In the above-mentioned example, the user can set the intensities of the RGB LEDS. This information is collected in a transmission package as shown in the Fig. 14 (on the right) and sent from the PC to the RP. When the RP receives the message it checks the program ID field and reacts accordingly.

The software implementation is open to different strategies; the application at hand can be implemented with a centralized control or distributed control. Furthermore, the user can choose to implement different communication strategies, e.g. connection oriented protocol or connectionless protocol.

Fig. 14. Left: A simple example GUI on the PC for changing the colours. Right: The transmission package produced from setting the colour in the GUI above.

IV. FIELD TRIALS

The main claim of this paper is that the dialogic component embedded in the RPs constitutes an added value in non-verbal communication, enabling the therapist to establish different levels of exchanges beyond verbal communication. In other words, the RPs create a shared interaction space in which the therapist has a number of different opportunities to influence the patient's behaviour, by showing specific sensory-motor interaction patterns with the RP and simultaneously affecting the feedback of the RP held by the patient. We do indeed believe that the dialogic component plays a critical role in mediating the communication between the therapist and the patient, favouring the spontaneous engagement of the patient in the activity and enabling basic forms of non-verbal communication such as imitation and coordination. In order to assess if this particular non-verbal and gesture-based exchange can sustain effective communication and coordination between therapist and patient, we designed an experiment to compare the use of the RPs in two conditions:

1) with the RPs used as independent devices, interactive but not communicating with each other (individual modality).
2) with the RPs communicating with each other (dialogic modality).

Specifically, we defined three hypotheses:

1) The first hypothesis concerns the capability of the RPs to activate consolidated sensory-motor patterns in the procedural memory therefore encouraging dementia affected people to participate in the activity: subjects working in the dialogic modality are more inclined to spontaneously engage in interaction with the RPs than subjects working in the individual modality.
2) The second hypothesis addresses the role of the dialogic

modality in stimulating sensory-motor coordination: subjects working in the dialogic modality establish a more stable and solid sensory-motor coordination with the therapist than subjects working in the individual modality.

3) The third hypothesis concerns the patient's involvement and engagement in the activity: subjects working in the dialogic modality manifest a stronger intrinsic motivation to participate to the activity than patients working in the individual modality.

A. The software application

Two programs have been defined for the experiment: the program used in the individual modality and the program used in the dialogic modality.

In both programs, the input to the system consisted in the shift frequency of the RPs. The shift frequency was calculated by the number of times the RP changed the direction of rotation within a given interval of time (1 second). In other words, the shift frequency depends on how fast the user rotates the RP forward and backward. Since this information is provided by the gyro, the detection of the shift frequency can be done independently of knowing the orientation of the RPs: this allows the users (both the therapist and the patients) to try different kinds of manipulation. However, in the experiment, the whole activity was carried out over a table.

In the program used for the individual modality four different shift frequency ranges have been identified. When the shift frequency of the RP is within the boundaries of a certain range, it provides specific visual and aural feedback. In particular, the colour blue and the tone C4 are associated with the lower values of the shift frequency (Table 1, range A) while the colour red and the tone B4 to the higher values of the shift frequency (Table 1, range D). The colours green and orange have been associated with the intermediate ranges (see Table 1). The shift frequency ranges have been defined in collaboration with therapists and physicians in order to assure that the patients have the physical skills to produce the required movements and the cognitive skills to discriminate among them.

TABLE I

INDIVIDUAL MODALITY : INPUT/OUTPUT RELATION

Shift Frequency Ranges	Colour	Sound
A	Blue (0, 0, 255)	C4
B	Green (0, 255, 0)	E4
C	Orange (255, 128, 0)	G4
D	Red (255, 0, 0)	B4

The values of the RGB parameters are in brackets. In the Sound column, tones have been reported adopting the letter notation.

The choice of the colours has been based on two considerations. First of all, we have exploited the natural mapping between cold colours (e.g. blue) and the impression of calmness, and between warm colours (e.g. red) and the impression of dynamism [20]. We have associated the lower values of the shift frequency with cold colours (blue and green) and as the shift frequency increases the associated colours progressively move toward warmer tonalities (orange and red). Secondly, in order to maximize the contrast between the presented colours and to facilitate elderly people in recognizing them, we selected two primary colours (red and blue) and their complements (green and orange). Also, in the case of sound, we have relied on the natural mapping between lower tones and calm movements and shrill tones and quick movements. In particular, in order to have a harmonic progression we have chosen the first, the third, the fifth and the seventh degree of the C major scale.

In the dialogic modality the two RPs communicate with each other: in the specific implementation adopted for the experiment, the local feedback of each RP is given by the sum of the shift frequency of the peers.

Table 2 shows the association between the shift frequency ranges used in the program for the dialogic modality and the visual, aural and tactile feedback generated by each RP.

TABLE 2

DIALOGIC MODALITY : INPUT/OUTPUT RELATIONSHIP

Shift Frequency Ranges (RP1 + RP2)	Colour	Vibration	Sound
A	Blue (0, 0, 255)	No	C4
B	Blue/Green (0, 128, 128)	No	E4
C	Green (0, 255, 0)	No	G4
D	Green/Yellow (128, 255, 0)	No	B4
E	Yellow (255, 255, 0)	No	C5
F	Yellow/Orange(255,192, 0)	No	E5
G	Orange (255, 128, 0)	No	G5
H	Orange/Red (255, 64, 255)	No	B5
I	Red (255, 0, 0)	Yes	C6

The RGB parameters are in brackets. In the Sound column, notes have been reported adopting the letter notation.

For example, whenever the sum of the shift frequency of two communicating RPs is within range A, each peer will show the colour blue and will generate the tone C4. As the sum of the shift frequency increases, the colour changes from cold to warmer tonalities and the tones become higher; when it reaches the highest value, both RPs start vibrating to reinforce the feedback. As it is possible to observe in Table 2, in the program used in the dialogic modality a new set of shift frequency ranges has been added (from E to I). This was done to discriminate between the different values resulting from the sum of the shift frequency of each RP. The colours and the associated sounds have been selected following the same considerations made for the individual modality program.

In Fig. 15, it is possible to observe the difference between the two programs in terms of mapping between shift frequency ranges and colours.

It is important to notice that the full range of feedback can only be experienced if both the therapist and the patient are involved in the activity.

Fig. 15. Mapping of shift frequency ranges and colours in the individual modality (left) and in the dialogic modality (right)

In fact, if the therapist does not move his/her own RP, the patient can only reach the shift frequency values from range A to range E/F.

B. Experimental Plan

A between subjects experiment with two independent groups was designed. One of the two groups interacted with the system set in the dialogic modality (dialogic condition) and the other one with the system set in the individual modality (individual condition). Both groups performed the whole experimental protocol (phases A, B and C – see section C later on). In the dialogic modality the two RPs communicate with each other: in the specific implementation adopted for the experiment, the local feedback of each RP is given by the sum of the rolling speeds of the peers. In the individual modality the RPs do not communicate with each other: the RP local feedback only depends on its own rolling speed. This modality of interaction constituted the baseline against which the subjects' performance resulting in the dialogic modality were compared.

The experiment was conducted in the nursing home "Casa Protetta Albesani", an institution located in northern Italy (Castel S. Giovanni, Piacenza) that provides hospitality to 150 elderly people with different degrees of cognitive and behavioral diseases. The experimental plan and the entire project were submitted to the Ethical Board of the Home Care institution and approved by all members. Therapists and geriatric physicians discussed the methodology and proposed a specific protocol for conducting the experiment and sampling the subjects. They later followed all of the phases of the experiment and collaborated in the final interpretation and communication of the results. Also, the relatives of elderly people participating in the study were involved in the conception of the experiment and were constantly informed about the evolution of the therapy. Together with physicians and therapists, 12 patients were sampled with a MMSE (Mini Mental State Examination) [21] resulting in scores in the range of 16 to 27. Each patient was randomly assigned an experimental group: we obtained two equally numbered groups (Table 3).

All subjects working in the two experimental conditions followed the same protocol composed of three phases (as detailed in section C "Experimental protocol"). Each phase was designed to test a specific hypothesis: phase A to test hypothesis 1, phase B to test hypothesis 2, phase C to test hypothesis 3. Therefore, in each phase, different behavioral indicators have been selected in order to evaluate the subjects' performance (for details see section D "Coding and Analysis").

TABLE 3
EXPERIMENTAL GROUP

System modality	N	Age	MMSE
Dialogic	6	76.2 (14.4)	20.5 (3.3)
Individual	6	86.3 (9.2)	21.5 (4.7)

Table 3 shows the number of subjects (N), the mean age (Age), and the mean MMSE (MMSE) for each experimental condition. Standard deviations have been reported in brackets. The MMSE (Mini Mental State Examination) is a test used to evaluate the cognitive impairments of dementia affected patients (0-15: severe; 15-24: moderate; 24-30: mild/normal). The age difference between the two groups can be explained by the presence of a younger subject (36) in the group working with the system set in the dialogic modality. Physicians and therapists considered that the cognitive impairment of this subject can be assimilated with the other subjects. His MMSE score (20) confirmed this.

C. Experimental Protocol

The experimental setting was the same for the two groups. The therapist and the patient sat down around a table one in front of the other. A Rolling Pin was placed on patient's side and another one on the therapist's side. The experimental protocol was composed of three phases and structured as shown in Table 4. Each phase was specifically designed to test one of the three hypotheses.

TABLE 4
EXPERIMENTAL PROTOCOL

	PHASE A
Description	Therapist repeats every single interaction pattern 3 times. At the end of each repetition, he/she waits (5-10 seconds) for the patient's reaction. The therapist initializes the phase saying: "let's see how these objects work".
Patterns	• Rolling the pin slowly over a short distance (from 5 cm to 10 cm) • Rolling the pin slowly over a long distance (from 15 to 30 cm) • Rolling the pin fast over a short distance (from 5 to 10 cm) • Rolling the pin fast over a long distance (from 15 to 30 cm)
	PHASE B
Description	The therapist produces the interaction patterns described below. Each pattern lasts about 30 seconds (except the last one which depends on the therapist's feeling about the situation). The therapist initiates the phase saying "let's do this together".
Patterns	The same patterns as in phase A
	PHASE C
	IMI administration. After the activity, the therapist administers the Intrinsic Motivation Inventory.

Phase A was designed to help clarify if the dialogic modality stimulates the patient's autonomous initiative to participate in the activity, without any additional instruction from the therapist (hypothesis 1). For this reason, the therapist was invited to pronounce a neutral sentence to initiate the activity.

Phase B was designed to observe the patient's behaviour in a coordination activity, in order to test hypothesis 2. The main difference between the two phases is that while in phase A the therapist generates discrete interaction patterns with the RP, waiting for the patient's answer, in phase B s/he interacts in a continuous manner with the RP explicitly inviting the patient to join the activity.

At the end of the session, the patients were asked to answer a standard version of the Intrinsic Motivation Inventory (IMI) [22] in order to test hypothesis 3 (Phase C).

D. Coding and analysis

Each experimental trial was video-recorded. The camcorder was placed on a tripod and positioned in such a way that it was possible to record the subjects' expression, and the therapist's and subjects' hands manipulating the RP. However, the video camera was not visible to the subjects. Two experimenters carried out the video-analysis with the support of a specific software (The Observer XT)

For phases A and B, a number of different behavioral indicators were defined and observed in order to verify the first and the second experimental hypotheses. Generally speaking, two kinds of behavioral indicators were defined: 1) discrete indicators codifying events whose duration is not relevant; 2) continuous indicators codifying events with a clear start and end. In the latter case, the video data from each and every trial of a given patient was segmented into one second intervals; the patients' activities were coded by scoring the continuous behavioral indicators every second of the trial. The scores for each trial were then summed up, yielding the total number of occurrences of each behaviour during a specific trial and the total amount of time the patient was engaged in each behaviour during that trial [9].

In order to test hypothesis 1, we defined a discrete behavioural indicator (called Answer) and observed its occurrence during phase A: we scored the number of times the patient reproduced the interaction patterns proposed by the therapist with his/her RP.

In order to test the hypothesis 2, during phase B we codified the patient's behaviour in relation to three continuous behavioural indicators:

1) the patient does not produce any interaction pattern while the therapist interacts with the RP (None);
2) the patient does not reproduce the therapist's interaction patterns but generates them randomly (Random);
3) the patient simultaneously reproduces the same interaction patterns as the therapist (Tuning).

In order to verify the hypothesis 3, we administered the Intrinsic Motivation Inventory (IMI) [22]. This is a multidimensional measurement questionnaire to assess participants' subjective experience related to a target activity. The questionnaire assesses participants' Interest/Enjoyment, Perceived Competence, Effort, Value/Usefulness, Felt Pressure and Tension, and Perceived Choice while Performing a Given Activity, thus yielding six sub-scale scores.

Sub-scales are rarely used all together; a number of sub-scales are usually selected in relation to the experimental objectives. In our experiment we used a questionnaire composed of three sub-scales: Interest/Enjoyment, Perceived Competence and Pressure/Tension [22]

V. RESULTS

Phases A and B in the two conditions lasted about 4 minutes. Table 5 details the mean lengths (and the standard deviation in brackets) of the two phases for each experimental group. Phase C (the administration of IMI) lasted about 5 minutes. Also considering the initial 5 minutes when patients familiarized themselves with the environment, each experimental trial lasted about 20 minutes.

TABLE 5
MEAN LENGTHS OF PHASE A AND B

	Phase A	Phase B
System modality		
Dialogic Modality	238.5 (85)	235.7 (70)
Individual Modality	234.7 (130)	244.6 (46.8)

Table 5. This table details the mean lengths (and the standard deviation in brackets) of phases A and B for each experimental group. Means and standard deviation are expressed in seconds.

Hypothesis 1.

An analysis of the Answer behavioral indicator was conducted on the data related to the video-analysis of phase A. The independent variable was the system modality, dialogic or individual. The dependent variable was the number of occurrences of the Answer discrete behavioral indicator.

In both conditions (individual and dialogic), subjects either reproduced each interaction pattern proposed by the therapist (12) or they ignored all of them. Every subject but one (who reproduced 11 interaction patterns out of 12) working in the individual condition did not autonomously reproduce any interaction pattern proposed by the therapist. Instead, in the dialogic condition, 4 subjects out 6 reproduced every interaction pattern proposed by the therapist.

In the Table 6, means and standard deviation of the two groups have been reported; on average, subjects working in the dialogic condition reproduced a larger number of interaction patterns than subjects in the individual condition.

TABLE 6
PHASE A RESULTS

	Dialogic N=6	Individual N=6
Answer		
Mean	8.00	1.83
st.dev	6.20	4.49
difference	6.17	
Mann-Whitney U	7 *(p = 0.045)	

Table 6 shows results of phase A: for each experimental condition the mean of the "Answer" has been reported. The reported values indicate on average the number of interaction patterns that the patients reproduced with his/her RP. Furthermore, the standard deviations, the difference between means (difference) and the statistical test have been reported.

As a result of the non-normal distribution of the "Answer" variable, a non-parametric test was applied (Mann-Whitney U): the difference of the means appears to be statistically significant (U=7, z= -2.008, *p=0.045)

Hypothesis 2.

A two-way (2x3) mixed ANOVA was conducted to examine the differences between the two experimental groups, codified during phase B according to three behavioral indicators (None, Random and Tuning). The independent variables included a "between groups" variable, the system modality (individual and dialogic) and a "within subject" variable articulated on three levels (None, Random, Tuning).

The dependent variable was the total amount of the occurrences of each behavioural indicator analysed in the one second video segments recording the entire duration of phase B of each trial. As stated in section D "Coding and Analysis", this value corresponds to the amount of time the patient spent on performing each single behavioural indicator.

The results of phase B have been reported in Table 7.

On average, the duration of None and Random behavioral indicators was longer in the individual condition than in the dialogic, while the duration of the tuning behavioural indicator was longer in the dialogic condition than in the individual one.

TABLE 7
PHASE B ANOVA TABLE

	None	Random	Tuning
Dialogic (N=6)	5.35 (6.29)	41.11 (58.26)	192.42 (57.949)
Individual (N=6)	41.00 (45.16)	95.46 (50.62)	98.17 (41.40)

Table 7 shows the means and standard deviation (in brackets) for each experimental condition in relation to None, Random and Tuning behavioural indicators. Means and standard deviation are expressed in seconds.

Furthermore, as Fig. 16 shows, in the dialogic condition there was a clear difference between duration means of Tuning and Random (151.31s), and between duration means of Tuning and None (186.07s), while the difference between duration means of Random and None was less evident (35.76s).

In the individual condition, the difference between the behavioural indicators means was less considerable than in the dialogic condition (the difference between duration means of Tuning and Random was 2.61s; the difference between duration means of Tuning and None was 57.17s; the difference between duration means of Random and None was 35.76s).

There was a significant interaction between the system modalities (individual or dialogic) and the behavioural indicators (None, Random, Tuning) (F2.30=8.802, ***p=.001).

Simple main effects analysis shows that the duration of the dialogic and individual groups' behavioural indicators was significantly different concerning Tuning (F1.10=10.509, **p=.009) but not concerning None (F1, 10=3.666, p=.085) and Random (F1.10=2.974 p= .115).

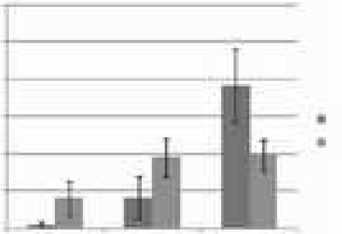


Fig. 16. The graph represents mean values of each behavioural indicators (None, Random, Tuning) during phase B, both for what concerns the individual modality and the dialogic modality. Mean values are expressed in seconds.

The simple main effect of the behavioural indicators was significant for the dialogic group (F2.15=26.136, ***p= .000) but not for the individual group (F2,.15=3.076, p=.076). Post hoc Tukey tests (at p 0.05) were conducted to further explore this effect. For the simple main effect of the behavioural indicators for the dialogic group, the duration was significantly different between None and Tuning and between Random and Tuning. However, the duration of None and Random was not significantly different.

These results clearly indicate that in the dialogic condition, the subjects are tuned-in with the therapist for a longer amount of time than in the individual condition; furthermore, while the subjects in the dialogic condition mainly performed the same interaction patterns of the therapist (Tuning), the subjects in the individual condition performed indifferently the None, Random and Tuning behaviours, without any statistically significant difference.

Hypothesis 3.

An analysis of the intrinsic motivation has been performed on the data collected from the administration of the IMI.

The independent variable was the "groups variable" system modality (dialogic or individual). The scores obtained by the subjects on the three sub-scales adopted in the IMI (Interest/Enjoyment, Perceived Competence and Tension) were treated as distinguished dependent variables. As shown in Table 8, there was a positive trend from the dialogic to the individual modality for the Interest/Enjoyment and Perceived Competence scales: the means of the Interest/Enjoyment and Perceived Competence scores are higher in the dialogic condition than in the individual one. The means of the Tension score were higher in the dialogic condition than in the individual one. Since Tension in the IMI questionnaire is considered a negative predictor of intrinsic motivation, there was a slightly negative trend concerning this scale. However, the Interest/Enjoyment means difference was significant (t=1.95, *p=0.041) and this scale was critical in assessing the emergence of the intrinsic motivation [22]. It should be noted that one subject in the individual condition did not agree to answer the questionnaire.

TABLE 8
PHASE B ANOVA TABLE

	Dialogic N=5	Individual N=6
Interest/Enjoyment		
Mean	6.4033	5.4
st.dev	0.4755	1,1606
Difference	1.0033	
Unpaired T-Test	1.95 *(p = 0.041)	
Tension		
Mean	4.75	4.55
st.dev	1.70	2.3678
difference	0.20	
Unpaired T-Test	0.16 (p=0.44)	
Perceived Competence		
Mean	5	4.12
st.dev	0.8854	1.1713
difference	0.88	
Unpaired T-Test	1.42 (p=0.095)	

Table 8 shows results of the Intrinsic Motivation Inventory. Mean and standard deviation of the three sub-scales have been reported. Furthermore, the difference between means and statistical test for each sub-scale have also been reported.

VI. DISCUSSION

The data derived from the behavioral analysis of phase A show that subjects working in the dialogic condition reproduced a significantly larger number of sensory-motor interaction patterns than subjects working in the individual modality: the dialogic modality favors the spontaneous participation of patients in social exchanges (hypothesis 1).

Fig. 17. This image shows two patients during phase A: one of them is working in the individual modality and the other one in the dialogic modality. In 1, both patients observe the therapist while he/she proposes a sensory-motor interaction pattern. In 2, while the patient in individual condition does not reproduce any interaction patterns, the patient in dialogic modality reproduces the therapist's interaction pattern. It should be noted that this patient expressed the will to stand up in order to better perform the activity.

A post-hoc analysis concerning the quality of reproduced patterns in the dialogic condition shows that the subjects on average imitated the therapist's patterns for 78% (mean=92.70s, st.dev=59.50) of the time spent using the RP, while for 22% of the time (mean=26.70s, st.dev=45.27), they reproduced a random sensory-motor pattern. These data suggest that the dialogic modality plays a significant role in sustaining the patient in spontaneously initiating the activity and joining the therapist in a dialogic exchange.

Data coming from the behavioral analysis of phase B indicate that in the dialogic condition, the subjects are Tuned-in with the therapist for a significantly longer time than in the individual condition; furthermore, while in the individual condition the patients performed indifferently None, Random and Tuning behaviours without any statistically significant difference among them, in the dialogic condition they performed the Tuning behaviour for a significantly longer time than None and Random behaviours. These results clearly indicate that the dialogic condition critically favors the emergence of sensory-motor imitation between the patient and the therapist (hypothesis 2). Therefore, not only does the dialogic condition stimulate the subject to join the activity, but it also actively sustains the subject in establishing a continuous and solid dialogic exchange.

The data collected from the Intrinsic Motivation Inventory show that the subjects working in the dialogic condition reported a significantly higher score concerning the Interest/Enjoyment sub-scale than subjects working in the individual condition. This sub-scale constitutes the self-report measurement of the intrinsic motivation: subjects working in the dialogic condition experience an intrinsic motivation to participate in the activity higher than subjects working in the individual modality (hypothesis 3). The appreciable (but not significant) difference between dialogic and individual modalities concerning the positive predictor, Perceived Competence, constitutes a further corroboration. Regarding the Pressure/Tension sub-scale, there was no difference between the two conditions.

VII. CONCLUSIONS

This paper presents a modular robotic system used in the context of dementia care to facilitate non-verbal communication supporting the therapist in maintaining a dialogue with the patient during therapeutic intervention.

Modular robotics offers a remarkable opportunity in the treatment of dementia: the use of simple units, easy to manipulate without explicit instruction, puts the subjects at ease and provides them with minimal but clear stimuli to both have a pleasurable experience and perform the tasks that better suit their problem. Furthermore, a dynamic, flexible and configurable system has proved to be a the key factor for obtaining an optimal stimulation tailored to the specific needs of each patient.

The results of the experiment demonstrate the positive effects of the use of the RPs on engagement, coordination and motivation in regards to therapy in the dialogic condition. In particular, we observed that, differently from the patients working in the individual modality, the patients working in the dialogic modality established with the therapist a non-verbal dialogue based on sensory-motor imitation of the pattern generated by the therapist.

A number of studies [18,23] have shown the importance of imitation as a fundamental and universal social function. Imitative behaviours constitute the basic form of communication and they are at the basis of early social interactions, providing the foundation for future communication. In parent–infant interactions, this reciprocal behaviour arises quite naturally and is both spontaneous and unselfconscious [23]. These non-verbal behaviours continue to play a role into adulthood in maintaining social interactions and important conversational activities such as turn-taking [24]. Furthermore, a case study conducted by Astell and colleagues on a patient affected by severe dementia illustrates the importance of imitation as a way to keep these types of patients in the social world [18]. Despite a severe cognitive impairment, dementia affected subjects are still able to engage in social interaction by performing imitative behaviour.

In our study the dialogic component embedded in the RPs plays a positive role in mediating imitative behaviour and constitutes the basis of a therapeutic intervention addressed to maintain social interaction.

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Bringing aesthetically-minded design to devices for disabilities

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ABSTRACT

Can therapeutic and rehabilitation aids be engaging and pleasurable to use? Can disability be seen in terms of aesthetically-minded design rather than only in terms of accessibility legislation? The paper explores the role that design could play in reducing the stigma associated with the use of rehabilitation aids that inherently manifest impairment and the inconvenience of the disability condition. The design case described in the paper shows that rehabilitation aids can be engaging, useful and pleasurable to use.

Author Keywords

Design approach, Special needs, rehabilitation, social relations

ACM Classification Keywords

H5.m. Information interfaces and presentation: Miscellaneous.

INTRODUCTION

There is huge potential for innovation in the rehabilitation practice and care of disabled people. Nowadays technology offers a full range of possibilities, from innovative prostheses to monitoring systems, from e-health care to augmented rehabilitation. Most of these technologies may have reference under the big umbrella of accessible and assistive technologies. A fundamental issue for the development of such technologies is to design for both accessibility by impaired people and effectiveness of the therapy [1]. These technologies mostly refer to the concept of "cognitive orthoses" or "cognitive prosthetics", that is compensatory strategies that alter the patient's environment and are directed to an individual's functional skills [2].

In this paper we present a design case that takes a different perspective in the design of rehabilitation aids. The approach emphasizes engagement and gratification in therapy with the goal of making therapeutic devices pleasurable to use while maintaining their value and efficacy as therapeutic aids. The ultimate goal is to counteract the impression of inconvenience of the disability condition that many rehabilitation aids inherently manifest and to exalt the beauty of interaction and satisfaction of recovery. We believe that design can balance the tension between a functional approach to accessibility and a more playful and aesthetic exploration of technologies supporting disabilities.

The idea that design sensibilities can be applied to therapeutic aids and that in return disability can provoke radical new directions in mainstream design is witnessed by famous and outstanding design cases.

In Design Meets Disability, Graham Pullin [3] shows how design and disability can inspire each other. By discussing insightful design cases, he states that disability can force some new questions onto the agenda that can actually open up new ways of thinking, and not just in terms of better accessibility.

On a similar mainstream, even if from a different disciplinary viewpoint, Cairns and Thimbleby [4] argue that disability in HCI is a source of richness, being HCI called to respond the question "can digital technologies, in all their forms, help their users have a better experience?". Harper et al [5] recommend that human values, in all their diversity, be better understood and charted in relation to how they are supported, augmented or constrained by technological developments.

In this paper we present a design case of an interactive system called Rolling Pins (RPs) developed to stimulate dementia affected people to empathically communicate with therapists and care givers. The valence of the aesthetic experience with the RPs is not correlated to the appeal of the system components but to the quality of interaction and the emotional tuning among people that is sustained and mediated by the system. The aesthetic experience lies primarily in the interaction and the way in which the system behaves and responds over time in interplay with the users [6].

THE AESTHETICS OF INTERACTION

The field of Aesthetics of Interaction has reached a certain maturity, partly consolidating the idea that in response to a change in the use of computers and interactive technologies, traditional HCI concepts of usability, efficiency, and productivity have to be enriched with other values such as curiosity, intimacy, emotion and affection. This is done in part through the development of new models and theories that explore many different directions and methods of technological implementation [7]. In the last years, different views have emerged that contributed in various way to the definition of a theoretical framework of Aesthetics of Interaction. One view understands the notion of aesthetics as being a result of the appearance properties of form as perceived visually [8]. Here, aesthetics is seen as an added bonus pertaining to the object apart from the context of use. According to this view, the judgment of beauty is a higher-level evaluative construct which is independent of the actual product-usage experience. However, satisfaction and pleasure are emotional consequences of goal-directed product usage. Other views consider aesthetics with a socio-cultural connotation, as the appreciation of different components (materials, forms) and properties that do not inherently pertain to the object itself [9]. Other views of aesthetics introduce the concepts of Resonance [10] which inspired the design case described below. The concept of resonant interaction is derived by the gibsonian theory of ecological or direct perception. Gibson [11] used the term "resonance" to mean the active engagement of a person with her environment, shown by actions spurred by perceptions. However, resonance does not only relate to perception and perceptual-motor skills but to our cognitive, social and emotional skills too. In the design case described below, the concept of resonant interaction is explored through the development and testing of a therapeutic system that mediates patient-therapist interaction by enabling perceptual-motor and social dynamics of resonant interaction.

THE DESIGN CASE

Several studies have shown the importance of social relations in preventing cognitive and behavioural decline in elderly people. Along a 12 year longitudinal study involving 2812 non institutionalized elderly persons, Bassuk and colleagues [12] provided evidence on how social disengagement is a risk factor for cognitive impairment among elderly persons. They explain their findings stating that social engagement can prevent cognitive decline and that people must maintain social skills, the ability to communicate, and the ability to sort out complex interpersonal situations. These results have a direct implication on the definition of therapeutic interventions: if elderly persons are actively provided with opportunities for communicating, exchanging, collaborating and being engaged, their cognitive abilities will remain more intact.

As said in the introduction, one of the motivations of the project was to apply design sensibilities to the development of therapeutic aids and to look at disability as an opportunity to provoke new directions in mainstream design. In doing this, we wanted rehabilitation aids to be both poetic and practical, engaging and useful, to try to reflect the inherent beauty and satisfaction of recovery and wellness.

Our view of aesthetical interaction was based on resonant interaction, choreographic movements, empathic relations, and embodied playful exploration as pivotal concepts for design. Inspired by the stereotypical movements of dementia affected people, we wanted to stimulate them to use these movements to explore expression modalities, establish empathic relations and create a shared communication code with the therapist. We believe that embodied explorations can arise self and social awareness and promote shared intentionality. They can activate opportunities to act in coordination and communicate beyond words.

In what follows we describe the design process we adopted and the challenges we met in bringing aesthetically-minded design to the development of the RPs, interactive objects designed to scaffold dialogic exchanges between the therapist and elderly people with relational disturbances.

A fundamental effort was devoted in understanding our users, their needs, their residual abilities (both cognitive and physical) and transforming them into requirements driving the design process.

USER STUDIES

Dementia subjects suffer from an acquired permanent neurodegenerative disorder that affects the global functioning of the individual, progressively impairing cognition, personality and behaviour. In particular dementia is strongly characterized by social isolation and difficulties in communication. Speech becomes increasingly inefficient and progressive short-term memory difficulties and problems with new learning make conversations and other social interactions problematic [13]. Consequently, most people become reliant on caregivers to initiate engagement and interaction, and to take care of everyday living activities and arrangements. The social sphere of the individual is jeopardized not only by the impairment of social abilities resulting from global functional impairment of the subject but also by the patients withdrawal from social interaction due to a number of contextual factors ranging from aural and visual ability impairment, institutionalization and interpersonal disorientation, lack of self-esteem and low motivation.

Analysis of residual abilities

An initial difficulty in defining a framework of key characteristics of dementia is that the clinical course of this disease is characterized by the progressive manifestation of cognitive and behavioural symptoms. However, the definition of a univocal progression of the cognitive symptomatology is problematic: the degree and the temporal manifestation of the impairment are different for each, individual patient. Nevertheless, it is possible to identify some commonalities across the different, individual cases [14].

Generally, the first symptoms to appear are episodic memory deficits and the related difficulties in remembering recent events. However, the implicit system (procedural memory) has been shown to be relatively well preserved until the later stage of Dementia: some authors [15] claim that implicit memory rehabilitation - that is the automatic acquisition of verbal and non-verbal knowledge or skills (procedural knowledge) - can improve or maintain the abilities for specific basic or instrumental activities to be carried out in daily living. For what concerns the attention, we can state that the ability to focus on two or more stimuli (divided attention) at one time is impaired early on. However the ability to screen out irrelevant stimuli or the continued focus of attention on a task over unbroken periods of time (sustained attention) are all compromised much later in the course of the disease. Since dementia affected patients lose the ability to retain and process complex stimuli, they experience an increasing difficulty in making sense of the external world. The progressive impairment in codifying, elaborating and integrating information, in the explicit modality, can be considered as a common characteristic among the different clinical courses. However, dementia does not affect the peripheral cognitive system: indeed, fine-motor abilities (manipulation) are not compromised by the syndrome and the execution of automatic sensory-motor routines is not affected by the deficit. Finally, language functioning may be relatively spared in the early stages of the disease, but it is likely to decline substantially in the mid to late stages.

A model of residual abilities

Figure 1 shows a model of the progression of the cognitive decline in relation to the cognitive functionality elaborated with geriatrics and therapists during participatory design sessions. The value of this model is not to be held rigorously to the actual progression of the syndrome (values do not have well defined boundaries); rather it permits the immediate appreciation of the abilities which are not impaired by the dementia syndrome (orange dots), a set of abilities that are impaired only in the later stages of the illness (green dots) and a set of abilities that are immediately affected and impaired (black dots). This model represents the first reference framework of the conceptual design.

More specifically the abilities marked as red dots constitute the parameters for the definition of an interaction model based on a set of familiar and consolidated sensory-motor patterns that if appropriately stimulated can be learned by the patients. The green dots are the abilities that the system should scaffold, for example driving the patient's attention among selected stimuli. The black dots identify abilities which are the most compromised: the design should try to minimise interactions involving these abilities.

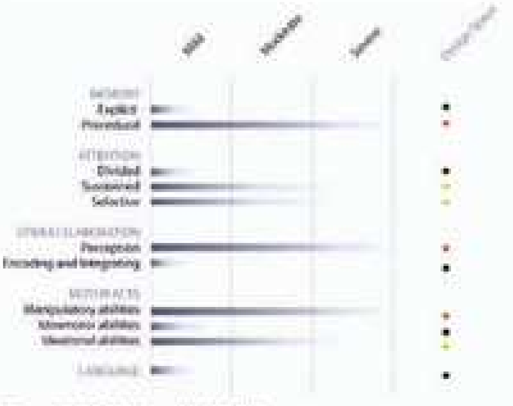

Figure 1 : Model of residual abilities

In light of these considerations two key principles guided the definition of initial requirements:

1. Patients affected by Dementia refrain from exploring novel situations since they perceive their competence as not sufficient. The patient should be stimulated to start the exploration of the system on a "safe" and familiar base. Engagement in the activity is fundamental to stimulating exploration and getting involved in the therapy.
2. Considering the limited cognitive resources of a dementia affected patient, the system should be able to capture and maintain the attention of the patients without directly affecting the cognitive load.

From residual abilities to requirements and design challenges

In order to meet these principles a set of features/requirements for the future system has been defined by expanding and elaborating the design space identified in the residual abilities model (see figure 1). Requirements were stated at a conceptual level with the specific aim of merging them with the concept design phase, and with the idea that only after their match with the concepts would they be refined in functional terms. The requirements were not produced as a list, but as a conceptual map where the landscapes were defined by key values of the future system.

Manipulation

Gross-motor physical limitation advocates for a limited interaction space populated by objects whose dimensions and weights are suitable for an easy manipulation.

Naturalness
Because of the difficulties in making sense of novel and complex situations, it is fundamental to design very simple and clear interaction modalities based on physical and sensorial manipulation.

Familiarity
In order to exploit residual abilities related to procedural knowledge, the system should be able to stimulate consolidated and familiar sensory-motor patterns.

Focus of Attention
Irrelevant stimuli should be considerably reduced in order to avoid the dispersion of the limited attention span of patients. At the same time, the patient's attention should be driven by relevant stimuli.

Responsiveness
Patients affected by dementia have trouble understanding cause/effect relationships. For this reason it is fundamental to provide an immediate feedback to the patient's action close to the input zone. Furthermore, the system's response should persist until the action is performed over the system. In other words, if the patient does not operate on the system the system should remain idle.

Multi-sensorial stimulation
The system should stimulate all senses: sight, hearing, touch and smell. The therapist will decide how to administer and control the stimuli during the activity.

Adaptivity
Because of the differences among the patients, in terms of residual skills and therapeutic objectives, the therapist should be able to adapt the system to the needs of each single patient by using the same set of tools and services.

Scalability
The system should provide the therapist with the possibility of controlling the quantity and the quality of the stimulation. The therapist should be able to define different configurations of stimuli and their progression (e.g. remove progressively some stimuli to scaffold the acquisition of a specific skill).

Non Verbal Dialogues
Due to the difficulties that patients affected by dementia have with verbal communications, the system should sustain non verbal dialogues.

Figure 2 shows the mapping between requirements and cognitive/physical abilities of patients suffering from dementia. System requirements have been largely discussed with therapists and geriatrics that supported us in envisioning therapeutic activities enabled by a system that meets such requirements.

Therapists considered the following three activities as fundamental to the definition of therapeutic protocols aimed at stimulating social exchanges:

- Imitation-based activities based on non-verbal interactions, intended to counteract isolation and stimulate exchange and coordination.
- Activities implying joint attention, a pre-requisite for the emergence of imitative patterns is joint attention. The patients and the therapist should join their attention on the same activity objects.
- Motivating activities: The active involvement of the patient is a fundamental aspect for a successful therapy. It is important to avoid a mere repetition of sensory-motor patterns or mechanic responses.

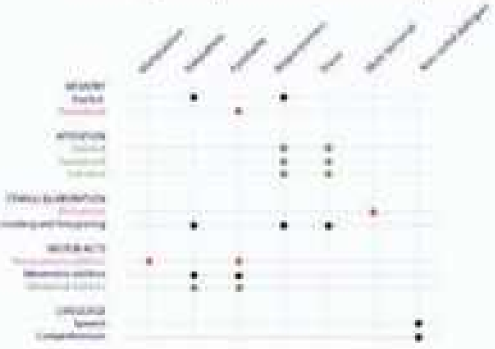

Figure 2 : Mapping between cognitive capabilities and system requirements. This figure presents a detailed elaboration of the design space presented in fig. 1 (the same color code has been adopted): it is possible to observe how each requirement addresses a specific subset of Residual Abilities. For example, the requirement Familiarity is intended to minimize the involvement of Ideomotor abilities (which are early compromised) in the interaction with the system (black dots), to actively scaffold Procedural Memory and Manipulatory abilities (orange dots) and to exploit ideational abilities that are longer preserved (green dots).

CONCEPT DESIGN

The design phase is unique for the fact that it is continuously fed by a concept generation activity. In this phase, often defined "simulate to stimulate", we developed scenarios of use and re-conceived the qualities and the attributes of the system. The concept generation phase allowed a constant flow of innovation into the design process, going beyond the mere interpretation of user needs to stimulate the demand of functionalities that could improve and transform the way in which the therapists carry out their activity. Geriatrics and therapists were constantly involved in the process even if a pure creative phase of concept generation was carried out independently by the design team and within the design team.

Out of necessity, this kind of approach generated an extraordinary diversity of 'components', technologies and concepts. We report hereafter two examples of the generated concepts.

Sense Ring
Sense ring (see fig. 3, C) is a system composed of coloured soft and deformable rubber rings. Each ring is divided in 8 sections in which a pressure sensor and a vibration actuator are placed. Each section is independently functioning system able to receive input (pressure), integrate the information coming from the other sectors and actuate a local output (vibrate) or an ambient output (light changing or sound). Each section is a module with is own characteristics configured by the therapist at the beginning of the therapy session. Aural, visual, tactile and auditory feedback can be associated to each sector. The ring is held by the user and the therapist together to create a collaborative sensorial.

I-Egg
The I-Egg (see fig. 3, B) is a system composed of spherical units that can be detached to produce a visual, auditory or tactile feedback. The feedback is modulated by physical manipulation. When the i-egg is opened the volume of sound, the intensity of the light or the vibration increase or decrease depending on the distance among the two halves.

Rolling Pins (RP)
The RPs are semi transparent cylinders capable of measuring their orientation and the speed of their rotation. At a local level they have three types of feedback: RGB light, sound and vibration. The peculiarity of the RPs is that they are able to communicate with each other. They are used in pairs by two actors (typically the therapist and the patient), and the local feedback of the single RP can be set depending not only on its own speed and orientation, but also on the speed and the orientation of the peer RP.

The RPs embed by design a concept of reciprocity, coordination and resonant interaction: the local feedback of each RP depends on the operations synchronously performed on the two pins. Therefore, the local feedback of each RP can be a function of the sum of the speed rotation of both RPs; potentially, it can be a function of any other operations between the speed rotations and orientations of two RPs.

The therapists assessed all the developed concepts. Frequent, small, informal evaluation activities iteratively improved the design. The evaluation was continuous and as closely and authentically related to use as possible. Concepts, ideas, scenarios, prototypes and evolving work practices were continuously examined to ensure quality and appropriateness to the concepts [10].

Figure 3 shows the mapping between the concepts, the therapeutic activity and the system requirements as defined in the previous phase. Since the RP were more likely to meet the majority of activities and system requirements, this concept was implemented.

Figure 3 : Mapping between concepts and requirements. The size of the circles shows the extent of the opportunity space that each concept offers in respect to the requirements.

TECHNOLOGY DESIGN

A RP consists of a semi transparent plastic tube with solid end caps of black sandblasted plastic (see figure 4). All the electronic components are placed on one large PCB inside the tube [11]. The RP has a length of 300 mm, a diameter of 50 mm, and a total weight of 350 gram including batteries.

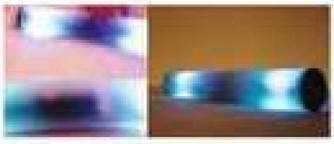

Figure 4: Rolling Pins

The RP has three types of feedback available: RGB light, sound and vibration. Furthermore RPs are able to communicate with each other and with similar devices equipped with the same radio communication technology. The RPs are capable of measuring their orientation and their speed of rotation.

The software framework for the RPs allows the applications to run autonomously in the tools, while however also providing the possibility for communication with a host PC [16]. The PC software is responsible for the control of application selection, thus allowing the user to select an application for usage. The PC side of the application consists of an easy to use GUI which has the capabilities to plug in the different applications. The therapist can set the programs for the tools, this information is then collected in a transmission package, and sent from the PC to the base that broadcasts the message via its radio transmission.

The RPs are specifically designed to support resonant interaction and empathic exchanges between the therapist and the patient, providing them with the opportunity to establish a "pragmatic dialogue" based on visual, aural, tactile and sensory-motor interaction modalities. The RPs embody a dialogic component supporting non verbal communication between therapist and patient. The RPs create a shared interaction space where the therapist has different opportunities to influence the patient's behaviour by showing specific sensory-motor interaction patterns with the RP and simultaneously affecting the feedback of the RP held by the patient.

In order to support rehabilitation activities in a playful and aesthetically pleasant way we have identified three ways of using the RPs: individual (no communication between RPs, the activity is mainly based on the reciprocal observation of the behaviour), transmission (RP1 modifies the response of RP2 but not its own feedback and vice versa) and dialogic (the local response of each RP depends on the synchronized manipulation of both RPs).

Different opportunity of coordinated "choreographies" can be obtained using the RPs. For example, in the "mirror" application (Manipulation: tilting, Stimuli: vibration, Communication: dialogic exchange) a RP can vibrate whenever it moves at a different speed from its peer. The task of the patient is to match the therapist's rotation speed to stop the vibration. The therapist can choose the vibration as a single feedback or reinforce the output with a visual or aural feedback. The particularity of this task consists in its dynamic nature: the therapist can decide to slow down the rotation speed in order to facilitate the patient in the synchronization or can decide to make the task more difficult to execute, by deliberately challenging the synchronization, moving the RP at different speeds and rotation patterns; in other words, the therapist can adapt the task complexity during the task itself. The opportunity to continuously adapt the difficulty of the task to the skill of the patient is fundamental to the creation of an optimal experience so that the therapist and the patient can resonate each other.

FIELD TRIALS

The RPs were tested for several months in exploratory field trials. 12 randomly selected patients who had received a MMSE (Mini Mental State Examination) score ranging from 16 to 27 (moderate cognitive impairment), were involved in different activities ranging from the execution of structured sensory-motor patterns initiated by the therapist, to the free exploration of the RPs [17].

We designed an experiment to compare the use of the RPs under two conditions: individual modality vs. dialogic modality. In the configuration for the Individual modality four different rolling speed ranges have been identified. When the rolling speed of the RP is within the boundaries of a certain range, it provides specific visual and aural feedback. In the dialogic modality the two RPs communicate with each other: in the specific implementation adopted for the experiment, the local feedback of each RP is given by the sum of the shift frequency of the peers.

Figure 5. Mapping of shift frequency ranges and colours in the individual modality (left) and in the dialogic modality (right).

For example, whenever the sum of the shift frequency of two communicating RPs is within range A, each peer will show the colour blue and will generate the tone C4. As the sum of the shift frequency increases, the colour changes from cold to warmer tonalities and the tones become higher; when it reaches the highest value, both RPs start vibrating to reinforce the feedback. In Figure 5, it is possible to observe the difference between the two programs in terms of mapping between shift frequency ranges and colours. It is important to notice that the full range of feedback can only be experienced if both the therapist and the patient are involved in the activity. In fact, if the therapist does not move his/her own RP, the patient can only reach the shift frequency values from range A to range E/F.

In conclusion, under condition Dialogic Modality the RPs communicate with each other (Communication: dialogic negotiation; the local response was given by the sum of both RPs' rolling speeds). Under condition Individual Modality, RPs were used as single devices, fully interactive but not communicating with each other (Communication: individual). Each patient was randomly assigned to an experimental condition and we obtained two equally numbered groups: a group working in the Dialogic modality and a group working in the Individual modality.

The activity protocol for each subject included two main phases: Phase A has been designed to understand whether or not the Dialogic modality stimulates autonomous initiative in the patient participating in the activity, without any additional instruction from the therapist. Phase B has been designed to observe the patient's behaviour in a dynamic coordination activity. Each session was video-recorded and a video-analysis was subsequently carried out.

The analysis of Phase A shows that every subject but one working in the Individual condition did not autonomously reproduce any interaction pattern proposed by the therapist; instead, for what concerns the dialogic condition, 4 subjects reproduced every interaction pattern proposed by the therapist. Data coming from the behavioural analysis of phase B indicates that in the Dialogic condition patients were tuned with the therapist for a significantly longer time than in the individual condition. Furthermore, differently from the Individual modality, in the Dialogic modality patients spend most of their time imitating the therapist's sensory-motor patterns rather than producing random behaviors [17].

These results suggest that the dialogic modality favours the emergence of a sensory-motor coordination between the patient and the therapist within a shared interaction space. A qualitative analysis of the movements performed by the therapist and the patient during the Phase B (dynamic coordination) of the Dialogic Condition has revealed the emergence of recurring choreographies as shown in figure 6 and 7. In particular in Figure 6 the patient and the therapist oscillated the RP from left to right, with a wide and calm movement; in Figure 7 they made fast circular movements, mirroring each other. Once acquired by the patients, both choreographies and repetitive patterns were used by the patient to communicate his inners emotional state. In the interpretation of the therapist, the patient took the initiative to pass from the oscillation to the circular movement to express different feelings during the session, from relax and enjoyment (oscillating movements) to anxiety and effort (rotations).

Figure 8 shows a different example. At the beginning of the session, the patient and the therapist rotated their RP on the opposite sides of the table. After a while, the patient started to perform a wider movement, reaching the side of the table where the therapist was performing her movement. The therapist decided to imitate the patient and they started rotating their RP at the centre of the table very close to each other obtaining the same sound and light. The patient enjoyed to be in control of the choreography and kept taking the initiative of smoothly proposing new movements in coordination with the therapist. The therapist interpreted this behaviour very positively, as a sort of empathic tuning implying communication, coordination, shared intentionality.

The use of the RPs promoted a communicative ecology reducing isolation and motivating communication and participation beyond the verbal exchange. Different studies [18] have demonstrated the importance of sensory-motor imitation and hand-eye coordination in facilitating social relations in people suffering from relational disturbances (in particular people affected with autism and dementia).

Figure 6 . The therapist and the patients were synchronized in oscillating their RPs.

Figure 7 . The therapist and the patients were synchronized in rotating their RPs.

Figure 8 . The patient takes control of the choreography.

CONCLUSIONS

The trials performed so far cannot still provide fully validated results to evolve the exploratory use of the RPs in therapeutic protocols for people suffering from dementia. However they provide insightful evidence of their potential to counteract isolation and promote social exchanges in people with relational disturbances.

More interestingly for the purposes of this paper is that the design case of the RPs can be regarded as a concrete example of how a functional approach to accessibility can be effectively re-thought in terms of a more playful and aesthetic exploration of technologies supporting disabilities. Moreover, the design case shows a range of design challenges inspired by disability; many of these sound niche at first, but we believe they have broad potential and a larger applicability in other domains.

By observing the relations between patients and their care givers we understood that the therapy is effective if culturally sensitive, and emotionally sensitive. These values are lost during the therapy if a functional approach prevails. An aesthetically-minded design can favour the re-appropriation of such values and restitute dignity and naturalness at the therapeutic intervention.

ACKNOWLEDGEMENTS

This research was carried out in strict collaboration with Prof. Henrik Hautop Lund of the University of Southern Denmark. The design, hardware and software development of the tools was performed in collaboration with the Entertainment Robotics team. We would like to thank the nursing home Casa Protetta Albesani and the director Dr Carlo Gobbi for the support we received from the therapists, nurses, doctors and patients with their families. We would also like to thank the sponsors: Targetti S.p.A. and Fondazione Piacenza-Vigevano.

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Know Techn Pol (2009) 22:7–15
DOI 10.1007/s12130-009-9062-3

ORIGINAL PAPER

Exploring User-Centred Design in Practice: Some Caveats

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Received: 10 November 2008 / Accepted: 3 February 2009 / Published online: 3 March 2009

Abstract This paper provides a nuanced perspective on the topic of user-centred design (UCD) in the human-computer interaction (HCI) field. After a brief outline of its emergence, we describe some of the central tenets of the approach, using the process model of Gulliksen et al. (*Behav Inf Technol* 22(6):397–409, 2003) as a well-documented exemplar. We then examine in more detail some of the difficulties one can encounter in performing user-centred design (UCD), illuminating these issues through vignettes from specific projects in which we have been involved. In this paper, we focus on issues that can arise in working with children and with people of differing mental abilities. Our argument is that, while a user-centred perspective is required at all times in the design team, the forms of participation of users in the design process needs to fit the context and can vary significantly from that presented as the pentotypical UCD approach.

Keywords UCD · Users forms of participation · Children · Impaired people

Introduction

This paper examines aspects of the user-centred design (UCD) model currently in vogue and discusses some of the issues involved through practical design cases. One of the aims of this paper is to encourage further discussion on the variety of ways in which designers can work on interdisciplinary design teams and the different ways in which "user involvement" can be managed across the different phases of the design cycle.

For students today who study the field of human-computer interaction (HCI) in computing or psychology courses worldwide, the notion of "user-centred design" has become a *mantra*. The term emerged in the early 1980s, sometimes in slightly different forms—user-centred system design (UCSD), user-centred design (UCD)— and implied an up-front commitment to taking the needs of the user as the central point for design. The psychologist, Donald Norman, is associated with the term "user-centred system design" (UCSD), as he was a joint editor of a collection of papers from the human-machine interaction project at the University of California, San Diego in the early 1980s with this title (Norman and Draper 1986).

Note that, while the UCD or UCSD terms serve as an important correction to other design approaches, which tend to ignore the human side of things, this did not imply that the users were necessarily seen at this time as active *participants* in the design process

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itself. Rather, as in (cognitive) psychological experiments, users were to be studied, questioned, observed, and their performance on tasks measured.

A more radical approach to user participation in design was emerging within the systems development field among a group of Scandinavian researchers. This "collective resource" model emerged from the work of people such as Nygaard, Ehn, Bodker, and Kyng in the early 1980s in the context of projects on the democratisation of working life. It is often commonly labelled, somewhat loosely, as the "Scandinavian model". Here, users are seen as *equal partners* in the development of systems (see the papers in Bjerknes et al. 1987). This perspective takes the work process as primary and attempts to support workers through providing them with skill-enhancing computerised tools (see Ehn and Kyng 1987). What is required are various methods for envisioning future work situations, so users can, in (hypothetical) use, discover potential problems and make suggestions as to how to re-design the planned system. This involves intense commitment on the part of both users and designers to acknowledge each others competencies and inadequacies and to attempt to construct a mutual dialogue.

The reason for discussing this systems development work in a paper on HCI is that this work began to influence and inform HCI in the early 1980s. This alternative approach would imply moving a step beyond a *user-centered* view to a *user-involved* view. Here, 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 more democratic work situation, so those who will be affected by change have an influence on the kind of changes that will be made[1]. Its influence within HCI has been to further explore a variety of *methods of involving users* at all stages in the design process. It moves us away from simple user surveys or interviews and evaluations towards more active engagement in exploring the design space, experimenting with prototypes, etc.

The UCD Approach

During the 1990s, the main features of a UCD approach became more clearly defined. This section provides a brief outline of a prototypical UCD approach, utilising the framework presented in a detailed yet concise paper by Gulliksen at al. (2003). This approach builds on a number of earlier attempts to elucidate key features of a user-centred approach, such as the work of Gould and colleagues on ensuring usability (Gould and Lewis 1985; Gould et al. 1997). The framework also builds on the general principles of ISO Standard 13407, *Human-centred design processes for interactive systems* (ISO 13407 1999), which enshrines the user-centred process approach in an industry standard. Gulliksen's framework outlines 12 principles for successful user-centred system design, based on a large body of field work and practical action-oriented systems development projects. These are enumerated briefly below (from Gulliksen et al. 2003):

1. "User focus (Gould et al. 1997, ISO 13407 1999)
2. Active user involvement (Nielsen 1993; Gould et al. 1997; ISO 13407 1999)
3. Evolutionary systems development—the systems development should be both iterative and incremental (Boehm 1988, Gould et al. 1997)
4. Simple design representations (Kyng 1995)
5. Prototyping (Nielsen 1993; Gould et al. 1997)
6. Evaluate use in context (Nielsen 1993; Gould et al. 1997)
7. Explicit and conscious design activities (Cooper 1999)
8. A professional attitude (ISO 13407 1999)
9. Usability champion—usability experts should be involved early and continuously throughout the development lifecycle (Kapor 1990)
10. Holistic design—all aspects that influence the future use situation should be developed in parallel (Gould et al. 1997)
11. Processes customization—the UCSD process must be specified, adapted and/or implemented locally in each organisation.
12. A user-centred attitude should always be established." (Gulliksen et al. 2003)

Given that there seems to be near consensus on the importance of UCD and on the ways in which it can be achieved, it might appear that we can close

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[1] In later years, the term "Cooperative Design" has come into use (Greenbaum & Kyng 1991) which, while preserving an interest in methods of user involvement, reduces somewhat the overly political agenda evident in the earlier collective resource model.

the book on the topic. However, things are not quite so straightforward, as we shall see in subsequent sections. Especially the exact ways in which users can participate in the design process and the stages in the design where they should be involved are often contentious issues. We highlight some of these issues in the context of attempting to apply a user-centred approach in projects where we are dealing with user groups who present a rather special set of circumstances—namely when working with children and with people with very different sets of mental abilities.

Case 1: Children-Centred Design: Varying Forms of Participation—Testers, Informants and Design Partners

Applying UCD approaches with children raises a number of issues. Alison Druin has written extensively on this subject, as an advocate of the benefits of participative design with children, and promotes a very open and participative approach where children can engage in virtually all facets of the design process. Druin (1998) defines four roles that children can play in the technology design process: *user, tester, informant* or *design partner*. She views children as users when they contribute to the research and development process by *using technology*, while adults observe and videotape with the aim of testing concepts and understanding the learning process. Children are testers when they *try out prototypes* of emerging technologies. The goal of this type of research is to shape new technologies before commercial products or research projects are released. Informants contribute at various stages of the design process mainly being by *being asked for their opinions* when researchers feel that children could provide needed information. Design partners are *equal stakeholders* in the design of new technologies. While children do not have the same specialised expertise that adults have, they have equal opportunity to contribute in any way they can to the design process. In her later writings, Druin strongly pushes for treating children as equal partners in design projects.

Scaife et al. (1997) also advocate a role for children in the design process but emphasise that the role of the child (user) may differ markedly in different projects and even within different aspects of the design process. They view children as *native informants*, a term that denotes the value of seeking a view from within the culture while still attempting to go beyond it to form more general theories. In this approach, children are involved in the design process through interviews, researchers probing them about their understanding of some specific concepts, asking them to explore the concepts, comparing abstract representations and real events, encouraging them to develop ideas about the future system and trying out mock-ups and low-fidelity prototypes. Even if the approach has proven successful in terms of suggestions and ideas developed by the children, however, the designers reported some difficulties in involving the children as native informants. Firstly, not all children are able or willing to be creative designers or even informants about current practices since talking with unfamiliar adults, in a school context, can be a significant inhibitor. Other difficulties are related to the management of the process—when and how to intervene and remain within the project vision.

Similar difficulties were observed in our development work on POGO (Rizzo et al. 2003), a real/virtual environment for supporting the unfolding of narrative competence in children of 6–8 years (primary school), where children create, explore and develop narrative language and social skills. Even if in the project children and teachers were constantly involved in the process (e.g., definition of pedagogical objectives, observation of practices related to the use of narratives in the school, definition of user requirements, development of scenarios, mock-ups and testing), a number of problems have been experienced. First of all, the teachers found it difficult to comprehend the potential of ubiquitous technologies to support storytelling. Even if they proved to be extremely creative in the classroom—involving children in narrative activities—they showed limited skills in envisioning new scenarios of use with ubiquitous technologies. On the other hand, children were extremely creative when involved in the assessment of early prototypes and enjoyed *Wizard of Oz* sessions (Erdmann and Neal 1971). However, without the support of external representations of the final system, they became less and less focused on the design activities, preferring to play with their friends.

For these reasons, the fundamental concept development was the prerogative of professional designers from Philips Design and Domus Academy. Partly inspired by user observations, designers produced 14 visions of narrative environments (Domus Academy 1999). These design concepts represented different ways in which technologies could facilitate narrative processes and mediate the development of children's communication. Only after this stage of the process were the different participants in the project (researchers, children, teachers and technology developers) asked to evaluate the design concepts. This evaluation was performed firstly by filtering the concepts through the defined pedagogical objectives proposed by the teachers and, secondly, through the comments of the teachers. This was an effective way to allow different stakeholders, such as teachers, social scientists, interaction and industrial designers, to join the design process and to promote the mutual awareness of theoretical issues and pedagogical and design practices. Children were involved later in the process, to refine the concepts, explore and test existing mock-ups and build new ones. The prototyping phase was carried out through *Wizard of Oz* testing sessions in the school. This method allowed user requirements and design concepts to be explored at an early stage in the design process. Teachers and children performed narrative activities using the available prototypes in iterative sessions, and the testing results were used to improve the prototypes until the final system was developed.

Some lessons were learned from the POGO project concerning children-centred design. First of all, working with a multifaceted design team composed of a number of professional designers tended to postpone the involvement of the children in the process, and collaboration with them was focused on specific phases like requirement elicitation, scenario definition and iterative assessment. This strategy meant that users did not experience a sense of inadequacy in fully comprehending the role of ubiquitous technologies in supporting narrative activities at the school. However, the children were still actively involved in the process. They created new narrative contents—re-combining elements of different stories in novel and unexpected ways, using the POGO tools in surprising ways. For example, the Beamer tool was extensively used to scan and acquire their own image so that they could become characters in the story (see Fig. 1b). Most of the tools were actually redefined and refined by the children. The designers mainly incorporated suggestions and practices that the children developed using POGO into newer and richer generations of the system.

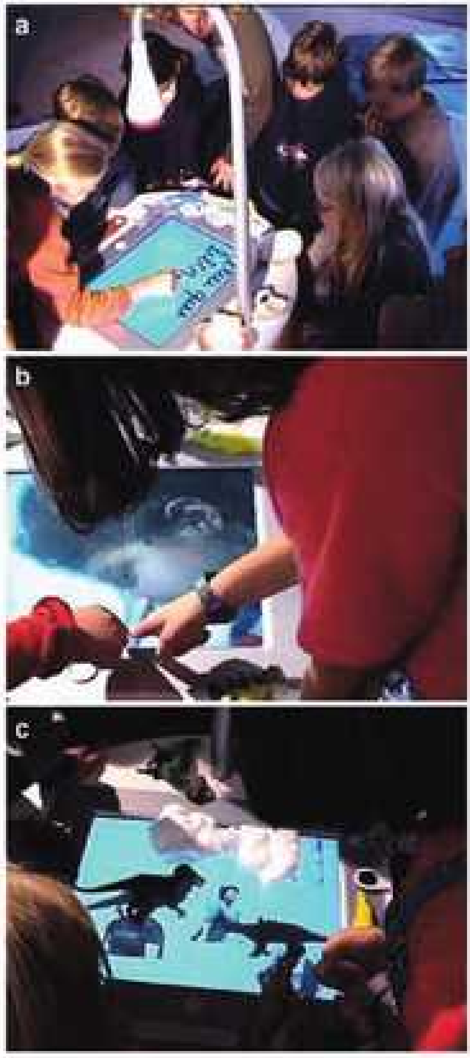

Fig. 1 **a** Children writing the title of their story on the Beamer; **b** child morphing her own image on the Beamer; **c** Children composing on the Beamer a background with cotton used as clouds

The experience of POGO also showed that 'low-tech' and 'lightweight' communicative and creative tools are particularly well-suited for children-centred design. They allow for *collaborative building* of mock-ups and *co-constructing* rapid prototypes, skills that children usually like to develop and practice. Thus, we see that user-centred and even user-involved design needs to be developed with a sensitivity to the work environment, the ages and skills of the users and mesh with the particular phase of the design process in which we are at any moment engaged. In sum, we see different users/informants as shaping the design at different stages: at the beginning, to help designers problematise the domain; in the middle, to test out and reflect on assumptions, and at the end, to evaluate prototypes in real-world contexts.

Case 2: Working with Dementia Carers and Patients

There are situations where user involvement in the design process may be very difficult to achieve and may even be undesirable. Domains like health care or rehabilitation are illuminating examples in this respect. The impairments of the users may limit the degree to which they can collaborate or express themselves appropriately, and external intervention, unless very carefully and sensitively managed, can produce irritation, or even fear, alarm, and anger. Design activities involving users of differing abilities can run the risk of confusing a specific, situated experience with a more systematic understanding of the problem space, thus leading to a potentially incorrect interpretation of real user needs. Furthermore, apart from important ethical issues concerning the development, deployment and evaluation of systems in such settings, methods for eliciting needs in such a complex setting are relatively under-developed. For example, direct observation of people in these contexts is regarded as not merely difficult but is often inappropriate and intrusive (Crabtree et al. 2003).

As a concrete example of this difficulty, we report in this paper a case study on the development of digital technologies for the treatment of dementia-affected patients. Dementia subjects suffer from an acquired permanent neurodegenerative disorder that affects the global functioning of the individual, progressively impairing cognition, personality and behaviour. In particular, dementia is strongly characterised by social isolation and difficulties in communication. Speech becomes increasingly inefficient, and progressive short-term memory difficulties and problems with new learning make conversations and other social interactions problematic (Ripich et al. 1991). Consequently, most people become reliant on caregivers to initiate engagement and interaction and to take care of everyday living activities and arrangements. The social sphere of the individual is jeopardised not only by the impairment of social abilities resulting from global functional impairment of the subject but also by the patients withdrawal from social interaction due to a number of contextual factors ranging from aural and visual ability impairment, institutionalisation and interpersonal disorientation, lack of self-esteem and low motivation (Marti and Giusti 2008).

Very early in the design, process we realised that directly involving such people in active participatory design processes would be inappropriate and unethical, as well as of little utility—as debate, interaction and negotiation were frustrating and inappropriate activities for them. The methodological response we adopted to face this problem took a number of forms. First of all, we turned our attention to a "light observation" of their everyday life practices, putting most of our effort into participatory design with therapists combined with an analysis of relevant literature and modelling techniques to feed the conceptual design. The observation resulted in a very naturalistic approach where we only used our senses, intuition and paid respect to the privacy of the Home Care guests. Quite soon, we were struck by the behavioural response of these people to simple external stimuli. Very basic sensory-motor patterns like grasping, rolling and pulling recurred in many of their activities; memories were stimulated by natural and unstructured stimuli like smells, lights and moving objects, so we used this simple observation to start developing design concepts.

We also had extensive discussions and interaction with the other people surrounding the patients—namely *therapists*, *care givers* and, on occasion, *family members* and associates. Thus, we extended the concept of UCD to encompass not just the designer–user direct relation but taking in the *ecology of the environment* where we were working, in all its complexity and richness.

An extensive analysis of the residual abilities of the elderly was conducted to define a framework for understanding the progressive manifestation of cognitive and behavioural symptoms. Even if the degree and the temporal manifestation of the impairment are different for each individual patient, some features can be commonly observed. For example, the first symptoms to appear are episodic memory deficits and the related difficulties in remembering recent events. Furthermore, since dementia-affected patients lose the ability to retain and process complex stimuli, they experience an increasing difficulty in making sense of the external world. Any system/technology/support to be successfully integrated in the treatment of dementia should strictly address the following requirements. For example, the gross-motor physical limitations of these patients suggest a limited interaction space populated by objects whose dimensions and weights are suitable for an easy manipulation. Because of the difficulties in making sense of novel and complex situations, it is fundamental to design very simple and clear interaction modalities based on physical and sensorial manipulation. In order to exploit residual abilities related to procedural knowledge, the system should be able to stimulate familiar sensory-motor patterns. Other stimuli should be reduced in order to avoid the dispersion of the limited attention span of patients. Due to the difficulties that patients affected by dementia have with verbal communications, the system should sustain non-verbal dialogues (Marti and Giusti 2007).

In parallel with the observation and the study of clinical cases and therapeutic practices, a number of creative design sessions were carried out by the design team using the results of the field study as design guidelines. Our approach generated an extraordinary diversity of concepts that were continuously assessed by therapists and physicians. In particular, a multi-sensory environment was developed, enhanced with ambient intelligence technologies. The aim was to obtain an optimal level of stimulation of dementia-affected patients through the use of lights, smells, images, and interactive tools that were able to stimulate engagement, active participation and intrinsic motivation in a therapeutic (leisure) activity and to favour the emergence of personal meanings (memories, interpretations and narratives). Two kinds of tools have been implemented: *Light & Sound Cylinders* and *Rolling Pins* (Marti et al. 2007). Both tools exploit the patients' residual skills, addressing the motor procedural memory that remains intact the longest. This memory contains sensory-motor patterns that are activated by specific configurations of stimuli. By evoking consolidated sensory-motor patterns, like rolling, grasping, shaking and piling objects one on top of another, patients can start to interact with tools. Natural interaction modalities trigger a behavioural answer and constitute a bridge to engage the patients in meaningful activities that can help to generate an intrinsic motivation to actively participate (Fig. 2).

The therapists became active co-creators of novel activities with the devices and also had many suggestions for tool enhancements. The design process was developed using relatively limited observational studies and participatory design sessions mainly with therapists and carers because of the difficulties and the ethical concerns connected with involving the patients and, in some cases, also the care givers in the design process.

The problem of the limited expressivity of our users was dealt with by adopting a co-evolutionary approach intertwining cycles in which user-driven and design-driven development were conducted in parallel, intersecting them frequently to compare the results and re-tune the process. Our stakeholders, mainly therapists and geriatrics, were constantly involved in the process even if a pure creative phase of concept generation was

Fig. 2 *Left* A trail with rolling pins; *right* a trial with light and sound cylinders

carried out independently by the design team and within the design team[2].

The Multiple Modes of Participation in UCD

We have noted the evolution of the concept of UCD over the years. In early HCI-related studies, the meaning of "participation" was often limited, being more a case of "consultation" than active participation[3]. More recently, there have been increased efforts at engaging with users in the *problem setting* and *concept generating* phases of design, as active actors and members of the design team. Thus, the role of users shifts from that of simply being informants and testers to being co-designers. One must also note that there are many different forms of design projects, from time-critical commercial product-oriented projects to more exploratory design research exercises, more focused on process, and these allow for differing levels and forms of end-user involvement. Attempting to work with users as full co-designers can be problematic for certain projects. Problems can range from a paucity of user skills necessary to engage in a meaningful way with the design team, both at the level of design skills, e.g. brainstorming and sketching ideas, to articulating and communicating their concepts with the design group and at the level of project management—involving such banal issues as securing sufficient time away from their regular activities to engage meaningfully in the design activities required.

The acceptance of the need for user involvement and the assumption that user participation at all stages in the design process is desirable are two of the *mantras* of the current HCI community. Nonetheless, there are occasional voices raised that question this way of thinking. For example, Webb (1996) argues that, in certain circumstances, user involvement may be neither feasible nor desirable: "not feasible because the design environment is new, innovative, creative and dynamic and users are heterogeneous and difficult to access. Not desirable because user involvement itself may constrain creativity" (Webb 1996). Webb looks favorably on the list of problems that can accrue in attempting to engage users in the design process, citing Woolgar (1994): "users don't know what they need; users don't know what is good for them; users cannot properly articulate their needs, even when they do know them; users change their minds; users say different things to different people; users disagree with other users about what they need; users may not be real users at all" (Webb 1996). Each of these statements is worthy of extensive debate, which we do not have time for this study, but it at last should raise our awareness of some potential difficulties. Gulliksen et al. (2003) refers to the critique of Constantine and Lockwood (2002) that "User studies can easily confuse what users want with what they truly need. Rapid iterative prototyping can often be a sloppy substitute for thoughtful and systematic design." Let us examine in some more detail a few critical issues regarding the role of users and how and why their role may not be quite as all-encompassing in the design process as is often advocated in the HCI community. We enumerate these possible difficulties below:

The Problem of "Users as Designers"

While there is a sense in which all users can be viewed as designers at some level—in terms of being able to have some ideas as to how to think creatively about new tools and uses—it is, of course, not the case that most users have the design skills necessary to play a positive role in all stages of the design process. Concept creation can be especially problematic. It is much easier to see a role for users in discussing their requirements and testing and exploring early prototypes. Of course, there is room for forms of engagement that can encourage and elicit useful user input in many aspects of design, but integrating users into certain design practices can be difficult, especially in situations where users may have certain fixed views on what is required, which may be difficult to incorporate into the design team's overall aesthetic design.

The Problem of (Consumer) Product Development

The kind of bespoke information systems developed in early participative design projects differ markedly from

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[2] Indeed, advocacy of designer-led activities for part of the design cycle, intertwined with joint user-designer experimentation, is persuasively argued in the paper by Agostini et al. (2000) on "user seduction".

[3] While there are subtle distinctions between the usage of the terms "user involvement" and "user participation", with the latter often connoting a more active engagement in the process, we will use the terms synonymously in this paper.

the kind of commercial environments in which much consumer product design is done in today's world. Indeed, identifying the user population ahead of time is not always so easy, and in any event, solutions are often driven by the availability of new technologies, existing product lines and market strategies. In this context, users are often involved, if at all, quite late in the development process (Grudin 1991).

The Problem of Comprehending New Technological Infrastructures and Ecologies

New kinds of pervasive sensor-based and embedded technologies require a very different understanding than traditional user-interface design activities. In this framework, users need to understand and control the composition of different system elements and also be able to make sense of them. They need to be aware of technological solutions on the *logical* level (what can be done with this, what can go together with what and for what purpose), the *functional* level (how to use it) and on the *physical* level (it must be possible to see what fits together and to actually build/rebuild). In this context, full participation in the design process may be very difficult for users.

The Problem of Limited User Expressivity in Certain Domains

Another aspect is related to the *application domain*. In specific domains like health care or rehabilitation, users are individuals whose temporary or permanent impairments may limit the degree to which they can collaborate or express themselves appropriately. In such cases, traditional participatory design practices can be simply inappropriate or unethical, since discussion, sharing and negotiation between users and designers can create confusion or upset for the user group.

The Problem of Working With a Multi-Faceted Design Team

A final factor that may limit the role of users in the design process is the *composition of the design team*. If the design team is composed of professional designers with skills in interaction, visual, graphical and product design, the involvement of the users will tend to be postponed in the process and to be focused on specific phases like requirement elicitation, scenario definition and iterative assessment. If the design team is made up of researchers in HCI, then more users can be involved early in the process and, in particular, in creative sessions to develop the vision of the project.

Concluding Remarks

Our purpose in noting some of the potential difficulties with UCD strategies is not to question the general approach, as we very much agree with it, from both a pragmatic, functional, ethical and political viewpoint, but to raise awareness as to the potential difficulties that may occur and argue for a more nuanced approach to the practical implementation of such a strategy. Furthermore, we highlighted, through the presentations of real projects, important issues about user participation, such as the importance of considering ethics and values in UCD and technology development. As Scaife et al. (1997) state, "the real issue would seem, therefore, to be not one of whether involving users is good or bad but rather how to more effectively engage them in the design process." User participation should always be regarded as a value; it should be tailored to the knowledge and the abilities of people involved in the design process. Users need to be prepared for playing their role effectively, for contributing with their domain knowledge to the project, for defining concepts, for evaluating and comparing solutions and identifying usage problems according to their abilities and possibilities to participate in the design process. We welcome and encourage a more widespread discussion from HCI researchers, interaction designers, and all interested parties, as to how we can ensure as open and participative a design process as is possible in any given set of circumstances.

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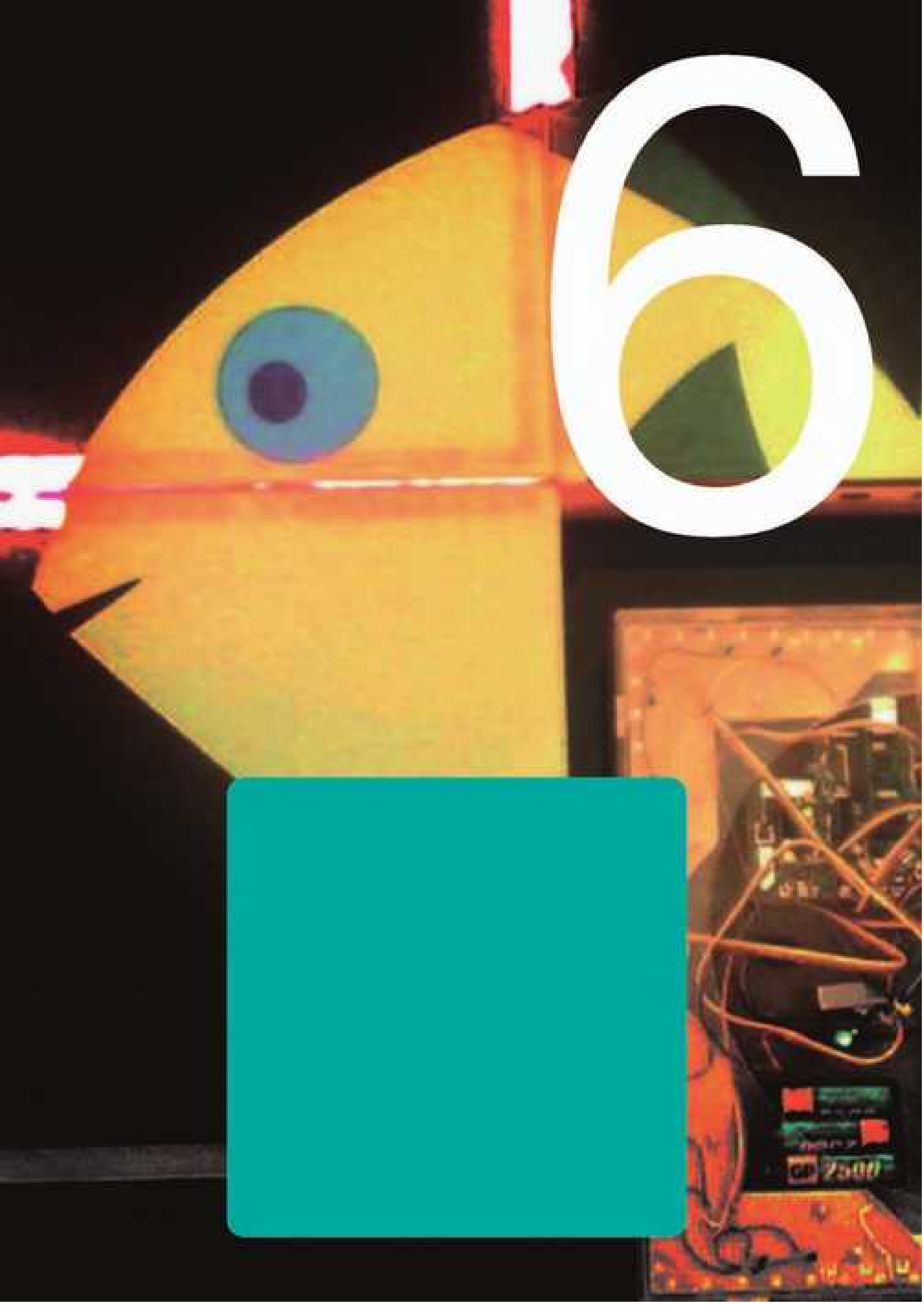

DESIGN CASE 2:
Active surfaces

6.1 The domain context

Physical and cognitive rehabilitation represents a complex whole of practices and approaches. Rehabilitation of people with permanent or temporary disabilities aims at enabling them to reach and maintain their optimal physical, sensory and cognitive functional levels. However, in the current practice, motor and cognitive rehabilitations are separated. Specific tasks and tools are designed for the motor physiotherapy; whereas other tasks, aids and tools are defined to support the acquisition of cognitive skills. Physical and cognitive rehabilitation exercises are seldomly integrated and very often result in repetitive, tedious and tiresome activities in particular for children.

6.2 The research context

Active Surfaces is a prototype developed in the context of a large EU co-funded project PALCOM (http://www.ist-palcom.org/) "Palpable Computing" - A new perspective on Ambient Computing" IST-FP6-IP 002057. The PalCom architecture is centered on the vision of easily and flexibly enabling people to dynamically assemble computational resources and services. The objective was to create a loosely-coupled system model that fulfils personal or business requirements. The architecture was challenged by a number of application prototypes in the field of healthcare, emergency services and landscape architecture. The PALCOM project was carried out by a multidisciplinary consortium:
University of Aarhus (project coordinator), University of Siena, Lund University, Malmö University, Lancaster University, Aarhus School of Architecture, Kings College, London University, Distributed Programming Laboratory, EPFL, Siemens, Whitestein Technologies AG, The Alexandra Institute, Aarhus, 43D
The project started in 2004 and ended in 2007.

I actively contributed in conceiving the whole Palcom project and detailing the project proposal that was submitted to the EU. I was the principal investigator of the team of the University of Siena that was composed by 3 PhD students and a number of external consultants from the Politecnico University (Milan) and a graphic designer. The team of the University of Siena developed two prototypes in the field of healthcare and rehabilitation: Active Surfaces (Design Case 2) and a monitoring system for premature babies (Design Case 3). The prototypes were developed in collaboration with the hospital "Le Scotte" in Siena. Doctors, nurses and care givers were involved in participatory design sessions and I developed techniques to facilitate them to collaborate and contribute to the design process. I also designed the concepts and most of the application scenarios.

6.3 Inspiration

Children usually enjoy playing in the water, and being in the water decreases the effects of gravity, making activities involving balance and coordination more attainable for the child. In the water children with special needs do not only increase their range of motion and coordination but also improve their independence, confidence and sensory processing. The water is an excellent medium to address the physical, cognitive, and psycho-social needs of children with a wide range of impairments, including, for example, cerebral palsy, Down's syndrome, autism, neurological disorders, perceptual difficulties.

Water has a number of properties that increase the wellness of the person and can be developed from a design viewpoint. The first property is the buoyancy. While submerged in water, buoyancy assists in supporting the weight of the person, reducing the force of stress placed on the joints. By decreasing the amount of joint stress it is easier and less painful to perform exercises. The second interesting property is viscosity of water that provides an excellent source of resistance that allows for muscle strengthening without the need of weights. Using resistance coupled with the water's buoyancy allows a person to strengthen muscle groups with decreased joint stress that can not be experienced on land. The third property is hydrostatic pressure that improves posture awareness by producing forces perpendicular to the body's surface. This pressure provides posture awareness and the improvement of proprioception. Lastly, the warmth of the water experience assists in relaxing muscles and vasodilates vessels, increasing blood flow to injured areas.

6.4 Focus on aesthetic and embodied interaction: Play and autonomy

Humans are born to play. Playing is instinctive and a source of energy and excitement, calmness and relaxation for the body and mind. Playing is also social and supports us to thrive in connection with others. Play develops our imagination, creativity, problem-solving abilities, and mental and physical health.

The Active Surfaces design case has an aesthetic focus on playful experiences and autonomy. Autonomy is achieved by designing the play experience in the water. In fact people with physical impairment can move autonomously in water. A modular system was developed, which is flexible in both set-up and activity building to allow for easy creation of games.

6.5 Prototype

The Active Surfaces (Fig. 8) is a modular system consisting of floating tiles measuring 300*300*50 mm. Children have to assemble the floating tiles into meaningful configurations defined by the therapist. Each tile is a resource constrained embedded system that communicates with the others over the six sides using only a low bandwidth short-range infrared link. Tiles can only communicate if they are close to each other. The output available to users is a set of light emitting diodes which provide feedback during the task and reward at the task completion.

The technological features of the system are contained in Paper 4.

Paper 5 contains details about the design process.

Video 2 shows an overview of the system and field trials at the swimming pool.

Figure 8 - Active Surfaces

6.6 Testing

Active Surfaces have been tested in different Italian institutions: the 'Le Scotte' Hospital in Siena, the Disabled Children Parents' Association in Siena and the D. Chiossone rehabilitation centre in Genova.

The system has been successfully used in spontaneous activities involving disable children and their fully able brothers or friends.

Details about the field trials are contained in Paper 4.

Paper 4

Lund, H. H. Marti, P. Designing modular robotic playware. Robot and Human Interactive Communication, 2009. *RO-MAN 2009. The 18th IEEE International Symposium*, September 27, October 2 2009, pp. 115 - 121, Toyama, Japan.
ISSN: 1944-9445.

The authors wrote this paper to reflect on the features of modular systems that may enhance playful experiences for children with different abilities. Two different games based on the combination of tiles were selected to illustrate design challenges. Henrik Hautop Lund edited the first part of the paper related to the modular robotic tiles and their application in kindergartens, schools and youth clubs in Odense, Denmark. Patrizia Marti wrote the second part of the paper related to the Active Surface prototype. The authors together wrote the sections related to the vision and conclusions.

Paper 5

Grönvall, E. Marti, P. Pollini, A. Rullo, A. Active Surfaces: a novel concept for end-user composition In Anders Mørch, Konrad Morgan, Tone Bratteteig, Gautam Ghosh, Dag Svanaes, "Changing Roles". *Proceedings of NorCHI 2006, the Fourth Nordic Conference on Human Computer Interaction*. October 16-18, 2006, Oslo, pp 96-104.

When the paper was published, my co-authors were PhD students under my supervision. Erik Grönvall mainly edited the part describing the software prototype. Pollini and Rullo edited the section of activity scenarios and early testing. I edited the other sections and structured the paper.

Video 2: Active Surfaces for physical and cognitive rehabilitation in the swimming pool
www.vimeo.com/patriziamarti/tiles

Designing Modular Robotic Playware

Henrik Hautop Lund, Patrizia Marti

***Abstract*— In this paper, we explore the design of modular robotic objects that may enhance playful experiences. The approach builds upon the development of modular robotics to create a kind of playware, which is flexible in both set-up and activity building for the end-user to allow easy creation of games. Key features of this design approach are modularity, flexibility, and construction, immediate feedback to stimulate engagement, activity design by end-users, and creative exploration of play activities. These features permit the use of such modular playware by a vast array of users, including disabled children who often could be prevented from using and taking benefits from modern technologies. The objective is to get any children moving, exchanging, experimenting and having fun, regardless of their cognitive or physical ability levels. The paper describes two prototype systems developed as modular robotic tiles, and discusses the challenges and opportunities of this modular playware when used by children with different cognitive abilities.**

I. INTRODUCTION

In this paper we describe a vision for the design of modular robotic technologies that combine constructive and sensorimotor play with creative and active participation of children regardless their specific abilities. Active games with physical involvement as well as building and creating outdoor fun and play in group or individually may all be supported by modular playware technologies that can not only help users reap the physical benefits of exercise, but also provides opportunities for them to learn, share, express feelings, set goals, and function independently. Playware is defined as intelligent hardware and software which aim at the creation of play and playful experiences.

The specific kind of modular robotic playware we present in this paper support play providing modular objects that are visible, manipulable, sharable and interactive and imply construction, active participation, creativity for assembling, mastery of the parts by the users who play with them. These technologies allow a range of play from simple exercise play up to construction play requiring sensory-motor skills as well as coordination/ manipulation of objects, acceptance of influences/inputs of others, turn taking, interdependency and collaboration. With such kind of play activities users can experience the pleasure of putting a "productive thought" into action, and can acquire and refine thinking and manipulation skills while using all their senses: the way toward complex forms of learning and social skill acquisition.

The concept that embraces this vision is today manifested in form of *Tiles*, modular units which can be assembled and are able to communicate with each other and to provide different kinds of feedback (light and sound). The different tile-components can support different play activities and can be set up by the user by physical (re)-programming or programming by examples.

II. RELATED WORK ON INTERACTIVE TILES

The concept of interactive tiles has been explored in different research projects and developed as commercial products along the last few years. Examples of interactive tiles are Sony DataTiles, tiles augmented by dynamic graphical information when they are placed on a sensor-enhanced flat panel display [18]; Z-Tiles, a floor made from networked sensor tiles integrating pressure sensors connected to an embedded computer [19]; U-Texture, a self-organizable panel that can change its own behavior autonomously through recognition of its location, its inclination, and surrounding environment [15]; interactive MEDIATE wall, a floor surface developed for autistic children that reacts to movements generating feedback [17], and commercial products such as Twall from ExergameFitness, a touch surfaces for fitness, and LightSpace from LightSpace Corporation, a pressure sensitive surface able to detect location, movement and density of players to give a realistic gaming experience.

Most of these interactive surfaces, in particular walls and floors are all quite static set-ups that do not allow for the user to perform physical reconfigurations at run-time in an easy way and restrict the possible activities to pre-defined play on pre-defined surfaces.

III. DESIGN FEATURES

In response to the somewhat static nature of much related work, we will present a design approach that leads to flexible, interactive play tools for both sensorimotor and constructive play activities as designed by the end-users themselves. It is our belief that the flexibility obtained through distributed and modular playware holds many advantages for developing engaging and inclusive games and play. Therefore, the design approach outlines the principles

Manuscript received March 15, 2009.

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that we suggest for the creation of flexible, modular play tools. The principles include the design of playware based upon modularity and flexibility, tangibility and immediate feedback to stimulate engagement, construction and physical movement, end-user activity design and inclusive games design.

A. *Playware*

The modular play tools that we develop are designed as playware. Playware is intelligent hardware and software which aim at the creation of play and playful experiences amongst users of all ages [9, 10]. Playware research and development seeks to understand play dynamics[1] and implement them in play tools. Playware is of course not the only type of products which can create play, but we believe that digital technology contains new and expanded possibilities, e.g. when developed with modern artificial intelligence. Playware-tools are tools with a "behaviour" that initiates play force (e.g. a motion, in the case of sensorimotor play) via interaction. This is the basis for the play dynamic to emerge through which the users are brought into a state of playing.

The modern artificial intelligence is used to design behaviours of the play tools. The understanding of play dynamics can help guiding this design of behaviours to be used specifically to create playful and motivating tools for a variety of play interactions, well-knowing that there are both similarities and differences in the play dynamics of different users, environments and activities.

Indeed, the modern artificial intelligence technology supports the development of playware by providing means for creating *adaptive* play tools. We advocate here that for the sensorimotor and constructive play, especially modular robotics provides the possibility, through synthesis, to implement, test and understand play dynamics as modular robot technology gives way for the creation of physical interaction with (flexible) intelligent tools, which are able to react to the players' actions in a suitable manner.

B. *Modularity*

The modular robotic concept demands the availability of robotic modules with certain properties. Each robotic module needs to have a physical expression and should be able to process and communicate with its surrounding environment. The communication with the surrounding environment can be through communication to neighbouring robotic modules and/or through sensing or actuation. A modular robot is constructed from many robotic modules.

The modular robotics approach is to some extend inspired by the behaviour-based robotics approach [1], though the modular robotics approach builds on the belief that behaviour-based systems can include not only the coordination of primitive behaviours in terms of control units, but also include coordination of primitive behaviours in terms of physical control units. We can imagine a physical module being a primitive behaviour. Thereby, the physical organisation of primitive behaviours will (together with the interaction with the environment) decide the overall behaviour of the system. Hence, in a similar way to the control of robot behaviours by the coordination of primitive behaviours, we can imagine the overall behaviour of a robotic artefact to emerge from the coordination of a number of physical robotic modules that each represents a primitive behaviour.

The modular robotic concept is known mainly as self-reconfigurable robotic systems such as M-TRAN [13], ATRON [16], Superbot [20], etc., in which the modules can reassemble autonomously. In these self-reconfigurable modular robotics systems, the focus is on creating flexible and adaptive systems that respond to different environmental conditions and tasks by autonomously making run-time changes of the physical shape of the robotic system. On the other hand, we can view *user-configurable modular robotic systems* as modular robotic systems, where the user at run-time will make the physical rearrangement of the robotic modules. Some user-configurable modular robotic systems will allow the user to make the physical rearrangement of modules for setting up activities, while other user-configurable modular robotic systems will allow the user to make the physical rearrangement as part of the activity (e.g. for play, learning, rehabilitation).

C. *Flexibility*

Both modalities of user-configurable modular robotic systems provide flexibility in the physical set-up and arrangement of the technological tool. It is the aim of such systems to allow for an easy way for end-users to make the physical and functional rearrangement. The design of such a flexible system demands a clear focus on how to create flexible and distributed technology.

Often, technological systems are created with a centralised, static set-up that does not allow for flexible rearrangement of the physical (and functional) arrangement of the systems. Even in the case of interactive tiles as presented in this paper, most other interactive surfaces are fairly static set-ups that most often only can be set-up in pre-defined physical configurations by a professional installation worker. So in such cases, play activities are most often limited to be performed on a pre-defined surface. There is little flexibility in terms of run-time development of the play activity based upon rearrangement of the interactive surface. The distributed system of tangible, attaching modules allow for a flexible use of the system by providing easy rearrangement (i.e. physical programming) possibilities.

In order to allow for flexible use of the different modular robotic devices, it becomes important to design and develop a distributed, generic, and versatile system (including communication protocol and framework) of the modular robotic devices, so that these modules can easily be added, removed, substituted, and rearranged.

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[1] A play-dynamic is the dynamic effect of the play-force which affects the player by placing this person in a state of playing.

D. Tangible interaction

Tangible interaction refers to the technology enabled experience of physically manipulating objects [5], the material representations of information and the physical, conceptual and cultural constraints they embed. The mapping between the physical affordances of the objects with the digital components (different kinds of output and feedback) is a design and technological challenge. Indeed implementing the tangible interaction does not mean to simply augment physical objects with digital components. The physical properties of the objects serve as both representations and controls for their digital counterparts [6].

The concept of modular playware makes digital information directly manipulatable, perceptible and accessible through our senses by physically embodying it.

While playing with the modular playware, children can take advantage of the distinct perceptual qualities of e.g. the interactive tiles and this makes the interaction tangible, lightweight, natural and engaging. Interacting with tiles just means jumping over, pushing, assembling, touching physical objects and experiment a dialogue with them in a very direct and non-mediated way.

E. Immediate Feedback

In order to design the play experience in all its richness, feedback is a key features to guide children through the play activity. They expect to see the results of their actions immediately and if nothing happens after their input, they may give up and abandon the game.

Modular robotic playware creates rewarding games that can be easily understood and can promote fun. The design of such playware does not simply concentrate on the mechanics of the interface but also on immediate feedback that will keep children engaged.

User motivation and engagement are as important as task efficiency in modular robotic playware. Value is only attained if children spend time playing, enjoining and keeping their attention focused on the play activity.

In order to engage children in play, the feedback in modular robotic playware should be early and positive, immediate, explicit and understandable, continual and constructive as the child progressed through the activity.

F. Construction and physical movement

Constructive play combines sensorimotor practice with symbolic representation of ideas. Therefore it does not only stimulate the physical movement but also provide opportunities for make-believe and creative play activities. The modular robotic playware allows construction and deconstruction of assemblies to modify, enrich and adapt play activities to children with different abilities in different contexts.

Challenges in enabling constructive and creative play with modular robotic playware require that each part of the assembly is easy to understand at different levels: on the logical level (what can be done with the tiles, which tiles can go together and for what purpose of play), the functional level (how to use the tiles) and on the physical level (it must be possible to see what fits together, the system behaviour and what can be actually build or rebuild or modified).

G. End-user activity design

The importance of physical action as an active component of play activities and the direct physical interaction with the world are a key constituting factor not only of cognitive development during childhood but also of the design of play activities. In modular robotic playware, the play activity is designed by the end user through physical manipulation and shape configuration of modules.

This way of designing games by showing the modules the correct solution and by assembling them in different shapes has some similarities with programming by example [14] and physical programming [12]. The user can define specific patterns of modules and these modules initiate exploring their relative position. Changing the physical configuration of the modules results in changing the play activity.

Further, inspired by the body-brain discussion of modern artificial intelligence (e.g. [7]), it is possible to design systems that allow the user to modify the physical shape of the assembly of modules in order to change the playful game and interaction at run-time. The software game implementation may be fixed in the modules, and the change of the physical arrangement of the modules will enforce different kinds of physical interactions. It is the physical rearrangement of the modules that changes the game/interaction modalities (and not a change in SW).

H. Inclusive games

Modular robotic playware aims to get also disabled children moving, exchanging, experimenting and having fun, regardless of their cognitive or physical ability levels. Indeed our modular robotic tiles have been successfully used in spontaneous play activities involving disable children and their fully able brothers or friends.

Modularity, flexibility, immediate feedback and tangible activity design make such kind of playware adaptable to different physical and cognitive abilities. The adaptation can be performed at run time by the system itself or by the user as the activity progresses. For example tiles can be used in the swimming pool to support play in the water. Indeed water is an excellent medium to address the physical, cognitive, and psycho-social needs of children with a wide range of impairments. In the water they can not only increase their range of motion and coordination but also improve their independence, confidence and sensory processing. Moreover some quality of the feedback like pace and duration can be adapted to the child responsiveness and still the play activity maintains its characteristics to be demanding (requiring a complete commitment by the player), progressive (becoming gradually and increasingly complex) and fun.

IV. MODULAR ROBOTIC PLAYWARE: TWO PROTOTYPE SYSTEMS

In what follows we describe two different implementations of the concept: the "Modular robotic tiles" modular tiles to support physical play on horizontal and vertical surfaces and the "Active surfaces", modular floating tiles to support construction play in the water.

A. Modular robotic tiles

We developed modular robotic tiles according to the key features of the design approach described above, in order to create a modular playware with the possibility for users to modify the physical shape and make easy setup for a variety of play activities. Further, we designed the modular system with the possibility of exclusion of external host computer, with self-contained energy source, with wireless communication (local and global), and with different games.

Fig. 1. The modular robotic tiles for sensorimotor play (left) and for construction play (right).

The system is composed of a number of modular robotic tiles which can attach to each other to form the overall system. Each tile has a quadratic shape (measuring 300mm*300mm*33mm), see Fig. 1. It is molded in polyurethane. In the center, there is a circular dent (diameter 200mm) which has a raised platform (diameter 63mm) in the centre. The dent can contain the circular printed circuit board with the electronic components. At the center of each of the four sides of the quadratic shape, there is a small tube (diameter 16mm) through which infra-red (IR) signals can be emitted and received (from neighboring tiles). Small magnets are placed on each side of the tiles. The magnets on the back provide opportunity for a tile to be mounted on a magnetic surface (e.g. wall), and the magnets on the sides provide opportunities for the tiles to attach to each other. The magnets ensure that when two tiles are put together they will become aligned by the magnetic forces, which is important for ensuring that the tubes on the two tiles for IR communication are aligned and it helps the end-user in making the correct assembly in a simple, easy and understandable manner. On one side of the tile, there is also a small hole for a battery charging plug.

There is a small groove on the top of the wall of the circular dent, so a circular cover (diameter 210mm) can be mounted on top of the dent. The cover is made from a circular transparent satinice plate and a polyurethane circle in the centre.

A force sensitive resistor (FSR) is mounted as a sensor on the center of the raised platform underneath the circular cover. This allows analogue measurement of the force exerted on the top of the cover. There are three NIMH AA rechargeable batteries on top of the PCB. A 2 axis accelerometer is mounted, e.g. to detect horizontal or vertical placement of the tile. Eight RGB light emitting diodes are mounted with equal spacing in between each other on a circle on the PCB, so they can light up underneath the transparent satinice circle. There is a radio communication add-on PCB with a XBee radio communication chip.

The modular robotic tiles can easily be set up on the floor or wall within one minute. The tiles can simply attach to each other with the magnets, and there are no wires. With the accelerometer, the tiles can register whether they are placed horizontally or vertically, and by themselves make the software games behave accordingly.

Also, the tiles can be put together in groups, and the groups of tiles may communicate with each other wireless (radio). For instance, a game may be running distributed on a group of tiles on the floor and a group of tiles on the wall, demanding the user to interact physically with both the floor and the wall (see Fig. 1, left).

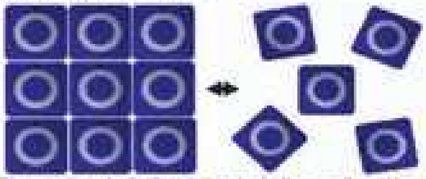

Fig. 2. The modular robotic tiles can be physically reconfigured by any user at run-time, e.g. as one cluster (left) or more clusters of size down to one tile for each cluster (right).

The tiles are developed according to the design approach to provide a flexible possibility to create a variety of playful applications for a variety of end-users. For instance, we designed applications for playful physical activities, which were installed in 6 kindergartens, schools and youth clubs in Odense, Denmark, and we made interactive soccer games with the tiles for children's entertainment at stadium during Danish national football league matches.

Among many different games, we implemented the colour race game, where the child has to chase a given colour, which jumps around on the surface of tiles. The modularity of the tiles provides flexibility for creating tangible interaction. If the child (or teacher) wants playful interaction with hands, she places the tiles on a wall so that the child needs to play with the hands, or if she wants interaction with the feet, she may place the tiles on the floor. Or she can choose a combination of some tiles on the ground and some tiles on the wall for playful interaction with both hands and feet. For the soccer game, a light is travelling around on the tiles, and the child has to hit the travelling light with the ball, which will light up all the tiles to indicate that a goal was scored – the game becomes an interactive version of playing soccer up against a wall (Fig.3, right).

Fig. 3. A child and her father in the multi-sensory room (left), and children playing soccer with the modular robotic tiles (right).

As a result of the design, other motivating play activities may easily be set up for children (and adult) *e.g.* for sensorimotor play such as stepper games, reaching games, dancing games, and more cognitive sensorimotor games such as Memory and Simon says.

Therefore, the design approach also allowed us to quickly reconfigure the modular robotic tiles to be used for playful cognitive construction games (see fig. 1, right). We used a set of 15 tiles and the construction game called *colour-mix*. The basic idea is to mix colours in different ways, dependent on how the tiles are assembled. 3 tiles are predefined as source tiles respectively with the colours red, green and blue. The other 12 tiles are normal tiles, with the property that they can change their colours accordingly to their local neighbourhood. If a normal tile is connected to a red source tile, the normal tile will become red just as its neighbour but with a lower intensity. The source tiles never change their colour. If a blue source tile also is connected to the normal tile at the same time as a red source tile, the normal tile will blend the two colours to become a purple tile. A normal tile should always light up with a lower intensity than its neighbours colour intensity, which makes the colour spreading from a source tile decrease when the distance to a source tile increases.

For the colour-mix construction game, we used a distributed control approach, which is fairly straight-forward since every modular robotic tile is equipped with both communication and computation capabilities. The tiles can be moved around and connected to each other in any configuration. In this distributed environment it is very easy to make local changes based on the local environment. A tile can easily read neighbouring tiles' states, and thereby change its own state accordingly to some local *rules*. By not having a central server to administer the data flow between tiles, the stability of the application will not depend on the reachability of e.g. a master-tile or a host computer. Simple rules based on the local environment are easily implemented and the software on the individual tile can be kept simple. Also, the distributed control facilitates the *emergence* of new behaviours, when different rules are influencing each other. It is not always possible to predict what can emerge, and this is in the hands of the end-users construction.

Also, we designed the tiles to be used as part of a multisensory room at the HCA children's hospital in Denmark (see Fig. 3 left). In a similar manner to the applications described above, the multi-sensory room composed of the modular robotic tiles and other modular devices (e.g. I-BLOCK cubes, and sound system) engage the hospitalized children in physical activities, and should motivate to perform physical activities by providing immediate feedback (coloured light patterns, sound, vibration) based upon playful, physical interaction with the system. The children hospital pedagogues allow the children and possibly their parents into the multi-sensory room to interact with the playful robotic tiles to provide a calm, relaxing and joyful environment. A main finding of the tests conducted at a children's hospital, was that it was found to be very important to create feedback that was easily recognised by the users [8]. Indeed, the tests showed it to be crucial to create feedback that was easily and immediately recognised by the users, and it was found that the interaction was boring if the feedback was too implicit (subtle) and not well understood by the user [8]. The users appreciated an *explicit immediate feedback* (e.g. a clear and immediately recognisable sound or light pattern from touching a tile) because it was obvious and understandable, and did not require any a priori knowledge of the dynamics of the games.

The modularity, ease of use and the functionality of the modular playware devices suits well into scenarios such as playful multisensory rooms, because they provide coloured light, sound and possibly other kinds of feedback (e.g. vibration). The tiles are designed generic, which means that they can be augmented with other sensors or actuators. The physical form and the weight of the tiles is important to allow for easy rearrangement of the tiles for any child.

Our design guidelines lead us to construction of tiles that lend themselves as inclusive games technology in that the user groups for the applications may span an array of abilities. Indeed, the colour mix application was actually developed and performed with therapists and 7 autistic children in the autism home Bihuset in Denmark. We will explore and exemplify the design approach for inclusive games technology in further details with the design of active surface tiles below.

B. Active surfaces

Physical and cognitive rehabilitation of children with special needs poses important technological challenges and design opportunities. For example, therapists need to be able to react flexibly and fast to children's different abilities, and therapists and children need multiple modes of interaction, including physical ones. These demands play out most interestingly in aquatherapy, where we must also add communication and resource challenges.

Aquatherapy is a crucial part of cognitive and physical therapy. Children usually enjoy swimming, and being in the water decreases the effects of gravity, making activities involving balance and coordination more attainable for the child. In the water children with special needs can not only increase their range of motion and coordination but also improve their independence, confidence and sensory processing. The water is an excellent medium to address the physical, cognitive, and psycho-social needs of children with a wide range of impairments, including, for example, cerebral palsy, Down's syndrome, autism, neurological disorders, perceptual difficulties.

Aquatherapy is mainly achieved through games designed to improve motion and cognitive skills. For the therapists this is a highly demanding task. Games must be invented or modified on the fly to take advantage of the children's widely varying strengths. Moreover, whereas a child with cognitive difficulties might respond to verbal encouragement to put objects in an ascending order (e.g. of size), children with communication difficulties respond better to visual cues and specific tangible rewards than to verbal directions, creating a need for flexible multi-media stimulation.

Currently the therapists' efforts are poorly supported, and there is a clear need to develop tools that support creative and situation sensitive therapy by being easily re-configurable during the activity and adaptable to evolving situations, and by supporting a range of multi-media feedback.

1) The system

The Active Surfaces is a modular system consisting of floating tiles measuring 30*30*5 cm (Fig. 4). Children have to assemble the floating tiles into meaningful configurations defined by the therapist. Each tile is a resource constrained embedded system that communicates with the others over the six sides using only a low bandwidth short-range infrared link. Tiles can only communicate if they are close to each other. The output available to users is a set of light emitting diodes which provide feedback during the task and reward at the task completion.

The tiles support multiple games by having a simple physical appearance and multi-purpose programmable hardware. Magnets are placed on the four sides of each tile to make the tiles "snap" together when they are in close vicinity. A replaceable plastic cover is on the top of the tile also held in place by magnets. The image on the cover depends on the game. Inside each tile an embedded system uses infrared light to communicate with and detect the presence of other tiles. Two tiles can only communicate if they are close to each other. The main computational unit is the UNC20 module, which is an ARM7-based embedded system running uClinux at 55MHz with approximately 8MB ram. The UNC20 module communicates with a sideboard using a serial connection. The sideboard is responsible for controlling the infrared communication and the LEDs. The bandwidth of the infrared communication is approximately 600 bits per second [2].

The Active Surfaces prototypes support construction activities on different levels: i) on the logical level the therapist can define what the rules of the game are and what the purpose is; ii) on the functional level users can mark out the relations and the sequences and; iii) on the physical level users can define which patterns and connections can take place, to reach the goal of the game [3].

Fig. 4: Examples of games with active surfaces

Games with different logics have been created to support aquatherapy on a resource-constrained device like the tile [4]. For example, children with perceptual problems can be stimulated using the *catch game*. In this game a set of tiles are placed in the swimming pool and another tile is given to the child. When the game is started the child has to get her tile close to a glowing tile, "catching the light" within a certain timeframe. If she succeeds, another random tile will light up and she tries to catch that one. When she eventually fails to catch the light in time her tile will blink how many lights she caught. Other games like the *scrabble game*, where the child has to form words out of letters can be used for children with language problems, or *sequence games* like putting in a sequence tiles with images of increasing size, or matching colours, can be used for children with Down's Syndrome (Fig 4).

Active Surfaces have been experimented in different Italian institutions: the 'Le Scotte' Hospital in Siena, the Disabled Children Parents' Association in Siena and the D. Chiossone rehabilitation centre in Genova (Fig. 5).

Fig. 5. Trials with active surfaces

In some therapeutic sessions, the system has been successfully used in spontaneous activities involving disable children and their fully able brothers or friends. In other cases children with mild cognitive delay and physical impairments were treated for attention and object manipulation tasks or the creation of logical sequences in the domino game. In all sessions, the children enjoyed the play activity. They tried out different construction games but also explored unusual combinations of the tiles like piling them one on top of the other. A remarkable result of the experimentation is observation of the emergence of the exploration of body schemes, like the trunk-shoulders coordination during the rotations, the left-right movements, the control of spatial relations among the floating objects (inside/outside, front/rear, top/bottom). The acquisition of the body schemes and the spatial relations among objects is a slow conquest for children not attributable to the simple mental access to these concepts. For children with multiple disabilities the acquisition of spatial concepts is enabled by the psycho-motoric activity and the experience of their body in the world. Active surfaces just stimulate such kind of exploration of our own body and its spatial relations with other objects. A second remarkable result of the trials is that the rehabilitation consisting of repetitive exercises is often considered by the children boring, gruesome and painful and for this reason children are reluctant or just refuse to practice the exercises.

With active surfaces disabled children accepted the physical competition of the construction games and collaborated with each other to their successful accomplishment. Also the therapists interviewed after the therapeutic sessions considered active surfaces to be an excellent substitute for traditional therapy because, though it requires body movements just like traditional therapy, it involves so much of distraction and fun that children ignore the discomfort [11]

V. Discussion and Conclusions

The two different kinds of tiles incorporate and exemplify the key features of the design approach. The modularity is obtained by the development of fully distributed and self-contained modular robotic tiles, which allow the user to make both physical and functional construction. Thereby, the tiles can be used in a flexible manner by allowing the end-user to make changes in an easy and very fast manner, so that it is the end-user who can design the activity. The design focus on tangible interaction led to solutions such as utilising the material properties to facilitate understanding of behavioural characteristics and manipulable possibilities (as an example, magnetic forces of tiles "invisibly" helped the end-users assembling (aligning) the tiles correctly). By sensing the exerted force and providing coloured light (and sound) stimuli, the tiles can provide an immediate feedback. If this immediate feedback is explicit and provided as part of a playful interaction game (for both sensorimotor and construction play), we find that it motivates and stimulates engagement, as exemplified with the variety of applications presented above.

These key features further make it possible to create inclusive games which may be adapted to users with different physical and cognitive abilities. Indeed, the tiles were easily adopted by children with different cognitive abilities as exemplified above, but also by adults for physiotherapy and for elderly cardiac and stroke patients' physical rehabilitation (at the hospital Sygehus Fyn Svendborg, 2006-09). The design of modular playware allows this adaptation to happen automatic by software adaptation or by the users' easy physical construction with the tiles. Further, in these cases, the design focus on playware results in playful applications that motivate to perform rehabilitation activities.

In the future, we will explore the design approach further, for instance by utilising it to create playful, interactive and flexible modular playware for rehabilitation of handicapped children at Neema Craft in Iringa, Tanzania. Here, it is our belief that the design approach comes to its full value when allowing for easy and flexible adaptation to the local, contextual needs.

ACKNOWLEDGMENTS

The authors would like to thank colleagues in their respective research groups, Center for Playware at Technical University of Denmark and Communication Science Department at University of Siena. Their contributions were essential for allowing the authors to form the ideas and principles presented here.

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Active Surfaces: a novel concept for end-user composition

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ABSTRACT

This paper describes the design process of a modular system for supporting physical and cognitive rehabilitation in the swimming pool. In such an environment, the therapist is called to creatively adapt rehabilitation protocols to the enhanced ability of the patients, often reacting to emerging behaviours enabled by the water. Therefore a strong technological requirement for such environment is to develop a modular system that can be configured and modified "on the fly" during the activity, exploiting the therapeutic properties of the water. To satisfy such a requirement the system of Active Surfaces has been developed. It consists of a number of position aware floating units, called tiles, able to communicate each other and to provide visual, acoustic and tactile feedback. By combining the different tiles the therapist can easily configure the dedicated tasks for the various typology of patients. The concept has been developed following the Palpable Computing approach, an innovative design paradigm complementing key features of ambient computing, such as invisibility and end-user composition of devices, with dual features (e.g., visibility and decomposition) that enable users to navigate, configure and influence the computing system.

Author Keywords

Ambient computing, Palpable computing, end-user composition, programming by example.

ACM Classification Keywords

Interactive System, Interactive environment, Design studies, User-centered design, Evolutionary prototyping, Advanced technologies, Portable devices, Wireless Communication, Sensors

INTRODUCTION

The notion of ambient computing has been consolidating focusing on the design of distributed, pervasive and reactive systems able to communicate with the users and to continuously adapt to their needs and expectations. However the users must always remain in control [11]. Balancing transparency and automation with awareness and control is the goal of PalCom (PalCom, http://www.ist-palcom.org), an European project that aim at developing an innovative design approach called Palpable Computing. Palpable computing complements key features of ambient and ubiquitous computing systems [13], [14], such as invisibility and end-user composition of devices, with dual features (e.g., visibility and decomposition) that enable users to navigate and influence the computing system [11]. The paradigm purposely addresses the way in which humans meaningfully interact with distributed computational systems available in the environment. Palpable computing aims at supporting user control by composing and de-composing assemblies of devices and services. The assemblies are configurable by the user depending on the context of use. Consequently, these assembled systems should support the continuous attribution and negotiation of meaning through interaction.

The notion of palpability also embodies the concepts of graceful degradation and inspection: palpable systems can support resilience in case of functional breakdowns. If part of the system fails, still some functionality should be available and working. Inspection allows the user to examine the current state of a system or component and to reconfigure the system accordingly. If a system is subject to degradation, it should be able to communicate its new state. A typical scenario for palpable computing could be the following:

You are on a train with a friend working on your laptop. You also have a camera-equipped mobile phone that unfortunately does not work any longer. Nowadays it is impossible to use the camera and other services in the phone, while the screen is damaged. Here a palpable mobile phone could prove useful. If you could define an assembly connecting the screen of your computer with the camera in the mobile phone, the camera could still be used, even if you cannot browse or see the pictures on the mobile display. If your friend needs to control his email, he could communicate over Bluetooth and GPRS, simply using the

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NordiCHI 2006: Changing Roles, 14-18 October 2006, Oslo, Norway

mobile as a network interface, then controlling the actual connection on his laptop. In this way he could still use the telephone communication capabilities disregarding the broken screen.

Thus palpable technology can provide the users with the opportunity to overcome some failures of the system by relying on the working components. System resilience and re-arrangement of the available resources are key features of palpable computing.

These themes become crucial if applied in critical domains such as health care and rehabilitation. In this paper we will address this discussion presenting a design study in which a tool supporting rehabilitation practice has been developed embodying some of the qualities of the palpable computing. Therapists working in cognitive and physical rehabilitation with disabled patients usually experience their job challenging and demanding. Every time the therapist starts a treatment she has to define a specific program and ad hoc solutions with the aim of designing a rehabilitation intervention that could adapt to the individual patients' needs. Thus, the work of the therapist is mainly characterized by creativity both in designing engaging activities and suitable tools.

Furthermore, rehabilitation in the water poses specific and interesting research issues both for the development of digital technologies and for the therapeutic practice. Indeed wireless connection, perceived feedback, robustness and stability of the system are continuously challenged by the environment, whilst the quality of the water creates a safe context where impaired people can move autonomously, something they cannot do elsewhere.

Active surfaces is the concept developed for rehabilitation practitioners being a support for physical-functional and cognitive rehabilitation treatments in a swimming pool setting. The system consists of a number of tile components. They constitute a network of physical (and software) objects communicating each other, exchanging data and able to recognize their relative positions in the space. These features support the construction of meaningful configurations of different tiles. Each configuration can be conceived as an assembly of components. The therapists can configure these assemblies by programming by examples. They can save successful configurations, keep memories of previous configurations and generate new assemblies to support patients' specific needs. Each tile acts as a building block whose behavior can be defined using a library of contents (images, sounds, pictures…). In this way the system provides the therapist with the possibility to design specific tasks and activities for the patients and to integrate cognitive training and physical rehabilitation. In this paper a design study we will reported on the initial implementation and testing of the Active Surface concept in the swimming pool setting. The work has been conducted following a co-evolutionary method [5], [6]. The approach integrates participatory design with creative concept design, using different typologies of scenarios for converging ideas into solutions. The early phases of our fieldwork have been devoted to understand the activity, to define requirements and to collect best practices. On this basis, the concept of the Active Surfaces has been developed, capitalizing on participatory design activities, creative workshops and following the Palpable Computing approach.

RELATED WORK

Systems of modular tiles have been explored in many research projects along the last few years. A benchmarking activity has been held to provide our design process with a frame on current projects on tiles, used technologies and explored prototypes. This early investigation of the field highlighted the strengths of each projects mainly based on characteristics like physical features and material (Sony DataTiles) [9]; I/ O systems (Playware and Tangible Interfaces) [2], communication (Z-Tiles) [10], configurability and position recognition (u-Texture) [7].

In particular the u-Texture pervasive application was of inspiration for our concept development. u-Texture is a self-organizable universal board that enables to change its own behavior autonomously through recognition of its location, its inclination, and surrounding environment by assembling them physically. The other work that mostly informed our process is the Playware developed by the Southern Denmark University [8]. The tangible tiles behave as building blocks in which the coordination of primitive behaviors through physical modules, such as a tile, together with the interaction with the environment, decides the overall behaviour of the system.

The following paragraphs will describe the peculiarity of the Active Surfaces context of use and the specific challenges we tried to explore in the design process. The major focus on end-users and Palpable qualities (such as understandability, end-user composition, change/ stability) makes Active Surfaces differentiating in respect to other systems of modular tiles.

THE REHABILITATION PRACTICE

Physical and cognitive rehabilitation represents a complex whole of practices and methodologies. The treatments protocols and the techniques, although representing the foundations of this discipline do not embrace all the aspects involved. Rehabilitation is a transversal process since it intervenes in the treatment of different typologies of patients, sometime in conjunction with other kinds of medical treatments. The patients can be temporary or permanently affected by diseases or impairments; they differ by age, problems and attitude toward their situation. Thus, each therapeutic session represents a unique and novel experience.

These initial considerations inspired a deeper understanding of the rehabilitation work practice. Our investigation mainly concentrated on the rehabilitation of disabled children performed at the Rehabilitation Unit at 'Le Scotte' Hospital (Siena, Italy) and at the public swimming pool in Siena. In our analysis we concentrated on these two contexts, investigating how their different features shape the work practice carried out by the therapists. The fieldwork included phases of observation, video recording, interviews and activity analysis.

Figure 1. Participatory design at the Rehabilitation Unit

The *psychomotor rehabilitation* therapy supports the development of higher cognitive and physical functions and helps to recover or improve individual capabilities.

In many cases (e.g. Hanart Syndrome, Moebius Syndrome, Angelman Syndrome) there is no agreement on the therapeutic protocol that should be used to aid in the development of even very basic skills (e.g. communication and motor coordination). Thus the modality in which the therapists approach the rehabilitation is based on a process of trials and errors, trying to configure 'on the fly' their therapeutic aids or adapting the existing tools. When something proves to be successful in a particular case they assimilate this as a best practice to be re-used in other situations.

For ***cognitive rehabilitation*** therapists use cards, pictures, photos, software applications and everyday objects in order to improve cognitive skills such as image recognition, image matching, visual memory and procedures. On the other hand, the development of motor abilities requires repetitive exercises to sustain coordination, balance and movements.

In their current practice, motor and cognitive rehabilitations are mutually separated. Specific tasks and tools are designed for the motor physiotherapy; whereas other tasks, aids and tools are defined to support the acquisition of cognitive skills. The two activities are usually never integrated.

The swimming pool represents a privileged environment for rehabilitation. At the public swimming pool in Siena a volunteer association provides training and group activities for disabled people. The swimming pool is a powerful setting from many respects., The water supports the body and gets the weight off the joints. Movements within the water are easier and less painful. In fact, water is a great 'equalizer' for disabled people who find that while inside the water, their movements are easier and less different from those of non-disabled people.

The subjects involved in these rehabilitation initiatives are both children and adults with different disabilities such as Down syndrome, cognitive and physical impairment, microcephaly, developmental delays and autism. Most of them have motor-physical disabilities and the water helps them to better coordinate their movements and to autonomously keep their balance. Water may also aid in the control of respiration, the understanding of space-time relationships and the perception of the self-motor activity. This particularly because of the global sensorial stimulation. Physically impaired people can be supported in structuring basic body schemas through freely moving in the water.

The trainers who assist the children in the swimming pool we studied, are all volunteers, without any specific previous experience in rehabilitation. The activities they perform today are not structured and non specific therapeutic objectives are stated. One of the main goals of these activities is the socialization. Therefore, the patients mainly interact with each other in different spontaneous ways. Usually there are few tools such as boards, bracelet, and balls commonly utilized for the swimming training that are used also by the impaired patients.

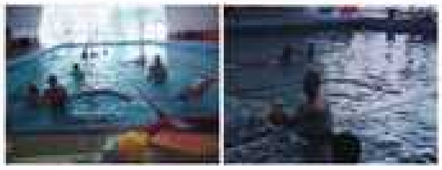

Figure 2. Group activities for disabled people

An intense period of observation in the swimming pool made us capturing some peculiar features of the rehabilitation practice.

On-the-fly configuration and creation of assemblies. A first consideration is on the rehabilitation activity. Dealing with continuously changing conditions and rehabilitation demands, the therapists should always find new solutions to adapt their tools and the environment to the patients and to capture their attention along the session. Consequently a core characteristic is that the tools have to be easily re-configurable to adapt to this evolving situation.

Dealing with failures and degradation. The therapists usually deal with dynamic settings and changing conditions. This implies the ability of rearranging the available resources even if in case of degraded performance of the socio-technical system (tool, environment, people, technology).

The possibility to re-use the assemblies and keep trace of the best practices. This is the possibility to define best practice and to re-use a configuration of objects and settings, creating a toolbox containing the know-how concerning creative usage of the existing therapeutic tools.

Combination of cognitive and physical rehabilitation. The lack of integration of the physical and cognitive rehabilitation represents another aspect of the rehabilitation practice of today. The cognitive tasks are usually quite boring for the children and they quickly get tired and lose attention. On the other hand, motor rehabilitation is very demanding at a physical level and is based on repetitive sequences of actions often perceived as tiring and not engaging.

At light of these considerations, the swimming pool presents a strong potential. The properties of the water can enable new opportunities for rehabilitation. The reassuring and calming qualities as well as the facilitation of body movements create a pleasant setting in which cognitive tasks can be easily combined with physical ones.

ACTIVE SURFACES

The concept

The fieldwork analysis and the different creative sessions with the stakeholders have informed the concept generation phase along the design process. We tried out different creative methods, like brainstorming sessions and attribute listing in order to produce concepts in collaboration with the stakeholders.

The main idea is to rethink the environment of the pool, making it a place for rehabilitation and play activities. Indeed the swimming pool is designed mainly for swimming, not for walking or running for example, as required by most of the rehabilitation activities. Our design process aimed at re-considering all the dimensions of the swimming pool (bottom, surface, vertical walls) and to invent new activities.

From an interaction design perspective the goal is to design new activities for the rehabilitation by designing enabling environments and tools. The Active Surfaces is the concept that embodies these issues.

The Active Surfaces concept accounts for the need for configurability, constructability, modularity, physicality and creativity in rehabilitation practice. 'One' Active Surface consists of a tile, measuring 30*30 cm. This is the standard tile that can be used for the different tasks. Each Active Surface is thought of as a modular unit that can communicate with the others by the six sides. The tiles are in fact able to recognize their relative positions. Then there exists a privileged tile: the Assembler Tile which is used by the therapists to program the other tiles. A number of tile components can be logically assembled (using the Assembler Tile) and can constitute a network of physical (and software) objects that communicate and exchange data. Many qualities of palpable devices are embodied in the Active Surfaces concept.

Active Surfaces are conceived as the modular units of an assembly. The Active Surfaces constitute assemblies on different levels: on the logical level the therapist can define what the rules are and what the purpose is. On the functional level the user can mark out the relations and the sequences. Eventually, on the physical levels user can introduce new affordances for building / rebuilding the surfaces. Thus Active Surfaces offer a valuable example of physical construction / deconstruction of components. In that way the physical construction of assemblies [4] provides end-users (i.e. the therapists) with control of the system behaviour and adaptation to the context.
To support *end-user composition*, the Active Surfaces is also complemented by a Migrating UI browser mechanism developed within PalCom project at the University of Lund [12], for programming the rules and the behaviours to be instantiated on the tiles. The therapist creates patterns by physically building tiles' sequences.

The tiles address also *scalability* and offer an opportunity to produce scalable solutions still relying on low-level resources management. Furthermore, the understandability of the system can be guaranteed by balancing between system automation and therapist' (i.e. user) control. Even meeting the requirements of ambient computing, the tiles have to preserve the *understandability* and support the users to maintain control on the technology.

Flexible ad-hoc networks support the connections among single devices where each tile preserves its own identity thus dynamically seeking for available tiles in the vicinity. The tiles continuously inspect what communication processes are taking place at the moment looking for specific connection on all its sides. When one tile starts to fail the communication the sequence is still guaranteed by the other tiles. Standing the persistence of their identity, the tiles dynamically recognize the available ones to maintain the pattern. The therapists can thus manage the activities even in situation of system *graceful degradation*.

The Active Surfaces also enables the exploration of the relation between *change/stability* in configuring the tiles. In fact the assembly's behaviors are instantiated in physical configurations that can be saved, reused (also in part) and instantiated in different physical patterns.

The construction and configuration of the different tiles and how they relate to each other is done through *physical programming or programming by example*. It is the physical programming that allows the therapists to work with the tiles, creating advanced activities without actual programming or computer skills. In fact, programming by example can prove to simplify some very complicated programming tasks through the physical manipulation and the constraints (and affordances) a 'real' physical object provide through its interaction.

She can show the right pattern (sequence) to the system and record (save) the configuration by using the assembler tile. Being a flexible system it has to guarantee a proper level of *persistence* as well. The dynamics between configurations' change and stability may address the future practice of rehabilitation and the way in which the Active Surfaces could support it.

Evaluation of the concept

Active Surfaces concept have been put through a number of Wizard of Oz sessions and the feedback from these activities informed the iterative design process and the construction of the interactive prototypes.

The Wizard of Oz has been used as a design method in order to explore how people use ubiquitous computing and carry out complex interactions. In Wizard of Oz session the user can experience interaction with working system, even if the responses of the system are activated by the designers who play the role of the wizard. In these sessions we placed the tiles on the ground (or the bottom) and on the wall (or the edge) of the gym and of the pool. The tiles have been explored mainly as components to be used in physical assemblies.

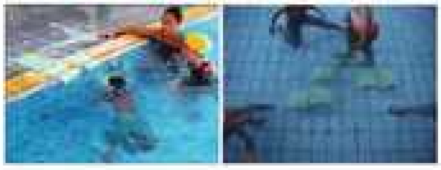

Figure 3. The Wizard of Oz sessions at the swimming pool

The children were engaged in a follow-the-path task in both horizontal and vertical configurations. The 'follow-the-path' task is based on guidance and feedback from the therapists. For the horizontal configurations we tried with surfaces on the bottom of the pool. Tiles were placed on a transparent surface through which they were fixed in the same positions. Patients have to follow a path made up of tiles coloured the same or following a shown model. During the Wizard of Oz sessions in the pool several wizards played auditory feedbacks from outside the water while other researchers, acting as therapists, supported patients in accomplishing the tasks.

We used low fidelity mock ups that embodied some (initial) physical features of the tool. In this way we assessed properties like weight, size, materials and possible uses.

End-user composition: concept scenarios

The Active surfaces concept was refined through an iterative scenario-based design process. Indeed scenarios were used in different phases of the design process since they are effective for structuring data gathered through activity analysis; for envisioning the system role and functionalities and finally to assess and validate envisioned solutions.

Along the different phases of the work analysis we used scenarios to evaluate, together with the stakeholders what we understood of their work, how the defined concepts could suit their needs and to show possible uses of the final tools. Scenarios themselves were used as design objects that have been evolved along the design process, being created, refined and also sometimes dismissed.

In the following part two concept scenarios will be presented to explain how the Active Surfaces enables end-user (therapist) composition. Indeed, the tiles act as building blocks and have different reactive behaviors in relation to the environmental changes including different input from the users. Each tile provides a visual, acoustic or tactile feedback, this in order to aid the patient accomplishing the tasks and to guide her during the interaction.

Designing a new game (programming, discovering and loading)

The therapist Laura decides to use Active Surfaces as a tool for spatial orientation acquisition and procedural memory skills with a patient with cognitive and physical delay. Through a simple interface Laura defines different activities or games by setting general rules . She configures interaction patterns defining when, along the therapeutic activity, different input and output should occur. The rules are now downloaded to the assembler-tile.

Laura combines some of the tiles in a specific pattern. She attaches the assembler tile to the sequence of tiles and they initiate the discovery of the available tiles exploring their relative position. The Assembler tile meanwhile passes the game rules into the different tiles. She now removes the Assembler tile and the game begins. At the same time, the constructed shape of the tiles and the rules used are saved into the assembler tile. Laura can now change the physical configuration of the tiles, thus changing the activity by simply re-arranging the tiles and re-attaching the assembler tile.

Re-using pre-defined game (saving, flexibility and versioning)

The therapist Alessia is now looking for one specific Active Surfaces configuration she designed a few weeks ago. She uses the UI to browse among the configurations previously saved and stored (via the Assembler tile).

She finds the desired game and plans to use just a part of the saved configuration, meaning reusing the same behaviour with a completely new physical combination. Alessia sets up the connections among the tiles' building the sequence. In that way she may experiment and try games through re-using pre-made behaviours in novel physical configurations. The rules (behaviours) have now

been instantiated in the new pattern assuming different meanings for the interaction.
The therapist now wants to save also the designed configuration for later uses, so that each step does not have to be created manually the next time. Configurations can be saved and reactivated later also by different therapists and for different therapeutic goals.

By means of scenarios and participatory design sessions the concept also has been revised and refined. The knowledge produced in these workshops with users has informed the next phase of the design process: the prototyping. In the meetings at the hospital we began to envision features of the application such as input and output systems, communication modalities and configurability. We addressed these issues trying to figure out the needs of the stakeholders asking for comments and suggestions at each iteration cycle.

Figure 4. Participatory workshop on input, output, configuration and communication support

During these sessions we decided to focus on floating tiles to proof the concept with the early prototyping. It seemed to be more promising for consolidating the composition dynamics and understanding how it could impact the work practice.

EMBEDDING ACTIVE SURFACES

Probing prototypes

We adopted a step-wise approach to transform our concept into early mock-ups and then into working prototypes. In this sense, traditional Participatory Design [3] and eXtreme Programming methods have been integrated in the development phase fostering a creative process with the stakeholders. A number of low-fi prototypes have been developed to verify the different assumptions, the potential design solutions and the integration with the swimming pool setting. This work has resulted in more mature prototypes that have been assessed by the stakeholders along the evaluation process. The users have been able to comment on functionality, look-and-feel as well as been able to use 'semi-working' prototypes in a way that is not allowed by the traditional Wizard of Oz approach. In reality, some of the prototypes turned out to be easier to develop then setting up the Wizard of Oz sessions.

Finally two more advanced prototypes where developed in parallel. The first had limited functionalities, but it was sufficiently working to be more easily adapted as new user requirements emerged. The second one was closer to a high-fi prototype built on the final target platform. The latter is now under development and meets the specific requirements regarding execution speed and flexibility that is needed in the final system.

PoolSim software prototype

In order to explore more deeply the outcomes emerged from the Wizard of Oz sessions we developed a Java application (PoolSim) as a horizontal prototype in order to test some basic behaviors of the Active Surfaces.

PoolSim shows basic behaviors like location awareness, colour and size recognition and more advanced features of the concept like graceful degradation as well as dynamic communication among the tiles (Figure 5). PoolSim was a tool used to try out our design ideas on the screen, to get a feeling of how the tiles could work, both simulating new games and also testing different communication strategies. It has been particularly effective the simulation of the inspectability while the degradation of some components. It has shown the peculiarity of Active Surfaces in respect to other tiles modular technologies (i.e. Z-Tile, u-Texture and Playware).

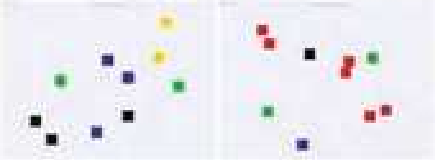

Figure 5. Screenshots from the Java PoolSim application

We used the PoolSim application in brainstorming sessions with the therapists at the hospital and at the public swimming pool. Examples of therapeutic activities were defined and were submitted to a refinement process.

Working prototype – Simple Model

The feedback from all the previous design made us develop the first actual 'tile' prototype (see figure 7). The development was based on the Basic Stamp 2 micro controller. Due to the constrains in the processor power and functionality, we limited this tile-prototype to communicate on two of its six sides. A simple communication protocol has been implemented so that the tiles can communicate and understand when they are placed in a correct sequence. When correctly located in relation to the other tiles, a light feedback is provided. This through a number of PowerLeds connected to the micro controller.

The outcomes of the trials with the prototype in the swimming pool indicate that the physical features of the surfaces are strictly dependant by the context of use. At this point we started to investigate the different materials that could be used for the casing, assessing how they worked in water, how the patients and the therapists in the pool perceive them and how they could reinforce the different rehabilitation activities.

The case needs to be fully watertight but still fairly easy to open, to access batteries for recharging as well as reprogramming the micro controller and to allow for changes that emerged during the trials. We also tried out different communication possibilities, experimenting which different technologies would be suitable to use within a swimming pool, both on the water surface as well as on the bottom. We learned that Infrared communication (IR) could fit our needs.

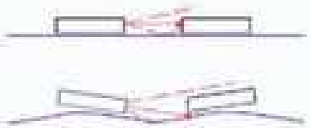

Figure 6. IR communications on the water waves

The IR also turned out to work well even while there are small waves on the surface, this since the IR emitted light (for the transmitter we up to now have been using) is spreading quite widely and due to water reflection. This is illustrated in figure 6.

The different envisioned activities seem to be based upon two different communication needs; the direct physical contact between the tiles and ~70 cm distance communication (above water). These seem to cover the needs of the end users involved in the rehabilitation activity. For the case colored materials should be used instead of transparent ones in order to provide users with consistent input for the activity. Transparent or blue surfaces may mislead the perception of the users being too similar to the edges of the pool or appear 'hard to detect' due to the reflections in the water.

Figure 7. Simple working prototype under construction and final result

One important requirement indicated by the therapist is that the patients should be able to both take two tiles at the same time by opening their arms and to physically snap the devices in order to fix them in a pattern. While correctly connected, the tiles can give visual feedback through red lights easily perceivable in the swimming pool. The prototyped tiles are characterized by the opportunity to apply layers on the top where different surfaces and materials can be attached as input for the activities, e.g. different surfaces can provide different tactile experiences to the users or parts of images can be composed to render the complete picture.

Activity Scenarios and early testing

The prototype we developed has been used for early exploratory tests with the targeted end-users, both the therapists and the patients during the current rehabilitation sessions in the swimming pool. The main activities we designed are based on the creation of sequences by just using three tiles. The activities were envisioned in the participatory design session with therapists and trainers relying on their current practice and on the expected potentials of the Active Surfaces. The exemplar activity scenarios presented below describe the game performed in the pool with different patients. The tasks have been tailored on the specific needs of the disable people. In fact we involved in the activity children with visual and physical impairments and or patients affected by Down syndrome.

Scenario 1: Image composition task

The therapist is designing an activity based on image composition (Figure 8). Each tile has a surface attached on top of it that is (re) movable in order to set different games. In this task each of the three surfaces has a part of the images that the children have to compose. The composition consists of placing the tile in the right sequence. The images to be composed are a circle and a star.

Figure 8. Image composition activities utilizing the Active Surface prototype

The parts of the images offer the affordances for the patients to accomplish the task. The side area of the surface shows the half of a complete image or symbol. Furthermore, a visual feedback occurs step by step, each time the tile is positioned in the correct order. This was designed in order to provide a progressive and coherent feedback during the creation of the sequence.

Scenario 2: Texture based task

The therapist is using Active Surfaces in order to design a rehabilitation game based on tactile experience (Figure 9). This activity is mainly thought for visually impaired patients. The therapist wants to stimulate the different sensory channels both providing specific inputs and appropriate feedback, such as vibration.

Figure 9. Tactile exploration

Thus she attaches three different surfaces made of woods of different dimensions on the top of the tiles. Using woods with different sizes, the textures provide the patients with diverse tactile perceptions. The goal of the activity is to create the sequence from rough to smooth. When the right tile is appropriately placed in the sequence, it vibrates to provide the patients with positive feedback.

State-of-art

During this exploration phase of the first prototype, we learned and defined the requirements for the final prototype developed by the University of Aarhus within the PalCom project. Each tile has to suit technical requirements such as response time and communication robustness and the need to run a framework that supports the features of palpable computing. The PalVM [11] is the language neutral virtual machine developed within the PalCom project in order to support object-oriented languages.

PalVM provides an execution platform for components to be embedded in physical devices and run in microprocessors as it is in Active Surfaces. Core PalCom functionalities such as communication, discovery, dynamic assembly, inspection and recovering degradation are implemented as components running on the virtual machine.

Each tile will embed the functionality as follows:

- It acts as an autonomous component, while being aware of its surroundings.
- During the activity the therapist can change the behavior of one or many tiles, responding to new therapeutic needs.
- A number of tiles can be assembled to create new or altered activities, also during the actual rehabilitation activity utilizing physical programming.
- The assembly can be physical and/or functional, allowing for different games and activities.
- If a tile starts to failure, it will communicate its new state to the others in order to allow system recovery. In this way graceful degradation shall be initiated allowing a continued rehabilitation activity.
- Although the tiles lack an active display, each tile can be equipped with an image or symbol that is attached directly to the top of the tile. In each direction, alongside the top borders, there will be rows of light emitting diodes to signal system and game states.

DISCUSSION

Our concept of Active Surfaces elaborates on a new challenging view of the rehabilitation practice. The concept addresses scenarios of fundamental lack of support for the therapists in treating disabilities. The Active Surfaces aims at offering opportunities for the therapists to appropriate their work practice by developing and building knowledge and creativity.

The scenarios we developed are based on the idea of end-user composition, configurability and control. In particular, users appreciate the idea of being supported by ready-at-hand technology, programming by example and system resilience. The Active Surfaces provides them with the possibility to improve the day by day rehabilitation practice.

The concept elaborates on a new challenging view of construction complemented with deconstruction of physical assembly. The therapist is asked to manipulate and physically configure the tiles while the dynamic and self-configuring discovering of components occurs. Re-configuring the system takes place at two different levels: the possibility to design specific activities; the possibility to re-arrange to available resources when there is a failure of the system. Thus, Active Surfaces makes the inner state of the system transparent providing a novel concept of user control.

The therapist can adapt the technology pursuing extreme changing and flexibility beyond system stability. In that way there are situations where total control is desirable, but it has always to be complemented with sense making and meaning attribution of events.

ACKNOWLEDGEMENTS

Thanks to Laura Cardosi, Maria Grazia Burroni and the therapists at the Functional Rehabilitation Unit of the "Le Scotte" hospital, Siena, for their open-minded collaboration and continuous support during fieldwork and participatory design. The research was part of the EC IST PalCom project.

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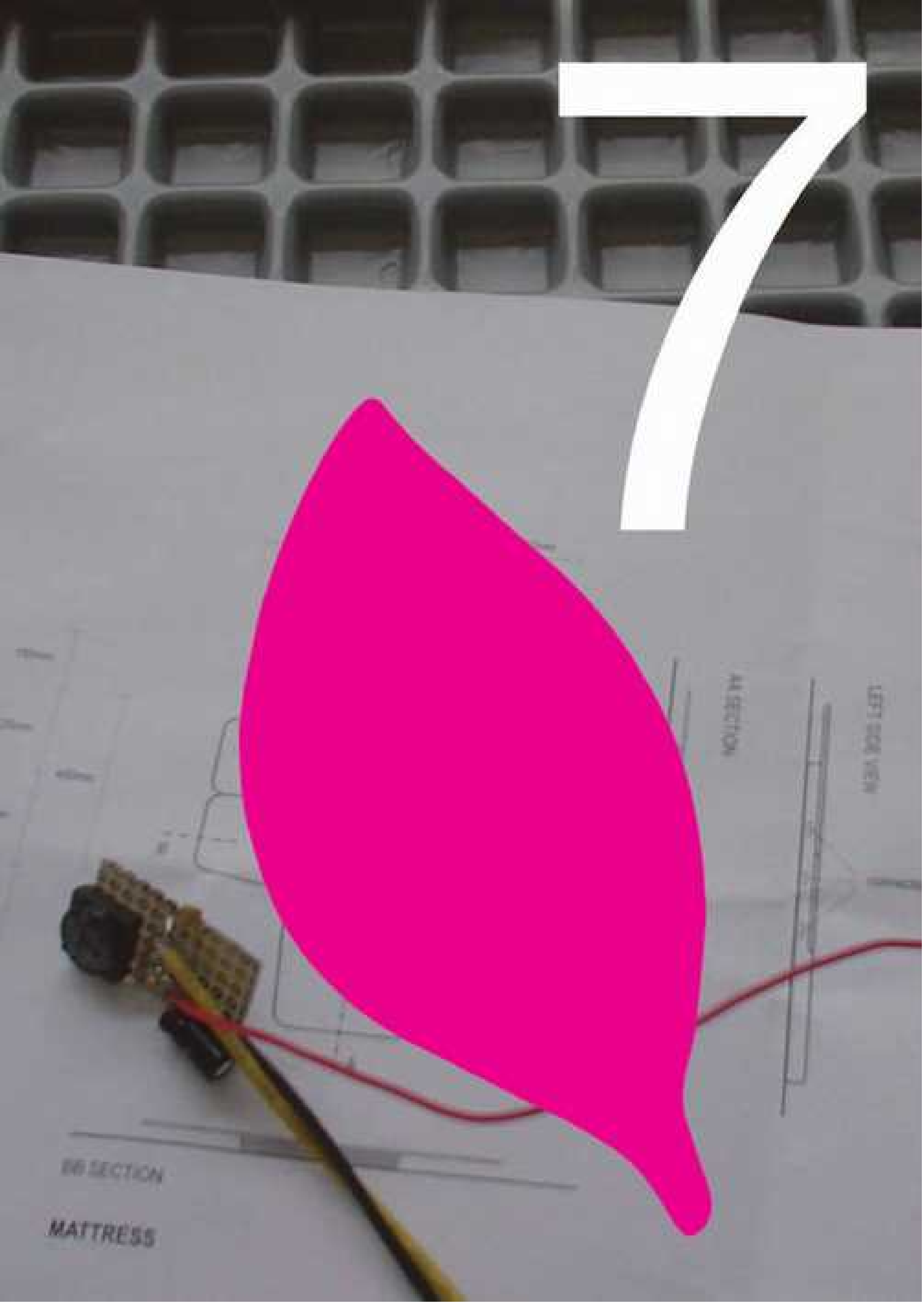

DESIGN CASE 3:
Premature baby care

7.1 The domain context

The incubator is the main stage in care of premature babies, as it aims to recreate some of the conditions of the mother's womb. However the incubator often appears to be an incomprehensible and frightening machine which is intimidating and emotionally overwhelming to parents. Alarms, wires, tubes and complex displays contribute to increasing the sense of discomfort and make it difficult to appreciate any improvement in the baby's health.

The infant should be as close as possible to the mother, but at the same time s/he cannot survive outside the incubator.

There is a need for physical contact and intimate exchange (smell, talking, mutual recognition, development of intimate codes of communication), but the incubator prevents all this. The baby in the incubator is isolated from the external world and thus isolated from a world of feelings.

7.2 The research context

The prototypes for non intrusive monitoring of premature babies were developed in the context of the EU co-funded project PALCOM (http://www.ist-palcom.org/) "Palpable Computing" - A new perspective on Ambient Computing" IST-FP6-IP 002057. All details about the research context are provided in paragraph 6.2.

7.3 Inspiration

Numerous studies have shown that premature babies are more metabolically stable and breathe better when they benefit from close contact with their mother. In particular, skin to skin experience provides the baby with more normal temperature, heart rate and respiratory rate (Ludington, 2005), increased weight gain (Charpak et al., 2005), fewer infections and reduced incidence of respiratory tract disease.

Kangaroo care was a main source of inspiration for the design of technology enhanced system for premature baby care. It consists in holding the baby upright against the mother's bare chest for an hour a day or longer. This practice is not only beneficial for the baby but has the undoubted advantage for the parents to feel close to their baby and establish earlier bonding.

7.4 Focus on aesthetic and embodied interaction: intimacy, fragility, (in)visibility

Intimacy

Nurturing physical contact can support the infant's emotional and psychological state and restore the mother-infant bond. The incubator should not be considered only a working place for the medical staff but also an environment supporting intimate contact between the parents and the child (for instance, making it possible to have a direct contact similar to that of Kangaroo care) and providing a context for emotional bonding.

Fragility

The neonatal intensive care is a delicate and highly specialised activity dealing with a systemic fragility which includes deriving frequent monitoring measurements from fragile babies; repositioning them within the incubator while trying to minimise very painful and potentially injurious interventions; supporting the relationships between the premature babies, their family and their carers; and reconciling parents' needs for information, communication and reassurance with psychological pressures on medical staff.

(In)visibility

The incubator often appears to be an incomprehensible and frightening machine which is intimidating and emotionally overwhelming to parents. The parents' perception of the premature baby's condition should be enhanced by making the baby's wellbeing more visible and helping parents make sense of the situation.

7.5 Prototypes

The premature baby care project developed two prototypes addressing mainly the need of intimacy and closeness between mother and child and unobtrusive monitoring. The first prototype was conceived as a leaf, a soft and protective environment composed of a foldable and sensitised mat that gently embraces the baby. In the final system the concept took the form of a soft mattress to be used inside or outside the incubator (Fig. 9 a). The second prototype called Bio-belt (Fig. 9 b) is a sensitised band developed as a system of sensors inserted in the textile fibre that can be configured in combination with the parameters detected by the other machinery in the NICU, according to the baby's specific monitoring needs. It is used as a means for unobtrusive monitoring.

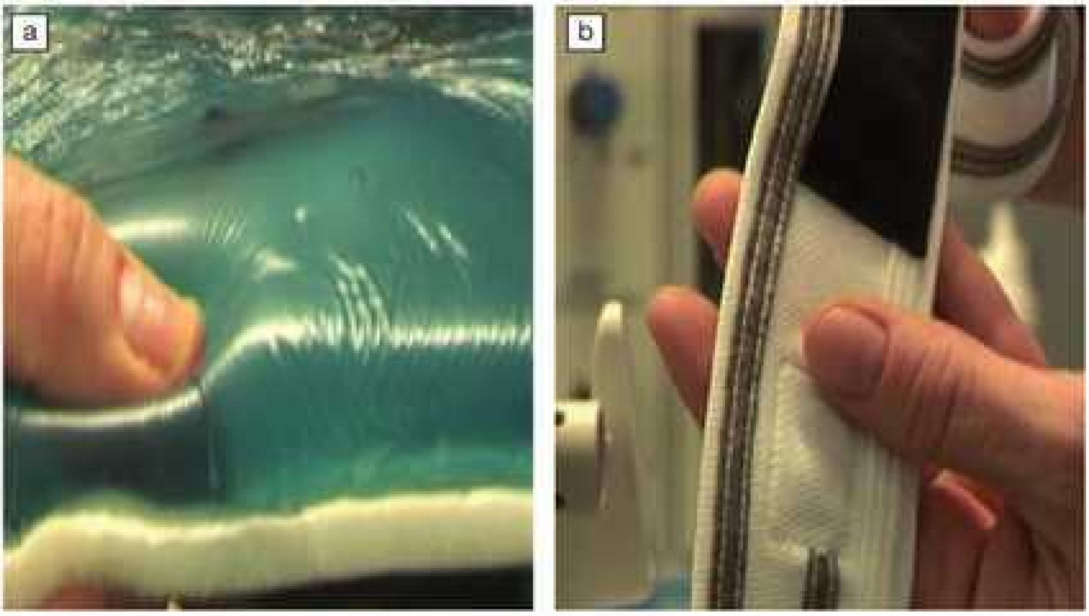

Figure 9 - Mattress (a), Bio-belt (b)

7.6 Testing

The incubator system composed of the sensitised mattress and the Bio-belt was tested using different strategies.

A qualitative assessment was carried out involving the medical personnel in role-playing sessions with mock-ups and simulated versions of the system. Parents were interviewed in the hospital.

The Bio-belt was tested with pre-clinical trials on a group of four children from 2 to 12 months who were close to being dismissed from the Neonatal Intensive Care Unit (NICU) of 'Le Scotte' Hospital in Siena.

Full details about the experimental design, methodology for data collection and the obtained outcomes are contained in Paper 6.

Video 3 "New scenarios for neonatal care" describes the research context and the prototype in use at the "Le Scotte" hospital in Siena.

Design Case 3: Paper

Paper 6

Marti, P. "Experiencing the unexpected". In Wei Chen, Sidarto Bambang Oetomo, Loe Feijs (eds) *Neonatal Monitoring Technologies: Design for Integrated Solutions*, IGI Global, 2011. (in press)

Video 3: New scenarios for neonatal care
www.vimeo.com/patriziamarti/neonatalcare

Experiencing the unexpected:
human-centred design in neonatal intensive care

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ABSTRACT

This chapter discusses a fundamental concern deriving from the need to increase the focus on the social, emotional and intimate aspects in the design of healthcare technologies. The development of such technologies is in fact often afflicted by conflicting perspectives. While technical perspectives demand rational methods, social perspectives ask for non-rationalistic, phenomenology inspired approaches (Jacucci, 2007). The issue is addressed from the standpoint of a particular socio-technical setting, the Neonatal Intensive Care Unit. In particular, the chapter describes the human-centred and participatory design process, from problem analysis to concept generation, prototype development and testing of a new incubator system employing different technologies. All these technologies aim to provide unobtrusive monitoring, improving the baby's comfort as well as parent-child bonding by lowering the emotional barrier created by the current incubator setup.

The specificity and the delicateness of the NICU setting offers an opportunity to reflect on how different stakeholders perceive, interpret and take part in the premature baby's care, and on the role that design can play in envisaging technologies that respect and harmonise different views and needs making the unlucky event of a premature birth a more sustainable experience.

INTRODUCTION

The progress that has been made in treatment of neonatal pathologies has significantly increased the life expectancy of children born prematurely (Costeloe et al., 2000).

However, while premature babies' chances of survival continue to increase, it is still difficult to reduce the sense of discomfort associated with a birth with complications.

In the event of a premature birth, the parents' expectations in relation to their child's birth and early childhood are completely overturned by a new, unforeseen situation. Just as the child is unprepared to cope with the environment outside the uterus, the parents are unprepared for their role in this situation.

A feeling of inadequacy pervades the parents, who feel unable to deal with the event and take care of their child. They are experiencing an unexpected event in which they seldom receive all the support they need.

The incubator often appears to be an incomprehensible and frightening machine which is intimidating and emotionally overwhelming to parents.

Alarms, wires, tubes and complex displays contribute to increasing the sense of discomfort and make it difficult to appreciate any improvement in the baby's health.

Many different players take part in the care of premature newborns from the moment of delivery. Medical staff members take care of the babies, attempting to fulfil all their needs and dealing with any possible problems or complications.

They may share the same workspace, but they do not share the same work: different actors have their own specific competencies, their own tasks and their own schedule for performing their duties. Parents try to get involved, but they are easily confused due to the stressful situation and their lack of knowledge about what is going on.

Development of technologies for the Neonatal Intensive Care Unit (NICU) therefore requires accurate interpretation of different viewpoints, roles and expectations, so that the necessities of the child, the medical personnel and the family can co-exist in a sustainable way.

THE INCUBATOR: THE TENSION BETWEEN PROTECTION AND BARRIER

The incubator is the main stage in care, as it aims to recreate some of the conditions of the mother's womb, providing the baby with an optimal growing environment with the right amount of heat, humidity and oxygen.

Most medical treatments are administered directly in the incubator to reduce the risk of complications due to outside elements.

The environmental qualities in the incubator are tightly controlled. For example, air temperature may be set to a specific value or automatically adjusted if the temperature of the baby's skin drops and needs to get warmer.

The NICU is a socio-technical system composed of other additional machinery and different stakeholders, including the parents, who have different access to the incubator and different requirements depending on their role.

The working practice of the neonatal team is based on the continuous combination and integration of data generated by different sources.

Various monitors are placed around the incubator and display the heartbeat and rate of breathing, blood pressure and oxygen level in the blood. Other parameters may also be displayed, depending on the baby's condition. For example, diagnostic tools permit data integration across the hospital, showing the baby's x-rays, laboratory results and other information at the bedside that might help clinicians speed up the decision-making process.

Most monitors are equipped with alarms to keep medical staff aware of any changes in the baby's condition; unfortunately, jarring warnings often alarm the parents, who need to figure out what is going on, and disturb the baby.

The infusion pump administers intravenous medications and fluids. Since the premature baby is sensitive to small changes and therefore precise dosing is fundamental, the pumps are fitted with safety features and alarms to control the dosages. This contributes to the machine's frightening appearance.

The ventilator administers oxygen to assist the underdeveloped baby's lungs until they mature to the point where the baby can breathe alone. Use of this machine is one of the causes of the baby's separation from its parents, creating an emotional barrier against holding the baby.

Other machines may be present around the incubator, such as a phototherapy system which shines a warm blue light over the baby and helps break down extra bilirubin, an open-care warmer to optimise the infant's temperature as s/he grows stronger and spends time developing outside the close-care incubator, or an x-ray machine.

This environment affects the way in which the different stakeholders make sense of daily care, and the way in which the continuous process of understanding is supported and maintained.

Making sense is fundamental for medical staff to intervene promptly in the care process, but also for families, in order to be able to psychologically sustain such a delicate situation and play an active role in their child's care, offering their presence and emotional support.

The infant should be as close as possible to the mother, but at the same time it cannot survive outside the incubator.

The incubator mediates all the relations between the child and the caregivers.

Its accessibility is different for the different players involved (Grönvall et al. 2005): the medical staff uses the incubator as the main stage for their work, whilst for the parents it represents a barrier. The need to protect the baby from the external environment separates the child from the outside world, impairing the fundamental mother-child relationship.

The mother-child contact is mainly visual. The mother can touch her baby inserting her hand through the holes in the incubator. But there can be no other exchange between them, such as exchanges of smells or sounds.

The baby is suddenly separated from the mother upon delivery, and the separation continues until the baby's condition is stable.

In practice, the baby is left alone when he or she most needs parental care.

There is clearly a need for physical contact and intimate exchange (smell, talking, mutual recognition, development of intimate codes of communication), but the incubator prevents all this. The baby in the incubator is isolated from the external world and thus isolated from a world of feelings.

The physical separation of the incubator space from the external environment reflects a conceptual separation (of values, priorities, accessibility, adaptation) among the actors in the community.

The baby's condition is not immediately understandable just by looking at the surrounding machinery.

Even small changes and fortunate improvements in health are not understandable by non-professionals such as parents.

INTIMACY, CLOSENESS AND MAKING SENSE

Numerous studies have shown that even premature babies are more metabolically stable and breathe better when they benefit from close contact with their mother.

In particular, skin to skin experience provides the baby with more normal temperature, heart rate and respiratory rate (Ludington, 2005), increased weight gain (Charpak et al., 2005), fewer infections and reduced incidence of respiratory tract disease. Furthermore, nurturing physical contact has been proven to aid the infant's emotional and psychological state and to restore the mother-infant bond following the sudden separation during the birth experience, particularly in premature births (Kirsten, Bergman, & Hann, 2001).

Kangaroo care consists in holding the baby upright against the mother's bare chest for an hour a day or longer. This practice is not beneficial only for the baby but has the undoubted advantage for the parents to feel close to their baby and establish earlier bonding.

Kennel and Klaus (1998) conducted a pioneering experiment in bonding, giving mothers of both premature and healthy full-term babies extra contact with their infants. The outcome of their experiment showed that mothers with more access to their babies in the hospital developed a better rapport with their infants, held them more comfortably, and smiled and talked to them more often.

Unfortunately, direct or skin to skin contact is not always compatible with other measures and continuous monitoring is necessary to keep the baby healthy. If the baby has suffered serious complications such as respiratory distress from an early birth syndrome, its health must not be compromised and direct contact with parents is limited to touch and strokes through the holes at the sides of the incubator.

However, bonding and the formation of mutual emotional and psychological closeness between parents and their newborn child is not only prevented by the lack of intimate physical contact.

Mother and father may be put off by the amount and complexity of incubator equipment (Weiss, 2008). Visiting a baby in an incubator can be a very intimidating experience without preparation and support to interpret the setting and face the emotional impact of the child's health (Trause, Kramer, 1983).

In addition to intimacy and bonding, the visibility and understandability of the baby's health are key issues. Parents don't usually have an opportunity to meet the staff before admission to the NICU and don't actually know how critical the situation could be.

Parents concentrate their attention, hopes and expectations around the incubator, and inadequate information displayed by monitors or provided by the healthcare team during such periods of emotional disturbance can only add to the parents' anxiety and fears.

Mok and Leung (2006) reported that mothers of preterm infants desire more information and supportive communication. Most parents do not want an extensive and complex explanation. They just want to be informed and be able to ask questions, which make them feel included (Gordin and Johnson, 1999).

Several studies (Shields, Kristensson-Hallstrom, O'Callaghan (2003), Bass (1991) and Miles (1989)) have demonstrated that the environment at the NICU is experienced as extremely stressful for parents of preterm infants, and the technological environment is experienced as frightening even if it is necessary to give the infants the best possible care.

ADVANCES IN PREMATURE CHILD CARE

In the last decade, while progress in the treatment of neonatal pathologies has significantly increased the newborn survival rate (de Kleine et al., 2007), different programs and projects have begun to attempt to improve the quality of life in the NICU.

For example, rooming-in care is a method for the care of newborn infants in which the baby stays with the mother in the same room, the mother takes care of her baby by herself, and the nurses and doctors help her care for her baby in her room. The concept has been widely tested, and a number of different experiments (So Yoon et al. 2008) have shown that infants who stayed in their mother's room had significantly quieter sleep and cried less than infants who remained in the nursery. Furthermore, rooming-in care offers the added advantage of improving neonatal emotional stability, and also has positive effects on maternal attachment and the establishment of breastfeeding. However, the rooming-in method can only be applied to full-term newborn infants who are born via uncomplicated pregnancies and deliveries.

Other concepts/programs such as family-centred care (Kovacsa, 2008) and NIDCAP (Newborn Individualized Developmental Care and Assessment Program) (Westrup, 2005) have developed new practices and methodologies to evolve the NICU from its initial conception as an "isolated environment" to a "place for care".

Family-centred service proposes an approach that sees families as integral and coequal part of the healthcare team. This approach aims to improve the quality and safety of the child's care by helping to foster communication between families and healthcare professionals.

A similar approach is taken by NIDCAP, implementing the concept of the "care community" as a community of people who play different roles in the child's care, being egalitarian actors in the child's wellbeing. NIDCAP is a multidisciplinary process in which care includes parental care alongside medicine, nursing and psychological care.

In both concepts, parents are called upon to play an active role, and the child is removed from the incubator as much as possible and entrusted to parental care. This practice has an obvious organisational impact on the life of the community, with results that have not yet been fully accepted throughout the medical community. However, in both these programs, the incubator remains a physical barrier to the day-by-day life of the care community, and the technology connected with the incubator is designed to support the biological development of the child but continues to ignore the psychological, emotional and social dimensions of the community.

The isolation created by the incubator not only protects the child and keeps the environment healthy for the child, but also shelters the child from positive interactions.

Other projects have tried to develop technologies allowing non-invasive monitoring of vital physiological functions outside the incubator as well, as a means of improving the baby's comfort and wellbeing.

Chen et al (2010) developed the Neonatal Smart Jacket, a wearable unobtrusive continuous monitoring system suitable for monitoring neonates inside the incubator and outside the incubator during Kangaroo mother care. The tests performed so far on the quality of the ECG signals obtained by textile electrodes inserted in the Smart Jacket are reliable and comparable to those obtained by traditional monitoring techniques.

RETHINKING THE INCUBATOR

An innovative concept of digital technologies for the NICU is presented below. Besides technological exploration, development and testing, an innovative aspect of the research is the human-centred approach adopted in engineering digital technologies to support the needs of very premature babies, and the whole care community composed of their parents and other family members as well as the various members of medical staff caring for them.

The research was conducted at the NICU in "Le Scotte" hospital in Siena (Italy), in the context of the European research project Palcom, Palpable Computing (www.ist-palcom.org).

Palpable computing is a vision of Ubiquitous Computing that purposely addresses the ways in which humans meaningfully interact with the distributed computational systems that are available in the environment. The project developed a vision of UbiComp technologies as used, controlled, created and envisioned by ordinary people with different needs, offering a middleware runtime infrastructure to concretely implement this vision.

The middleware runtime infrastructure was used to develop different application prototypes demonstrating the potential of the approach. Among the prototypes available from the project, a new concept of incubator has been developed with the main aim of making preterm birth a more sustainable experience for the baby and the caregivers, promoting the active involvement of parents and the medical staff in the care of the newborn.

Human-centred design: approach and methods

A participatory design approach (Greenbaum and Kyng 1991) was adopted throughout the project and development of the design focus was part of the research, not specified beforehand. A multidisciplinary design team was set up including IT and design researchers (computer scientists, architects, engineers, interaction designers, industrial designers, sociologists, ethnographers) as well as neonatal doctors, nurses and parents.

Field studies have been performed as part of the participatory design process, including technology and literature reviews; participant observation with users, definition of the challenges, design principles and visions to be addressed, definition of scenarios to describe the visions; and development of physical mock-ups and IT-based prototypes to materialise the solutions and try them out together with the stakeholders.

Besides gaining a better understanding of the domain, fieldwork provided the design team with a common pool of material which served as a resource in discussion of problems, challenges and vision development. Furthermore, the professionals gained a better understanding of their own work. This was extremely useful to stimulate them to formulate and take actions regarding both possible organizational and social improvements and technical developments.

A set of methods was defined to favour full participation of all members of the design team. These methods included:

Data sessions: Interdisciplinary review of ethnographic data, selection and analysis of significant pieces of data.

User Workshops: workshops organised to develop and evaluate a joint understanding of the work, the potential impact of sociotechnical innovations, activity models, scenarios and prototypes for future users and researchers through discussions, focus groups, experiments.

Fieldstorms (Büscher et al. 2003): Brainstorming sessions grounded in analysis of ethnographic data and experience, where ideas were documented as sketches, video prototypes, animations and mock-ups.

Travelling Architects: A group of architects took turns in travelling to the different partners' organisations (users and developers). They participated in some fieldwork, participatory design and evaluation activities and played a key role in connecting problems in use with technological solutions and application prototypes.

Reflections corner: A whiteboard was located in the NICU to collect data, document the activity, capture ideas in situ using post-its and photographs, collect probes and "vote" for ideas.

Diary probe: A shared diary was designed to document best practices, activity breakdowns, problems encountered and not solved, and ideas for improving the activity. A disposable camera was made available in the ward to take pictures of places, tools or situations, to exemplify what was reported in the diary. An 'object collector' (a large envelope) was used to collect small objects or tools representing meaningful events or situations. The diary was designed to be used collectively and anonymously by all the actors in the NICU.

The participatory design sessions helped us to define the focus of the project and articulate the following set of requirements:

Intimacy and closeness

The incubator should not be considered only a working place for the medical staff but also an environment supporting intimate contact between the parents and the child (for instance, making it possible to have a direct contact similar to that of Kangaroo care) and providing a context for emotional bonding.

Source: medical staff, parents

Empowerment

Parents must be encouraged and empowered to care for and form an attachment with their new baby. This

not only boosts parents' confidence in handling their babies whilst in hospital but increases their competence when the baby is discharged.

Source: medical staff, parents

Unobtrusive monitoring

Adhesive sensors applied to the fragile skin of the baby may be harmful. Replacement of the sensors causes skin irritation and the large number of wires contributes to engendering a sense of discomfort in the parents. Ad hoc network of sensors could be used for unobtrusive and continuous monitoring through portable devices. This solution can suit many different situations such as the initial intervention on the baby just after the delivery, transportation from the delivery room to the NICU and the daily care.

Source: medical staff

Information visibility and understandability

The parents' perception of the premature baby's condition should be enhanced by making the baby's wellbeing more visible and helping parents make sense of the situation.

Source: parents

Remote monitoring

The possibility of remotely monitoring the child in the incubator using a video streaming source is required by the medical personnel as well as by the parents.

Source: medical staff, parents

Handling the baby

The baby should be handled with extreme care and unnecessary manipulation should be avoided.

One of the reasons why the baby is manipulated is to change the body position in order to avoid pressure sores. In order to move the baby only when strictly required, the medical personnel deemed it very useful to have a trace of the pressure points of the baby's body on the mattress, in order to prevent loading on high risk areas and avoid pressure sores.

Source: medical staff.

Detailed requirements related to the incubator

Incubator opening system

Performing treatments on babies (such as intubation and placing of sensors) now requires the incubator to be opened. This dramatically affects the environmental conditions (especially temperature) inside the incubator. It should be possible to preserve the temperature of the baby's body even during intervention by medical staff.

Source: medical staff

Temperature control inside the incubator

The child should be kept in a temperature-controlled environment as much as possible. The temperature should be set and maintained by staff during all kinds of interventions. The incubator is currently opened during some interventions, directly changing the controlled environmental qualities in the incubator.

Source: medical staff, parents

Acoustic pollution

The NICU environment is noisy and there is a desire to prevent the noise from reaching the newborn. Some acoustic pollution is also present inside the incubator. Most modern incubators generate noises (e.g. generated by the internal engine) that disturb the child and may be potentially harmful. The new incubator should protect the child and sensibly reduce or eliminate such noises.

Source: medical staff, parents

Light control

A premature newborn child is very light sensitive. The amount of light inside the incubator should therefore be controlled and constant, not dependent on external light sources.

Source: medical staff

The bed

The mattress on which the baby lies is currently made of a hard plastic material and is not adaptable to the baby's body. A soft, flexible mattress is required to support medical intervention and preserve the child's comfort. The mattress should be considered as a delicate layer which embraces the child, sustains the baby's body and promotes direct contact with the parents. It should also help keep the infant's body in place, reducing the need for external manipulation

Source: medical staff, parents

INSPIRATION FOR CONCEPT DESIGN

Two design cycles were generated from the initial set of requirements. The first cycle focused on the physical model of a new incubator conceived as an autonomous system that doesn't need to be connected to other external devices (Rullo et al., 2006). The various units needed for the treatment of the premature newborn are plugged into a rack on the back on the incubator (Figure 1). A system of different modules contains the different machines used for treatment. The premature newborn is placed in the incubator immediately after the delivery. The incubator's dome is removable and its circular shape makes it possible to access the incubator from different sides (Figure 1). Inside the incubator, a mattress with embedded pressure sensors detects pressure points on the baby's body. In order to avoid pressure sores, the medical staff can change the position of the baby without opening the incubator. This manipulation is made possible by a system of moving pins. Each element can be moved up and down manually or tele-operated.

A bio-monitoring system is integrated in the incubator to detect biomedical signals from premature newborns by use of wireless bio-monitors (Kristensen et al., 2005).

Figure 1: The incubator prototype model, the mattress embedding the moving pins, a map showing pressure points.

A physical model of the incubator has been developed in collaboration with the Aarhus School of Architecture, a partner in the Palcom project, and submitted to users' assessment in order to evaluate and refine the concept. An important criticism was raised since the prototype still embodies a traditional concept of incubator which does not promote any kind of direct contact between the child and the parents. This was a major requirement of the families as well as the medical staff.

For this reason a second cycle of concept generation was started to which more closely addresses the requirements of intimacy, closeness and sense-making raised by the stakeholders.

The design concentrated in particular on the definition of three concepts of an innovative incubator mattress: The leaf, the water lily and the baby bag (Figure 2).

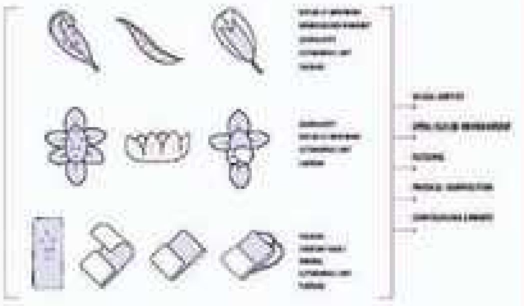


Figure 2: Different concepts of an incubator mattress

The Leaf and the Water Lily concepts are inspired by nature as the main metaphor.

The Leaf offers a soft and protective environment composed of a foldable and sensitised mat that gently embraces the baby.

The Water Lily supports a dynamic process of discovery and awareness for the parents. The petals may gradually reveal the infant to the parents as they become more and more aware of the situation. This feature directly addresses the need to help the parents to psychologically process and gradually understand a situation they were unprepared to cope with.

The baby bag design is inspired by objects used every day to hold and carry the baby. The design is minimal and emphasizes portability.

All concepts drive the construction of a comfortable, safe and manageable environment adapted to the needs of preterm born infants, medical staff and parents.

More in detail, the Leaf concept (Figure 3) presents the following features. Thanks to use of a special material it offers thermoregulation of the baby, postural stabilization, adaptive shape as needs change, transportability, and light filtering.

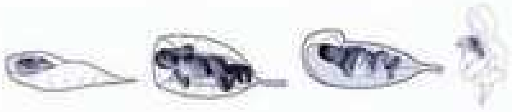


Figure 3: The Leaf concept

A number of pressure sensors are placed inside the matt to detect and communicate pressure on each unique point on the mattress surface (Figure 4 left). The mattress can be reconfigured on the basis of the data detected by the sensors to prevent postural problems and pressure sores.

The outer surface of the leaf contains LEDs connected to the pressure sensors placed on the inner surface. Depending on the intensity of the pressure, the LEDs change their intensity to show that the baby has been lying in the same position for a while and need to be moved to prevent postural problems and pressure sores.

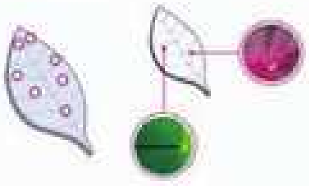


Figure 4: Left: Pressure and temperature sensors placed in the inner part of the leaf (mat). Right: the outer part of the mat with LEDs connected to pressure sensors

In order to improve the continuous monitoring of all the baby's vital parameters, the concept of the Bio-belt may be associated with the Leaf. The Bio-belt is a sensitised band of textile fibre with embedded sensors and transducers which is placed around the baby's abdomen to monitor heart rate, breathing, body movements and temperature. The combination of the Leaf and the Bio-belt ensures redundant collection of data and therefore continuous and accurate monitoring.

PROTOTYPING CONCEPTS

The Leaf and the Bio-belt have been consolidated in form of working prototypes to be tested in the NICU.

The Leaf prototype

The Leaf took the form of a soft mattress to be used inside or outside the incubator. It was developed as a mat made with a gel structure and equipped with body pressure and temperature sensors to allow measurement and monitoring of the baby's pressure, temperature, respiration (indirect measurement from the rhythmical variation in pressure over time) and physical movements.

A specific material was selected for implementation of the prototype (Figure 5).

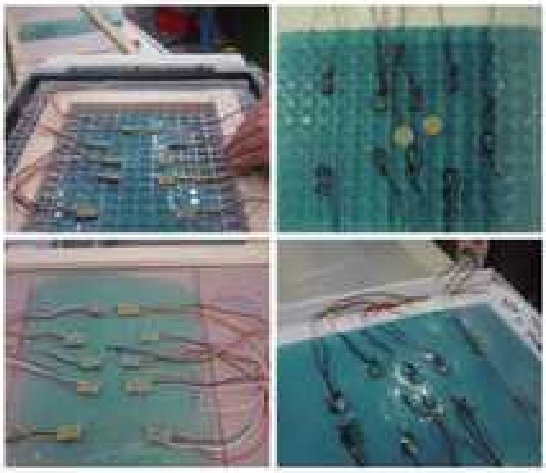


Figure 5: The gel structure of the mat containing pressure and temperature sensors

The Mattress prototype is made out of polyurethane gel with embedded sensors intended for recording temperature, movements and interface pressures at specific anatomical points. The gel has anti-decubitus properties, as it distributes interface pressures over a wider surface than standard foams and displays isotropic behaviour, relieving contact points on the body.

This material is called Technogel® (www.technogel.it) and presents the following characteristics:

- when pressed by the body, Technogel moulds itself to the individual's shape by deforming along the three axes (up-down, right-left, forward and backward)
- It is free of plasticising agents and other volatile agents
- It retains its elastic mechanical properties for a considerable time
- Its polyurethane base is completely non-toxic
- It can be injected into moulds like foam, permitting a large amount of freedom
- It does not expand and remains compact
- Long life and stability without plastic deformation
- Maximum pressure distribution capacity and excellent weight distribution
- Great ability to absorb shocks and vibrations

The gel also has a high thermal inertia and thus favours maintenance of body temperature. The pressure and temperature sensors can be embedded in a distribution matrix so that they cover the entire area under the body. These permit measurement and monitoring of pressure, temperature, respiration (indirect measurement from the rhythmical variation of pressure over time) and physical movements. The signals are collected through a dedicated DAQ and a UBS that is connected to and powered by a PC containing visualisation and settings software. If the PC is a notebook or a PDA, the newborn's portability is assured with continuous monitoring.

A matrix of pressure sensors is placed in a pattern inside the mattress which detects and communicates the pressure on each unique point on the mattress surface. The mattress reconfigures itself according to the data detected by the sensors to prevent postural problems and pressure sores. The mattress is also equipped with sensors to detect mattress temperature. This information can be combined with the value of the temperature sensor in the belt to dynamically adapt the baby's micro-climate.

The baby lying on the mattress can be held and embraced to allow a sort of Kangaroo therapy without renouncing constant monitoring of vital parameters.

The Bio-belt prototype

The Bio-belt is a sensitised band developed as a system of sensors inserted in the textile fibre that can be configured in combination with the parameters detected by the other machinery in the NICU, according to the baby's specific monitoring needs.

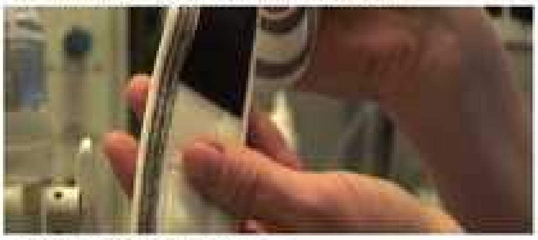


Figure 6. The Bio-belt prototype.

The Bio-belt was developed as an early prototype with embedded sensors and transducers for monitoring heart rate (HR), breathing rate (BR), body movements (BM) and temperature (T). The belt aims to facilitate continuous HR, BR, BM and T monitoring with proper signal acquisition and pre-processing systems, ensuring unobtrusive measurement of physiological parameters.

The Bio-belt is made of cotton (recommended for neonatal and pediatric use) and lycra (to reduce contact instability by better fitting of sensors to body). The belt is 65cm long and it is wrapped around the baby's chest with two ends gently set on the cot. The band measures 4 cm in height and can be adapted in relation to the baby's measurements; the fabric is soft, extremely thin and pleasant to touch and wear. Electrodes for ECG and sensors for measuring respiratory frequency are already a functioning part of the belt itself, while temperature and movement sensors are accommodated in special pockets, so that they do not enter into direct contact with the child.

The belt can be adapted to fit the size of the baby and adjusted in a non-invasive way to avoid direct contact of scratchy material with the baby's skin. The tips are squeezed together with a buckle until the band fits the newborn's chest size. It has a pocket for external transducers on the front, including an NTC thermistor (B57550G550, Epcos, Germany) for body temperature measurement and a linear accelerometer produced using Micro-Electro-Mechanical Systems (MEMS) technology (LIS3L06AL, STMicroelectronics, Italy) in order to sense movements of the thoracic wall as a result of newborn respiratory activity (Piccini et al, 2008).

Respiratory patterns in premature newborns include paradoxical breathing (out-of-phase movements between abdomen and thorax) often resulting from partial or complete obstruction of the upper airways. Therefore a system capable of displaying breathing activities in both the upper and lower chest areas gives deeper information about the respiratory system which goes beyond the breathing rate or central apnea events. Thanks to the Bluetooth transmission system, the Bio-belt can send wireless signals to a generic remote position, offering new possibilities for non-invasive monitoring of fundamental parameters for the child.

MAKING INFORMATION PORTABLE, VISIBLE AND UNDERSTANDABLE

In order to make the data detected by the Mattress and the Bio-belt more visible, portable and understandable for the medical staff and the parents, these devices can be connected together or to other devices used at the NICU with the goal of comparing parameters collected by different devices and obtaining more accurate monitoring as well as better data visualisation.

For this purpose, the Palcom project developed an Open Architecture that can run a variety of different devices, from microprocessors to biosensor monitors (IST-002057, P.P. PalCom Public Report).

The Open Architecture exploits the concept of "assembly" that is a fundamental mechanism for service coordination (Schultz, Corry and Lund, 2006; Ingstrup and Hansen, 2003).

A system that is constructed by means of assemblies can be inspected in a service browser, making its inner structure visible at a certain level. In fact, the assembly concept targets construction of systems from services that were not originally created for cooperation with each other. By inspecting the interfaces of a set of services, it is possible to construct an assembly that combines them.

Assemblies in Palcom are defined by assembly scripts that can be loaded at runtime by interacting with an assembly manager. When an assembly is loaded the assembly manager makes the appropriate connections and governs the flow of service invocations.

The assemblies may be thought of as physical and logical entities, consisting for instance of a webcam and an EEG sensor that the neonatologist can set up to study any correlation between the baby's movements and the development of the central nervous system and convulsions (Rullo et al., 2006).

The creation of assemblies implies that each part of the assembly is easy to understand on the logical level (what can be done with this, with what can it be combined and for what purpose), the functional level (how to use it) and on the physical level (it must be possible to see what fits together and to actually build/rebuild the structure).

Dynamic construction and deconstruction of assemblies entails that the available services are distributed and able to discover and interact with each other. The discovery process can in principle reside on any of the participating devices.

The assemblies can be constructed using the NICU browser, a graphical interface that allows doctors to construct loosely coupled assemblies of different devices present in the neonatal intensive care unit (Grönvall et al., 2008).

The NICU Browser allows the medical staff to discover what machinery is available at the NICU and the available services. This implies that the NICU browser also enables the neonatal team to discover, create and manage assemblies of services and devices (Svensson et al., 2005).

The specific user interface adapted to the specific needs of the NICU is designed to explore the assembly's features and combine the assembly elements according to the newborn's monitoring requirements.

For example, the neonatal doctor can compare the values of SpO2 (monitored by the pulse oximeter) with the child's diaphragmatic movements (monitored by the Bio-belt) in order to improve the monitoring of hypoxia/apnoea. This allows the neonatal doctor to investigate new correlations among the monitored values and experiment with novel uses of the existing devices.

Furthermore, neonatal doctors can create novel assemblies dedicated to the monitoring of other correlations. For instance, they can decide to explore novel uses for the information coming from the pressure sensors in the Mattress and the respiratory frequency values gathered by the Bio-belt.

Thus, they create a new assembly among the Mattress and the Bio-belt to have a more accurate monitoring of the baby's breathing function, when the newborn starts to breath autonomously. Indeed, the expansion of the chest involved in each respiratory act can also be registered by the pressure applied to the mattress surface when the infant breaths, and this information can offer safer monitoring of the child.

The NICU browser also supports mobile services. For example, the monitoring data can be shifted from the central incubator display to a Smartphone (Fig. 7).

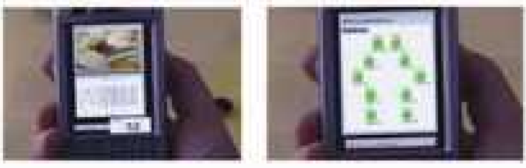


Figure 7: Monitoring the incubator through the Smartphone

This is achieved by easily adding the Smart phone as a new display device within the NICU Browser. In this way, the doctors can control the baby when they are away from the neonatal ward and promptly intervene, if necessary. They can share the data with their colleagues or with the parents, relying on new forms of visualisation of the data and information sources.

Some services of the NICU browser are available also to the parents who can receive some information on their own Smart phone and also see the baby through a webcam placed inside the incubator. The webcam is managed by the NICU browser and connected to the Smart phone as a new assembly of services and devices. The information delivered to the parents is adapted for them, making visible only the data that parents can understand to make sense of the baby's improvement.

This solution concretely demonstrates a vision of technology developed within the PalCom project that allows people to construct and control technologies and interpret their output in their everyday and working practices. This vision allows people to dynamically combine resources as prompted by immediate circumstance, take them apart and reconstruct them to explore their workings. A fundamental advantage of this approach is that technologies and their output and services are made visible and available for inspection, reconfiguration and interpretation, and the way in which the information is presented is adapted to the role that the different users play in the system in order to help them make sense of what is going on.

USER ASSESSMENT AND TESTING

The incubator system was assessed on the basis of different strategies.

A high level user assessment was adopted to evaluate the concepts, mainly involving the medical personnel in role-playing sessions with mock-ups and simulated versions of the system. This strategy was adopted to preserve the safety standard of the NICU and to avoid overstressing or disturbing the daily routine of the ward.

The assessment combined the principles of the User-Centered Design (UDC) and Scenario-Based Design processes. The user involvement was not simply required to increase the effectiveness of the resulting system, but also to tweak concepts and functionality to better answer user needs, come up with different ways to use the technology, and develop new social practices around the possibilities opened up by the new technological system.

Concepts, mock-up and working prototypes underwent different design iterations. Each evaluation informed the redesign of the next prototype, and users' requirements were progressively refined and elicited in continuous user research.

Different methodologies were used to collect feedback on the acceptance of the new system:

- Field observation at the NICU to collect examples of assemblies to try out new monitoring practices.
- Interviews with parents and neonatal staff.
- Workflow sessions were regularly organised to analyse emergency situations occurring in the NICU and to appreciate any organisational changes deriving from introduction of the new incubator system.
- Workshops and hands-on activities in which the nurses and neonatal doctors tried the Mattress and the Bio-belt to reflect upon their use at the NICU.
- Contextual enquiries with parents to assess the appropriate level of information required to compose a picture of the health conditions of their baby, to follow the therapy and appreciate improvements.
- Different scenarios to evaluate the concepts and the reliability of the system.

The main outcomes of the evaluation activity are summarised below.

The medical staff

Interesting outcomes from the initial assessment were related to the possibility of dynamically constructing assemblies of devices and services. In trying out the system, the neonatal doctors designed a set of assemblies to improve monitoring with different levels of visibility and various access methods.

The main assembly used was the vital parameters assembly, representing all of the values representing the child' condition. These parameters constitute the fundamental interpretive tool permitting comprehension of the situation.

The assembly of vital parameters comprises values pertaining to:

- PaCO2
- PaO2
- Sa02
- Respiratory Rate
- Heart Rate
- Blood Pressure
- Temperature

The parameters are listed in order of importance, taking into consideration their reciprocal correlation.

Using PalCom architecture, a single centralized display can be used to visualize the progression of these values. In addition, each of these parameters has a specific alarm that can be configured by the doctor. The alarm systems, aside from being customized to each parameter, can be configured by identifying sensitivity thresholds, the more a variation in one paramater is accompanied by variation in another.

For example, when there is a variation in the SaO2, CO2 and temperature values, a "type 1" alarm is activated. When a variation in blood pressure level is added to the previous variations, a "type 2" alarm is activated, indicating a more critical situation.

The alarms can thus be configured differently according to the risk that is presented. This means that various thresholds of seriousness correspond to different kinds of alarm, including soft acoustic alarms in the case of simple warnings.

This possibility of adaptation of output consequent upon variation of one or more values profoundly modifies the quality of the feedback given by the system. In this way, feedback becomes more precise and more informative, as it provides not only an indication that the values of a certain threshold have been exceeded, but also sustains the possibility of understanding the meaning of that variation according to the more complex logic of possible correlations between the parameters identified.

As anticipated, the vital parameters assembly permits different levels of visibility, according to the type of elaboration necessary for comprehension of the clinical situation. For example, it is often necessary to complete the clinical framework with blood gas analysis.

Using the NICU browser, it is possible to access blood gas data directly from the screen that displays the vital parameters assembly in order to identify possible alternative correlations.

The interface of the NICU assembly is deliberately designed to be simple and basic in order to avoid generating any additional cognitive load for medical personnel. The blood gas analysis values are thus available via "more internal" levels of information than are accessible from the main interface.

In the same way it is possible to visualize and navigate other assemblies for monitoring other correlations.

In this way use of the Bio-belt or Mattress offers promising new monitoring possibilities that could open up new diagnostic opportunities. Examples of possible correlations concern preliminary identification of pneumatic problems or obstruction of the endotracheal tube, made possible by the option of intersecting SpO2 data with the respiratory frequency monitored by the respirator and the respiratory frequency recorded by the belt.

The combination of these parameters could contribute to anticipatory diagnosis of respiratory anomalies consequent upon a change in the child's condition or malfunctioning of equipment.

The possibility of configuring the assemblies on hand was evaluated as a major strength by the medical staff. The various different elements of the incubator (e.g. the mattress, the biosensors, the Bio-belt), can easily be added, removed and combined to support different care activities. This also implies the possibility of centralising or distributing the monitoring function in the environment, depending on what is happening in the ward (e.g. parents' visit or therapeutic treatments).

Even if this possibility of flexibly configuring the incubator system and its services is recognised by doctors as a tremendous improvement with respect to the current situation, continuous construction and re-use of assemblies raises serious issues for critical safety settings such as those in the NICU.

The security of the overall system and privacy-related issues in treating different data (e.g. remote monitoring) and managing the access to the system represent key factors requiring more carefully consideration in this context.

The parents

Interviews with parents confirmed that they do not need extensive complex technical explanations about the health of their baby, which they do not fully understand most of the time. They basically want to be informed, to be able to ask questions, and to feel included both in the care of the baby and in sharing information.

The features of the new incubator system they appreciated most are related to the visibility of the system, the possibility of having more intimate contact with the baby, and the continuous monitoring provided by the mobile service on their Smartphone.

With regard to the visibility of the system, parents reported that the environment at the NICU is experienced as extremely stressful, and the technological environment is experienced as frightening even though they realise it is necessary to give the infants the best possible care. Unobtrusive monitoring provided by the Bio-belt and the Mattress greatly improve the image they have of the incubator.

They also greatly appreciated the possibility of practicing a kind of Kangaroo care augmented with the monitoring capabilities of the Mattress and the Bio-belt. In this way the parents feel close to their baby and establish earlier bonding while still being able to rely on continuous monitoring of vital parameters.

The Smartphone application was considered a great opportunity to feel in contact with the baby at all times, in particular when only one parent (usually the mother) can be present beside the incubator. In this way the father can share the experience with his wife and other relatives. Furthermore, the Smartphone application delivers a sub-set of information, avoiding the need to interpret all the data displayed on the screens beside the incubator.

All these features help the parents to feel as a family with the newborn.

Experimental test

During the project it was also possible to test the Bio-belt with pre-clinical trials on a group of four children from 2 to 12 months who were close to being dismissed from the NICU of 'Le Scotte' Hospital in Siena. The purpose of the experiments was to test the accuracy of the monitoring technology in the real setting, even if it was not possible to test the technology with premature newborns for safety reasons.

The method

The table below shows the general information on the subjects involved in the experiment (Ciani, 2007).

Subject	Sex	Gestational age	Birth weight	Age (months)	Weight (kg)
A.	F	41	2.710	6	6.600
C.	F	39 + 6 days	3.740	12	11.200
D.	M	24 + 4 days	0.660	2	2.500
L.	M	24 + 4 days	0.750	4	4.740

Table 1: Subjects involved in the experiment

Child A. and child C. were full-term newborns with a birth weight appropriate for their gestational age. The tests were conducted at their homes using the Bio-belt for recording the signals.

Child D. and child L. were very premature newborns. The monitoring session was conducted at the NICU in the context of follow-up sessions, which are necessary to identify potential early motor or cognitive problems and intervene with appropriate rehabilitation programs if necessary.

A NICU nurse cooperated in the preparation of the children by positioning the sensors and assisting the session. She remained available for the whole duration of the test, as did the neonatal doctor in charge of supervising the trial. Children D. and L. were monitored using the Bio-belt, a pulse oximeter and a commercial thermometer.

The pre-clinical testing set-up was defined to enable collection of the following experimental data: ECG, respiratory movements, skin temperature and derived parameters.

The tests were structured differently according to whether monitoring was performed at home or in the NICU.

As previously mentioned, in two cases monitoring was performed at home using only the BioBelt to collect the signals and assess their quality. This led to considerations about the sensor's proposed configuration, the design of the band and how to maximize the acquisition time of useful signals. All this information will be useful for improving the Bio-belt and its performance during monitoring.

During the tests conducted at the NICU, it was possible to monitor the values of oxygen saturation using a portable pulse oximeter (Masimo Radical-7TM Corp.), equipped with a RS232 serial port (Piccini et al. 2008).

The use of the pulse oximeter made it possible to obtain a tachogram which was compared to the sequence of instantaneous heart rates derived from the ECG detected with the BioBelt. Body temperature was measured during the tests using the thermistor contained in the Bio-belt and a commercial infrared thermometer (Necchi N1190). It must be pointed out that even if the use of infrared thermometers is increasing due to the tool's practicality, measurement uncertainty (1 to 10 ° C) is higher than with a traditional mercury thermometer.

One of the main requirements in definition of test procedures has certainly been minimising the disturbance to the infants involved in data acquisition. For this reason the monitoring session lasted between 15 and 25 minutes. All the sessions were conducted in the presence of one or both parents, who were informed in advance about the characteristics of the Bio-belt, the type of data collected and the test protocol. The parents expressed their written consent to take part in the experiment.

The testing took place in a heated room where the children were placed, sitting or supine, on a stable shelf with the Bio-belt wrapped around the chest. The temperature and acceleration sensors were placed in a front pocket of the belt to avoid wrong positioning due to unexpected movements. During the session the children were free to move, play and interact with the parents.

For subjects monitored with both the Bio-belt and the pulse oximeter, the sensor for measuring SpO2 was placed on the child's foot. At the end of the session, temperature was detected using the ear thermometer.

Before discussing the results of the test it is worth noting that all the children seemed to feel perfectly at ease during the experiment. The subjects showed no signs of nervousness or anxiety at any time during the monitoring period.

Results

Post-processing algorithms were applied to the ECG and accelerometer output voltage signals in order to extract instantaneous HR and BR of children throughout the monitoring session (Ciani et al., 2008). HR and BR together with the body temperature obtained by calibration of the temperature sensor gave a significant, consistent review of the baby's health status.

Figure 8 shows an example of signals acquired through the Bio-belt where we can see one accelerometer channel recording thoracic wall movements during breathing, synchronized with the ECG signal.

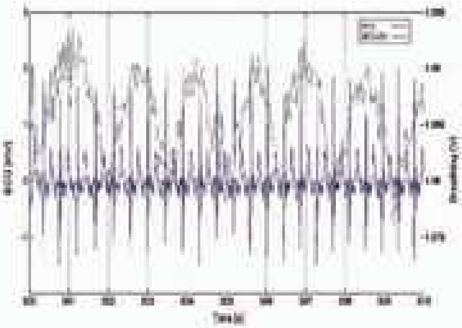


Fig. 8 An example of ECG signal and output voltage signal of the accelerometer related to breathing activity of a child involved in the experiment.

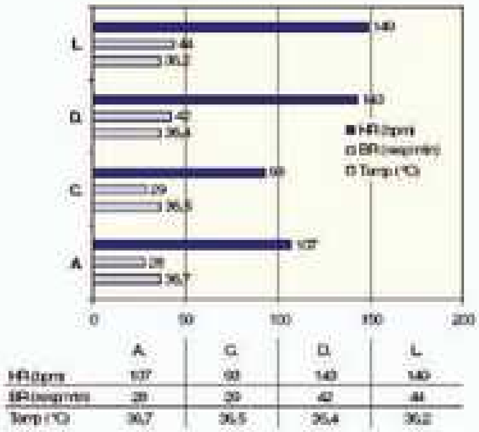
As may be seen in the figure above, the ECG wave is of low quality since the baby's movements caused instability of skin-belt contact.

Even if this result could lead to redesign of the mechanism to wrap and fasten the belt around the baby's chest in order to ensure more stable placement, we may reasonably assume that the problem will be reduced during clinical trials on premature newborns since they express poor motility, especially during the first months of life. This aspect of the monitoring system should be investigated further.

Figure 9 shows the monitoring results obtained for each child. The figure clearly shows that the heart rate recorded for all subjects is compatible with the range of normal physiological values considered for neonatal patients and those only a few months old.

Similar considerations apply to the respiratory rate, which in healthy infants is approximately between 35÷45resp/min.

Neither the full-term newborns nor the premature ones demonstrated episodes of apnea during monitoring. Child D. occasionally made larger inspiratory movements, similar to yawning, which were judged as physiological by the neonatal doctor who supervised the testing.



	A.	C.	D.	L.
HR bpm	107	93	143	149
BR (resp/min)	28	29	42	44
Temp (°C)	36,7	36,5	36,4	36,2

Figure 9: Temperature, HR e BR of monitored subjects

The estimated skin temperature values were compared with measurements provided by a commercial thermometer with the results shown in Table 2.

Temp (°C)	A.	C.	D.	L.
BioBelt	36,7	36,5	36,4	36,2
N1190	36,8	36,4	36	36,2

Table 2: Comparison of skin temperatures of subjects measured with a commercial infrared N1190 thermometer and the Bio-belt

The experimental setup included parallel monitoring with a pulse oximeter for SpO2 detection and measurement of heart rate derived from the photoplethysmographic. This comparative assessment was conducted on the subjects monitored in the NICU. Unfortunately, monitoring with pulse oximetry was problematic because of the instability of the probe: the sensor made available by the NICU was suitable for the hands or feet of premature babies and therefore was too small for the subjects involved in the test. For this reason the monitoring values obtained cannot be considered reliable.

Unfortunately the hypothesis of measuring chest dilatation through a textile extensometer running straight along the entire length of the belt failed because a useful sensor preload would have required overly binding bandaging of the baby. It will be necessary to enhance the prototype in this respect to include adjustment of strain gauge sensitivity in order to permit more complete investigation of preterm respiratory system functionality.

CONCLUSION

The Neonatal Intensive Care environment is a complex socio-technical system populated by a significant number of technologies and devices distributed in the environment that the neonatal team, consisting of doctors, a variety of medical specialists and nurses, uses in treatment of premature babies.

As described above, the delicate and highly specialised environment of the NICU presents a very wide range of difficulties, which include deriving frequent monitoring measurements from fragile babies, repositioning them within the incubator while trying to minimise very painful and potentially injurious interventions; supporting the relationships between the premature baby, its family and its carers; and reconciling parents' needs for information, communication and reassurance with psychological pressures on medical staff.

Parents live at the edge of this socio-technical system whose centre is the premature newborn.

Issues of visibility, intimacy and closeness are as important as monitoring and control.

This chapter has described the user-centred and participatory design process from problem analysis to concept generation, prototype development and testing of a new incubator system composed of different technologies. All these technologies aim at providing unobtrusive monitoring and improving the comfort of the baby as well as parent-child bonding by lowering the emotional barrier created by the current incubator set up.

The participatory approach proved to be successful in combining different sensibilities to design health technologies that combine accurate, effective therapy with solutions that reduce the sense of discomfort and support the different needs of the care community.

This approach led to development of a new incubator system composed of different technologies: a Mattress for a preterm child to rest upon inside the incubator, equipped with pressure and temperature sensors; the Bio-belt, a wearable device augmented with a set of sensors placed around the infant's abdomen; and the NICU browser, which allows neonatal doctors to construct assemblies of devices and services in order to obtain a more accurate interpretation of the baby's vital parameters.

From a design viewpoint, the new incubator system has a number of distinctive features:

- Instrumental qualities, since the design choices combine effective and accurate monitoring with social inclusiveness and exchange.
- Aesthetic qualities that relay both in the appearance of the wireless devices and the quality of the information, which is adapted to the information needs of different users, including parents.
- Innovation: the smart material embedded with sensors used in the Mattress and the Bio-belt is innovative, and this technology can be exploited in different domains. Furthermore, the concept of the assembly is innovative in helping people to make sense of what technologies could do for them if they use them creatively.
- Ethical qualities and human values: the design process was centred not only on the medical staff but also on the parents and their needs. They were involved from the very beginning and regarded not as objects of study, but as active agents within the design process itself. The lessons learnt working with them have been fundamental for evolving and refining possible design choices.

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8

DESIGN CASE 4:
Robot for kids

8.1 Domain context

Children with cognitive and social disabilities are often unable to engage in play activities with their peers, because it is difficult for them to establish relationships and to explore their social environment (Besio, 2008). Difficulties which affect playing skills in childhood lead to a general impairment in the learning potential and results in isolation from the social environment. Children with physical or cognitive impairments prefer to play alone or in limited dyadic interactions. In everyday social life the ability to engage in activities requiring shared attention is the key to understand the interaction partner as intentional agent and to form cooperative strategies based on this understanding. The function of play, to develop and improve this ability, is for disabled children usually not given.

8.2 Research context

The robot was developed in the context of a Specific Targeted Research Project (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. The project was called Iromec - Interactive RObotic social MEdiators as Companions (http://www.iromec.org/) and was carried out by a multidisciplinary consortium composed of PROFACTOR GmbH (coordinator), University of Hertfordshire, Robosoft SA, Vilans, University of Siena, Università della Valle d'Aosta, AIJU-Toy Research Institute, Risoluta S.L.L, Austrian Institute of Technology GmbH.

The software and hardware components of the robot were developed by Profactor and Robosoft. The University of Siena was responsible for the design (appearance and behaviours) and the development of some application modules of the robot. Furthermore the University of Siena performed field experiments in two primary schools in Siena. Other experiments were performed by our partners in UK, The Netherlands, Italy (Aosta and Milan), Spain, Austria.

I was the principal investigator for the University of Siena and coordinated a research team composed of two post doc assistants and five external consultants with competence in graphic, visual and interaction design.

The project started in November 2006 and ended in October 2009. However, I continued the research individually in a follow up project with the objective to design additional components of the robot (illustrated in paper 7) and to perform new experiments at a primary school in Siena. The follow up project is still ongoing.

8.3 Inspiration

Recent research in human-robot interaction has produced the so-called robot companions, that is robots that engage in social exchanges with humans.

Within the area of robot companions, some of these have been specifically designed to stimulate social exchanges and play activities (Marti at al, 2009) and to support the cognitive development and maturation of children with socio-relational disturbances, from slight linguistic retardations to Down Syndrome (Marti, et al. 2005); from developmental retardations to relational deficit problems such as autism (Dautenhahn, K., Werry I., 2004); from light to severe motor impairment to stimulate the execution of coordinated movements

(Marti et al. 2005) and explorative behaviour. Other studies have been performed on autistic children (Murray, D., Lesser, M (1999), to study the therapeutic role of robots in the treatment of autism (Robins et al. 2004), (Kozima et al. 2005), (Michaud et al 2007).

Robot companions are designed to be patient, predictable, able to play many games, both intellectual and physical, and in this respect they can open unexplored opportunity for learning.

8.4 Focus on aesthetic and embodied interaction: Perceptual crossing

The Design Case 4 explores the possibility of achieving by design a shared perception with a robot companion to enrich the experience of use as an emergent and dynamic outcome of the interaction. In exploring shared perception and empathic interaction with the robot, the concept of "perceptual crossing" is taken as a main aesthetic focus for design.

Perceptual crossing is the recognition of an object of interaction which involves the perception of how the behaviour of the object and its perception relate to our own. Examples of perceptual crossing in human-human interaction occur when two people catch each others' eye, in case of mutual touch, kinaesthetic or acoustic interactions (proto-conversation with babies, dialogue, choral singing etc.), synchronisation of movements.

Mechanisms of perceptual crossing with the robot are described in Paper 7.

8.5 Prototype

Iromec is a robotic companion that engages in social exchanges with children with different disabilities (Fig. 10). It is a modular robot composed of a mobile platform, an application module and a number of additional components that modify the appearance and behaviour of the robot. The robot can assume different configurations and appearance. In the vertical configuration, the robot has a human-like stance by being mounted on a dedicated support that provides stability and maintains a fixed position. This configuration supports imitation scenarios that require the children to reproduce basic movements, like turning the head. The robot can also assume the horizontal configuration to support activities requiring wider mobility and dynamism. In this configuration the robot looks like an imaginary character that can assume the appearance of a vehicle or an imaginary animal.

Paper 7 discusses how the concept of perceptual crossing was used in the design of the robot's behaviour. It also presents some concrete examples of such behaviours.

Full details about the robot design can be found in Paper 8.

Video 4 shows the play scenarios and the related educational objectives.

Figure 10 - Iromec

8.6 Testing

Iromec has been experimented in two primary schools in Siena (Italy). The trials involved 4 children with different levels of disability from 6 to 11 years of age (global cognitive disability, Tuberous sclerosis, Attention Deficit Hyperactive Disorder (ADHD) and motor impairments).

Paper 7 shows excerpts from these field experiments.

Design Case 4: Papers

Paper 7

Marti, P. Perceiving while being perceived. *International Journal of Design* , 4(2), 2010.

Paper 8

Marti, P. Bringing playfulness to disability. *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending boundaries. NordiCHI 2010*, Reykjavik, Iceland, 16-20 October 2010, pp 851-856.

Video 4: This video gives an overview of four play scenarios with the robot and their educational objectives.
www.vimeo.com/patriziamarti/iromec

Perceiving While Being Perceived

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Under what conditions can we engage in a meaningful, expressive interaction with an electronic device? How can we distinguish between merely functional objects and esthetic, poetic, interactive objects that can be potential carriers for meaningful experience? This paper provides some answers to these questions through considering an aspect of aesthetic interaction that is still quite unexplored. Taking a phenomenological approach to action and perception, the paper explores the possibility of achieving by design a shared perception with interactive devices in order to enrich the experience of use as an emergent and dynamic outcome of the interaction. In exploring shared perception with interactive devices, the concept of "perceptual crossing" is taken as a main source of inspiration for design. As defined by Auvray, Lenay, and Stewart (2008), perceptual crossing is the recognition of an object of interaction which involves the perception of how the behaviour of the object and its perception relate to our own. In this sense, a shared perceptual activity influences the behaviour of interacting entities in a very peculiar way: we perceive while being perceived. Here, this argument is explored from the design viewpoint, and prototypes that illustrate the dynamics of perceptual crossing in human-robot interaction are presented.

Keywords – Aesthetic Interaction; Shared Perception, Perceptual Crossing, Human-Robot Interaction.

Relevance to Design Practice – This study considers perceptual crossing as a central theme for aesthetic interaction. The prototypes presented demonstrate the possible use of this concept as inspiration for design.

Citation: Marti, P. (2010). Perceiving while being perceived. *International Journal of Design, 4*(2), 27-38.

Introduction

Electronic devices have undergone an alarming trend related to their aesthetics; the search for appearance and perfection often turns into a loss of sensuous and emotional content. Instead of inviting a sensory and perceptual intimacy and exploration, they frequently signal a rejection of sensuous curiosity and pleasure constraining the user to execute action without the possibility to experience their inherent effect. Modern touch-based interfaces make it possible to directly manipulate information, for example by sliding icons over screens. However, this kind of interaction only slightly involves our senses while not permitting us to perceive the inherent properties of the moved objects. The interface is necessary to interact with technology, but through the interface we touch surfaces without quality, experience spaces without gravity, and exercise actions without forces and their inherent effect. The Aesthetics of Interaction is an emerging field of research that tackles these topics while considering beauty of use and expressivity and meaning in interaction as paramount values for design.

Under what conditions can we engage in a meaningful, expressive interaction with an electronic device? How can we distinguish between merely functional objects and aesthetic, poetic interactive objects that can be potential carriers for meaningful experience? Here, "aesthetic" does not refer to a property that is inherent in the object itself, but rather a property of the (inter) action. According to this view, aesthetics is not only related to the form as perceived visually or with the functionality of the system (Fogarty, Forlizzi, & Hudson, 2001), but it is a potential that is released in dialogue as we perceive and act in the world. Consequently, the Aesthetics of Interaction should primarily study action and perception, as well as the intentional affordances that move us to act and interact in the world.

Aesthetic Interaction

The field of Aesthetics of Interaction has reached a certain maturity, partly consolidating the idea that in response to a change in the use of computers and interactive technologies, traditional Human Computer Interaction concepts of usability, efficiency, and productivity have to be enriched with other values such as curiosity, intimacy, emotion and affection. This is done in part through the development of new models and theories that explore many different directions and methods of technological implementation. Given that there seems to be near consensus on the importance of designing interactive systems beyond rational and functional requirements, the ways in which this can be achieved are not so straightforward, and the notion of Aesthetics of Interaction is still ambiguous and often contentious. In fact, different views have emerged.

One view understands the notion of aesthetics as being a result of the appearance properties of form as perceived visually (Fogarty et al., 2001), perhaps through the use of exquisite materials

Received April 18, 2010; **Accepted** July 20, 2010; **Published** August 31, 2010.

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and form. Here, aesthetics is seen as an added bonus pertaining to the object apart from the context of use. According to this view, the judgment of beauty is a higher-level evaluative construct which is independent of the actual product-usage experience. However, satisfaction and pleasure are emotional consequences of goal-directed product usage. Other views consider aesthetics with a socio-cultural connotation, as being a result of the human appropriation of the object, a socio-historical appreciation of different components (materials, forms) and properties that do not inherently pertain to the object itself (Petersen, 2004). Other views of aesthetics introduce the concepts of Flow (Csikszentmihalyi, 1990), Rich and Meaningful Interaction (Wensveen, Overbeeke, & Djajadiningrat, 2002), and Resonance (Hummels, Ross, & Overbeeke, 2003), all of which are challenging and dense concepts for study and experiment.

This paper concentrates on a different and complementary perspective of Aesthetics of Interaction. Shared perception is considered as having paramount importance for the aesthetic experience, along with other conditions which include embodiment, bodily skills, cultural context, social practices and contextual aspects. It is a potential that is released in dialogue as we perceive and act in the world while being perceived by the world itself. It is a prospect of reciprocal influences and dynamics of mutual perception. Taking into account shared perception, the aesthetic interaction develops as a shared, reciprocal rapport between interacting entities. This mutuality of influences is a key property of the interaction process. It is dynamic and implies the exploration of the other at the level of our perceptual-motor and emotional skills, at the level of our cognitive capabilities, at the level of our value-related personal and social system.

Examples of Shared Perception

As an illustrative example of shared perception, consider the automatic glass doors of modern train coaches. We know by experience with similar systems that the automatic doors should open when approaching them. But do they show their intention to open when approaching? It is not rare to see passengers making strange movements in front of the door to signal their intention to cross. Likewise, one can often see the automatic door open for no apparent reason. Each of the interacting entities (the person and the door) can potentially perceive the other one, but neither of them clearly show and share their own intentionality.

Sharing intentionality roughly means the process by which agents interact in a coordinated and collaborative way either in order to pursue some shared goals or share a common experience. In order to reach this shared intentionality, perceptual crossing is required. In this view, intentionality is not a result of an internal judgment but is a social product created dynamically as an emergent outcome of the interaction. Social interaction is a product of a perceptual crossing in that the recognition of an object to interact with does not only consist of the simple recognition of a particular form, behaviour, or pattern of movements, but involves the perception of how the behaviour of the object and its perception relate to our own (Auvray, Lenay, & Stewart, 2008). In this sense, intentionality is not a matter of unilateral perception where each intentional subject acts in order to achieve goals by the most efficient means available. On the contrary, it is a shared perceptual activity that influences the behaviour of all the interacting entities.

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In order to realise mechanisms of shared intentionality, we should design systems which are sensitive to perceptual crossing. This makes interaction expressive, embodied and responsive to individual actions without the use of an interface or without a previous representation or plan of the interaction itself. From this perspective, and in order to illustrate better what perceptual crossing is, the example of the train door can be taken further. For example, a glass door could show its perception of a person from a distance, perhaps by becoming less opaque. It could also start opening just a bit in the presence of a person, and then open completely very slowly or quickly depending on the quality of the movement of the person towards the door. Of course, the type of interaction here is too limited to offer a very rich experience. However, even in a simple example like this, the timing, intensity, and form of an action can have a corresponding effect to enable the interacting entities to show their shared intentionality and resonate with one another. We could confront a door, rather than functionally approach it. With this example, we can experience the act of entering, not simply seeing the visual design of the door. Further, we can look in or through its transparency as a source of experience, rather than looking at the glass door itself as a material object.

The question remains, though, of how to develop interactive systems able to show perceptual crossing with their users. An alternative view to the concept of interface and structured sequences of action should be developed in order to let people access stimulus information directly through their senses while perceiving and being perceived by the surrounding world. Restoring direct perception using all our senses will enrich people's experience through a dialogue with artifacts of everyday use. To better understand this concept, take as an example the vending machine. The basic design of a vending machine is usually comprised of a cabinet that holds all internal components and an outer panel containing the electronic controls that allow customers to purchase and receive goods. The outer door usually includes signage and illustrations to show the sequence of actions required to operate the machine. A panel of control buttons lets customers make their selections. The sequence of actions is pre-determined: put in money, press a selection, and receive the food or drink. Occasionally, one may make a selection when the machine is empty, or even mistakenly enter a wrong code and receive an undesired product. This kind of machine is not open to the user's actions and it requires an interface to be operated. The kind of interaction enabled by this design is error prone as well as dramatically reduces the opportunities for action.

A completely different approach to the design of a vending machine has been taken by Guus Baggermans. For his master graduating project at TU/e Industrial Design, under the supervision of Kees Overbeeke, he created the *Friendly Vending Machine* that communicates on a personal level with customers, thus enhancing their experience. The vending machine basically invites one to explore interaction possibilities using the customers' movements and their gestures. The cans, aligned in a series of glass tubes, follow the customer's movements and turn toward him or her. They show they can see the customer and can behave in coordination to his or her way of approaching the machine. The customer can interact without using any button or browsing menus. Once the customer has decided which drink to buy by physically pointing at the can, a coin is fed into the machine and the tube gently opens allowing the can to be grabbed. The machine elicits an emotional response instead of a rational one. This interaction develops as a reciprocal perception in that the user can perceive the machine and be aware of being perceived by the machine itself at the same time.

Perceptual Crossing

As mentioned, the concept of perceptual crossing as defined by Auvray et al. (2008) is taken as a main source of inspiration in exploring shared perception with interactive devices. Important empirical evidence has been found in their experiments to sustain the central role of dynamic mutuality and shared intentionality in forming several aspects of an ongoing interaction. Auvray et al. (2008) carried out the following relevant experiment. Two blindfolded subjects interacted in a virtual one-dimensional space. Each subject moved a receptor field using a computer mouse, and received an all-or-nothing tactile sensation when the receptor crossed an object. Each participant could encounter three types of objects:

1. The other participant's avatar.
2. A fixed object (inanimate).
3. A mobile object (the "mobile lure", a shadow inanimate object similar to the avatar, with the same form and movement of the avatar).

The key point of the experimental setup is that the only difference between the avatar and the mobile lure is that the avatar can both perceive and be perceived, while the other objects can only be perceived. The participants' task was to click the mouse when encountering the other participant's avatar. In practice, the subject had to distinguish if the tactile stimuli received from the encounter were related to the other participant's avatar or to an inanimate object. A result of the experiment is that participants clicked significantly more often on the other participant's avatar (i.e., correctly) than on the fixed object and the mobile lure. Remarkably, subjects were able to distinguish animate objects from inanimate ones with the same appearance and movement (in the case of the mobile lure) only by perceiving very simple tactile stimuli.

A fundamental insight we can draw from this experiment in regard to designing for expressive interaction is that an important clue in interaction is its interwoven nature which has to be shared between the subjects. This is a property of the dyadic system and does not belong to the single interacting entities. Following this argument, interactive systems should show their capability to perceive while being perceived, to be sensitive to others' movements and actions and their corresponding actualisation in timing, intensity, and form in order to enable the interacting entities to 'resonate with' or 'reflect' one another. We should also design for action coordination. The human body and cognition are specialized for mutual regulation of joint action. We should take a dual perspective of perception so that each partner in interaction can perceive while being perceived by the other and can modulate his/her behaviour accordingly. These insights will be explored in more depth through the examination of the following design case.

The Robot Companion

In the past few years, human-robot interaction has received a significant and growing interest that has led to the development of a number of so-called robot companions, a term that emphasizes a constant interaction, co-operation and intimacy between human beings and robotic machines. The robotic companions are not supposed to simply execute tasks; a continuous and natural dialogue is expected to be held between the human being and the robot companion. A high quality interaction should occur that is not merely functional (entering a command so the robot can execute it) but emotional (asking "Is the robot or the human angry?"), aesthetically pleasurable (declaring "My cute robot companion"), social (robots mediating social exchanges), and intentional (asking the questions "What can the robot do for me? What can we do together?"). In this respect social robots can represent an ideal test bed for aesthetic interaction and, in particular, for designing for perceptual crossing.

Iromec is a robotic companion that engages in social exchanges with children with different disabilities. The robot has been developed within 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).

It is a modular robot composed of a mobile platform, an application module and a number of additional components that modify the appearance and behaviour of the robot (Marti & Giusti, 2010). The robot can assume two main configurations, vertical (Figure 1) and horizontal (Figures 2a and 2b). In the vertical configuration, the robot has a human-like stance by being mounted on a dedicated support that provides stability and maintains a fixed position. This configuration supports imitation scenarios that require the children to reproduce basic movements, like turning the head. The robot can also assume the horizontal

Figure 1. The vertical configuration.

Figure 2. The horizontal configuration.

configuration to support activities requiring wider mobility and dynamism.

The head of the robot is composed of an 8-inch display for visualizing facial expressions, while the trunk presents a 13-inch display showing graphical elements that can play a role in expressing the robot's behaviour. For example, the body screen can display a digital fur which moves according to the direction of the platform's movement. When the robot stops, fur clumps appear that extend when it moves again (Figure 3).

The robot is able to show different facial expressions that incorporate the mouth, nose, eyes and eyebrows, as well as different levels of expressiveness and emotional states. Colors, visual cues (shadows and shades) and smooth transitions have been used to provide a life-like impression. Different masks can also be mounted on the head to hide parts of the face, modify the physical appearance of the robot, and to reduce the expressiveness (Figure 4). This last feature is specifically designed for autistic children whose competence level in processing facial expressions can vary considerably according to the severity of cognitive impairment. The combination of digital and physical components allows the robot to be experimented with in several setups in order to find the solution that better fits the needs of the children.

The robot can engage in a number of play scenarios (Robins, Ferrari, & Dautenhahn, 2008), including *Turn Taking*, *Imitation Game*, *Make it Move* (a cause and effect game), *Follow-me* (coordination game), *Dance with Me* (imitation and composition game), *Bring Me the Ball* (cause and effect game), and *Get in Contact* (Sensory stimulation game). Each scenario has

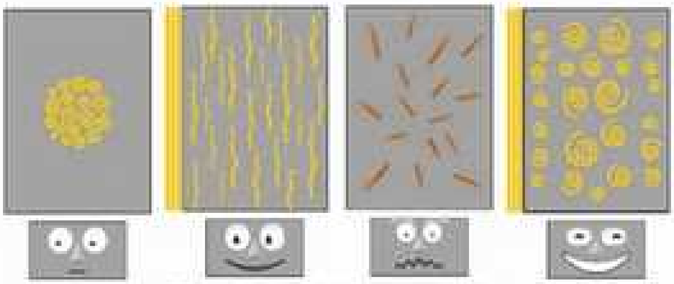

Figure 3. Graphical elements of the robot.

a number of specific educational and therapeutic objectives. For example, the *Tickle* scenario (Figure 5) consists of an exploration of the robot's body to discover where it is sensitive to being tickled. The game was developed to improve the perceptual functions (auditory, visual, tactile and visuo-spatial perception) as a basic form of communication. This is important to the learner since the tactile sense can help to provide awareness of one's own self and each other, to build trust, and to give or receive support in order to develop social relationships during play. In fact, the ability to use one's senses in an active and involved manner is linked first and foremost to orientation, attention, perception and sensory functions from which knowledge must be acquired and applied to communicate and to take part in social and educational relationships.

The *Tickle* scenario is enabled by covered modules embedding smart materials. A pressure sensitive textile covering module was developed that fixes a soft woolen cover on top of two metallic and conductive layers separated by an isolating layer. The conductive layers are made of steel wires, while the isolating layer can be made of coloured polyester or transparent PA6 monofilament depending on the type of connection to the commutation. The fabric works like a switch – whenever the child strokes a sensitive area, the robot emits an audible laugh. The tickling zones change dynamically and children have fun in trying to guess where the robot is more sensitive.

A particular attention in designing the robot has been paid to the use of sounds. Since most of the play scenarios aim at improving auditory perception, original sounds have been created to structure and articulate the play experience. Indeed, even if we are not normally fully aware of the significance of hearing in coordination and spatial experience, sound can provide the temporal continuum in which visual impressions are embedded and acquire meaning. The robot's sounds have been designed to give the impression of a living entity without any specific human or animal connotation. The primary objective was to assign a tempo to the activity, to structure spatial and proximity relations,

Figure 4. The masks.

Figure 5. "*Tickle*" scenario.

to anticipate an intention to act, to underlie the effect of an action, and externalise the robot's perception.

A set of covering modules can be mounted on the robot's body in order to obtain different tactile and visual effects (Figure 6). Some of these modules are interactive (Figure 10) and affect the robot's behaviour. The covering modules embed smart textiles that provide the robot with unusual visual, tactile and behavioural feedback resulting from material transformations.

Implementing Perceptual Crossing:
Movement and Coordination

The objective of this design case is to provide expressive, aesthetic interaction with the robot companion. With this case and with perceptual crossing in general, the goal is to develop interactive objects/systems which show their capability to perceive while being perceived, and to use shared perception as a means to influence the behaviour of the interacting entities.

The human body and cognition are specialized for mutual regulation of joint action. People interindividually coordinate and reciprocally influence their movements in social interaction – they mirror each others' movements, anticipate them, temporally synchronise or desynchronise and so on. A specific feature of social coordination is that patterns of coordination can dynamically influence the behaviour of the interacting partners. This happens also in situations where the interaction carries on even though none of the participants wishes to continue it.

In discussing mechanisms of social understanding through direct perception, De Jaegher (2009) reports as an example the familiar situation where one encounters someone coming from the opposite direction on a narrow footpath. In attempting to walk past each other, it may happen that both pedestrians step towards the same side. This may happen a few times before they are finally able to pass each other. Here, the coordination of movements (a temporally synchronised mirroring of sideways steps) ensures (for a brief while) that the interaction process is sustained despite the fact that the persons both want to stop interacting in this way. We can exploit this natural ability of coordination by taking a dual perspective of perception where the interacting entities adjust their behaviour according to the evolving dynamics of the interaction. This can be illustrated through an analysis of the robot's *Follow Me* scenario, which will show the dynamics of mutual coordination in a situation of perceptual crossing.

The *Follow Me* scenario is an exercise and simple symbolic game with primary objectives related to energy and drive functions, like improving motivation to act and to feeling in control. The scenario aims to develop the understanding of cause and effect connections and to improve attention to mobility, coordination and basic interpersonal interaction. The game consists of playing with the robot that follows a child. Other children can compete to attract the attention of the robot in order to be followed.

The game starts when the first player activates the 'follow-me' mode by stroking the digital fur clumps displayed on the robot's body (Figure 7 step 1). The robot starts to move (Figure

Figure 6. Covering modules.

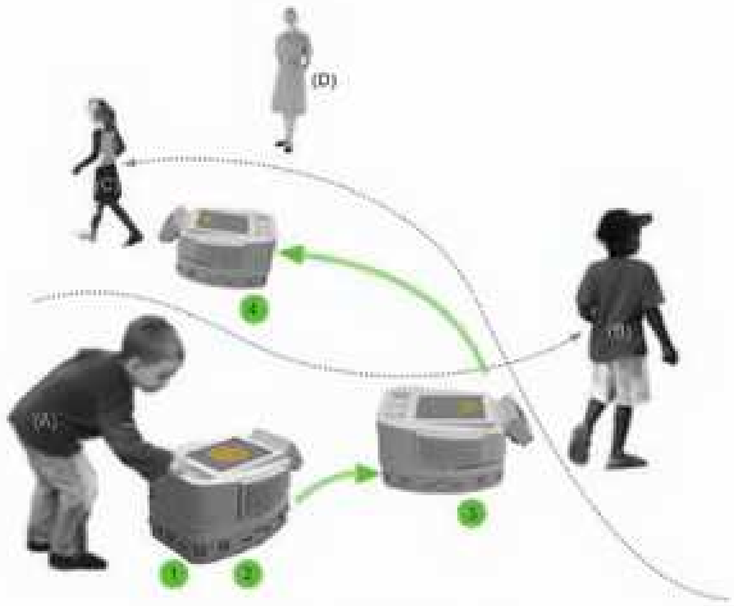

Figure 7. *Follow Me* scenario.

7 step 2), searching for a child. When the robot finds a child, it follows him or her within a predefined distance (e.g. 50 cm) (Figure 7 step 3). If the child stops, the robot stops too. When a second player (another child or the teacher) approaches the robot, and the robot is closer to the second player, it starts to follow the second player (Figure 7 step 4). In practice, the children and the robot have to coordinate their movements while expressing through movement their intention to act. The behaviour of the individual actors is influenced by their shared perception and it is dynamic.

Frames a-h in Figure 8 show the *Follow me* scenario played with a very early version of the robot prototype during an experiment at a primary school in Siena, Italy. In this version, the appearance of the robot was not finalized yet, but a great deal of attention was put into designing coordination dynamics between the robot and the child. In fact, the trajectory, pace and speed of the child's movement were dynamically coupled to a corresponding actualization in the robot's movements with a similar form, timing, and intensity.

The child involved in the trial was nine years old and had a mild cognitive disability entailing a learning delay and difficulties in focusing attention on the same activity for a sustained time. In Figure 8, we can see the child walking in the gym of the school being followed by the robot (frame a) that keeps the same pace and trajectory of movement. She looks at the teacher while she is walking and shows that the robot is able to follow (b). Sometimes, she stops and slows down and the robot synchronises its movement to the child's pace. All of a sudden, the teacher starts moving, passing quickly in between the child and the robot (c – d). By doing so, she attracts the attention of the robot which starts following her instead, coordinating its movement to the teacher's speed. The child observes the scene (e) and tries to obtain the same effects by walking between the teacher and the robot (f – g). Ultimately, the initiative is successful and the student can get the attention of the robot and have it follow her without hesitation (h), while adjusting the pace and speed of its movement to those of the student's movement.

The video recording of this scene was analysed and discussed with the teachers, where it was agreed that the behaviour of the child was remarkable. She was focused on the activity which lasted 30 minutes without interruption, and which produced interesting variations in the behaviour of the child. She enjoyed trying out different movements in the space, changing the geometry of her trajectory, increasing or decreasing her speed, and stopping and going back to experience the timing of her way of walking to the robot's movement. The robot showed a clear intentional behaviour that was situated and contingent on the behaviour of the other actors (child and teacher). The effect was mainly due to a shared perceptual activity that was embodied and contingent.

Implementing Perceptual Crossing through Micro Movements

Another exercise game and symbolic play scenario implemented in the robot is *Get in Contact*. The game is played by one or more children, and an adult has a supportive role during the activity to stimulate storytelling and to control the behaviour of the robot. Through a wireless Ultra Mobile PC unit, the adult can dynamically select the robot's behaviour among a set of behavioural patterns throughout the activity. Each behavioural pattern is characterized

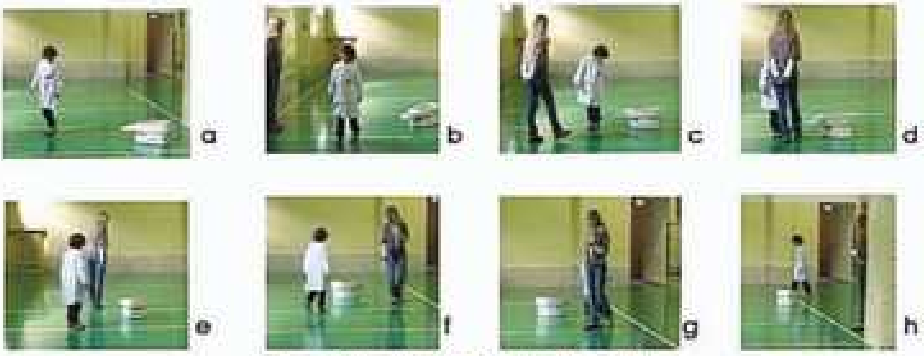

Figure 8. ***Follow Me*** **scenario: trials at the school.**

by a certain configuration of the robot movements, interfaces (e.g. face expressions), and covering module transformations.

At the beginning of the game, the adult selects the behavioural pattern expressing a 'feeling of fear'. Here, the robot does not approach the child and maintains a safe distance from him or her (Figure 9 step 1). When the child tries to approach the robot, it retreats and its digital fur gets darker and rough. Such a pattern creates a context that encourages the children to interpret the robot's behaviour and to change their behaviour towards the robot accordingly (e.g. to approach the robot kindly). When the child gently approaches the robot, the adult modifies the behavioural pattern and the robot now approaches the child showing warm colours in order to invite the child to a more intimate interaction (Figure 9 step 2). The adult can then select the behavioural pattern specifically related to the tactile exploration. The robot and the child are next to each other, and when the child touches the robot, it responds as if it were purring to engage the child into an intimate and emotional exchange (Figure 9 step 3).

This play scenario has been enriched through developing a covering module of interactive fur (Figure 10) that implements dynamics of perceptual crossing. The fur is made of a soft woolen cover with static and moving hairs. The static hairs are knotted on a copper knitted fabric covering a dome-like fiberglass shell. Also, the moving hairs are fixed to the copper fabric but their lower part is connected to a Nitinol spring (Figure 11).

A total of 20 moving hairs are distributed on top of the shell. Each Nitinol spring is connected at the centre to an electric wire wrapping the hairs. The Nitinol springs are fixed to the inner part

Figure 9. ***Get in Contact*** **scenario.**

of the dome shell by means of screws, and the electric wires are inserted through holes in the shell itself. When electricity passes from one extremity of the spring to the centre, the other extremity contracts. In this way, the electric wire at the centre of the spring moves left and right together with the hair it is wrapped to. The movement of the hair can be controlled in timing, intensity and form. Since the hair is inserted in the copper fabric, which is not elastic, the movement of the lower part of the hair is transformed in a rotation of the hair, which in some cases can reach more then 100 degrees. When half of the spring contracts, it is necessary to wait at least 20 seconds for it to cool down before the other half of the spring can contract. This makes the effect of the moving hairs seem quite natural, similar to the fur of an animal.

The hardware architecture (Figure 12) of the module is composed of the following components:

- **Input Pins**: These pins are used to get inputs by sensors. In particular, SRF04 sensors have been used to obtain object proximity information, and a long distance microphone to capture sound variations.
- **Output Pins**: The Nitinol wires inserted in the fur are controlled by an Arduino Mega micro-controller. Each

Figure 10. The interactive fur.

Figure 11. The inner shell of the interactive fur with Nitinol springs.

interactive hair is composed by a Nitinol wire and covered by a heat-resistant fabric.

- **Arduino Mega**: A microcontroller board based on the ATmega1280. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.
- **L298 Motor Driver**: The L298 is a dual-motor driver used by the Arduino pins to control the Nitinol wires by changing the input voltage of the wires. The prototype uses eight Motor Drivers that can be independently controlled to obtain different behaviours of the fur, and two batteries.
- **5V Battery**: This battery is used to power Arduino Mega and the L298 Motor Drivers.
- **18V Battery**: This battery is used to power the Nitinol wires. The use of this kind of battery is necessary since the prototype uses the maximum discharging capability for a short time to obtain a realistic sudden movement.

Figure 12. The prototype hardware architecture.

A software program in C/C++ calculates the speed with which to approach the robot by using three different sequential position values to avoid measurement noise. Then, the input voltage to the wires and the stimulation time is varied according to the approach speed values (a range between 0 and a maximum speed threshold).

Different implementations and controls of this module have been tested through embedding different kinds of sensors. For example, a software program has been developed to control sound sensors which have two different thresholds. The low threshold is the minimum sound value needed to obtain a certain kind of behaviour, called "quiet activation". In this case, a small voltage value is assigned to the hairs for a long time. In this way, the hairs are slowly warmed up to obtain a slow activation. When the hairs reach the complete activation and extension, the voltage stimulation is stopped so that the hairs can cool down and slowly come back to the deactivation position. When the hairs are midway through their descent, a small voltage is administered again to allow the hairs to reach the maximum extension position. At this point, the stimulation is definitely stopped and the hairs slowly reach the deactivation position. When the sound value exceeds the high threshold, a new behaviour called "afraid activation" is reached. In this case, the maximum input voltage is sent to the hairs (18V) to obtain a sudden complete activation to give the effect of the fur of a frightened pet.

Figure 13 shows an interaction scenario where the robot presents interactive fur connected to audio sensors. If the person whispers to the robot from the right side and talks to the robot in the right "ear", the fur raises gently starting from the right side. It is usually more fun for children to shout in order to frighten the robot. In this case the fur reacts suddenly and the robot moves away.

Figure 14 shows a different robot behaviour in response to an approaching person. Here, the robot presents interactive fur connected to proximity sensors. When a person approaches the robot, its hairs raise corresponding in timing and intensity to the movement of the person. If the person moves toward the robot quickly, the fur reacts with quick movement.

Figure 15 shows a variation in the implementation of perceptual crossing using LEDs in a free scenario where the robot moves autonomously in a room without any specific goal. When the person enters the room and crosses the robot, the LEDs light up and follow the person passing by. This simple behaviour is extremely expressive and interpreted as intentional in that the robot perceives the person and shows its readiness to interact.

Conclusions

Most of the studies conducted to date to investigate the mechanisms involved in shared intentionality consider the possibility of sharing another's intentionality as granted by an inferential cognitive process based on the discrimination of, first and formost, facial expressions but also of body movement, gestures, and language. In this view, the ability to recognize intentionality becomes a

Figure 13. Interactive fur with sound sensors.

Figure 14. Interacting fur with proximity sensors.

Figure 15. Interactive fur with LEDs.

prerequisite for adopting the other's outlook and separating it from one's own. This allows one to share the other's intentionality in a secondary way and to represent it. For this discrimination to take place, it is necessary to acknowledge the other as an animated entity with intentions and goals, capable of expressing its internal state.

For social robots, intentionality is a fundamental characteristic. Their credibility as autonomous entities is given by their ability to show intentions, and to express and pursue them. But what are the minimum requirements that need to be fulfilled to design social robots capable of showing and sharing intentionality in interaction with human beings? This paper tries to answer this question adopting an alternative view inspired by the concept of perceptual crossing. According to this view, some of the mechanisms underlying the recognition of others as intentional entities are intrinsic to the shared perceptual activity – we perceive the others while being perceived. This mutual interdependency is a product of a perceptual crossing and is dynamics.

Along these lines, in order to design robots able to engage in social interaction with human beings, we do not necessarily need to represent internal states and implement complex inferential processes. The prototypes described above attempt to enable perceptual crossing in a direct, non-mediated perceptual way. The design solutions adopted do not require a representation of complex internal states and inferential mechanisms.

From the review of these design cases, it is clear that a fundamental challenge for the design of interactive objects including social robots is to enable mechanisms for perceptual crossing based on the awareness to perceive while being perceived by the other. Perceptual crossing is a fundamental perceptual competence for the aesthetic experience. Meaning is released in dialogue as we perceive and act in the world while being perceived by the world itself. The perception of mutual affordances shapes the interaction and is a fundamental ingredient of the aesthetic experience.

Acknowledgments

I'm grateful to the Iromec partners, experts, and children who collaborated and participated in the research project. A special thanks goes to Claudio Moderini for his support in the robot design, to Ernesto Di Iorio of QuestIt who implemented the interactive fur, and to Riccardo Marchesi of InnTex s.r.l. for producing the textile of the interactive fur.

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Bringing playfulness to disabilities

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ABSTRACT

This article presents the design case of a robot companion targeted at children who are prevented from playing normally, due to cognitive, developmental or physical impairments. The robot design presents some distinctive qualities. From an instrumental viewpoint it reflects inclusiveness and social exchange. It enables inclusive play activities that promote confidence and self-esteem. All children blossom as children with different abilities, including "fully able" children, collaboratively achieve success, in games that are fun for all. A specific effort in the design was spent in creating consistency between the form, visual qualities, and the behaviours of the robot, in order to enable play scenarios that were specifically targeted at autistic, mild cognitively-impaired and severely motor-impaired children.

Author Keywords

Robot companion, inclusive games, modular design, smart textile design.

ACM Classification Keywords

H5.m. Information interfaces and presentation, Hm. Miscellaneous.

INTRODUCTION

Children with a disability not only experience the physical and psychological consequences of their impairment in the short-term but their disability profoundly affects the development of their social skills for their whole life. For full participation in society, communication and social interaction skills are fundamental: both of these skills can be acquired during play in childhood, and robot companions can play a key role in supporting the development of such skills.

Iromec (www.iromec.org) is a robot companion that promotes play in physically and cognitive impaired children – in particular autistic, motor-impaired and mild cognitively-impaired children. A key issue for the design of Iromec has been to understand the needs and expectations of disabled children, to enable and support play activities in all their richness through a range of design solutions. The objective is to have disabled children moving, exchanging, experimenting and having fun, regardless of their cognitive or physical ability levels. By offering exciting activities that entice children to participate, the robot not only helps them reap the physical benefits of exercise, but also provides opportunities for them to learn, share, express feelings, set goals, and function independently.

USER STUDIES

The design process combined the principles of User-Centered Design (UCD) and Scenario-Based Design [1]. In fact user involvement was required not simply to increase the effectiveness of the resulting system, but also to define play scenarios, tweak concepts and functionality to better answer user needs, come up with different ways to use the technology, and develop new social practices around the possibilities opened up by the robot. Concepts, mock-ups and working prototypes underwent multiple design iterations. Each evaluation informed the redesign of the next prototype, and the user requirements were progressively refined and elicited in a continuous user research cycle.

The user requirements elicitation process was organised in several panels of experts organized by the project's partners in various European countries (Spain, Italy, The Netherlands, Austria, UK). The panels involved professionals from different special education schools, teachers, therapists (e.g. psychotherapists, speech therapists, play therapists, physiotherapists, occupational therapists), as well as parents and family members. A common methodology was used in all the panels' interviews consisting of an introduction to the project, followed by a story-telling session where the members of the panel provided insight into the current play of the children and its characteristics, together with specific examples of the children's play [2]. The session usually continued with a brainstorming discussion around pre-set questions that aimed to find possible activities to be carried out with the assistance of a robotic companion; the role of the robot in the social play context; characteristics of the environment where the robot could be of added value; functionalities

NordiCHI'10, Reykjavik, Iceland
ACM 978-1-60558-934-3/10/10

suitable for the target groups; possible critical aspects of the children's behaviour and needs that such a robotic toy could address; ethical issues, wishes and other information considering robot toys.

In parallel with the expert user panels, other fieldwork research has been carried out including:

- The use of the cultural probes method [3] with disabled children in order to obtain inspirational material about the children's wishes, preferences, viewpoints and daily practice of play. The children collected small objects they usually play with, took photographs, and recorded brief notes. All the probes were used as a source of inspiration for the concept design.
- Field observations were conducted at primary schools of structured and spontaneous play activities.
- "Construction workshop". This was a hands-on activity where the therapists and the teachers played with cardboard boxes with different shapes, different materials and sensors. It was an exploration and construction activity supported by simple materials of different shape and dimensions, physical connectors to assemble the robot and sensors used to reflect upon the robot's appearance and the play scenarios.
- Contextual enquiries were conducted with children with different disabilities and their parents to document the use of toys and the "hacking" practices necessary to adapt the toys to the specific abilities of the children.
- Workflow and scenarios of the current therapeutic and educational activities were examined. In particular the scenarios were defined to illustrate the context of play, the educational and therapeutic objectives, artefacts (both material artefacts as devices, and conceptual artefacts as rules, practices, roles etc.) and social relationships.

From the initial fieldwork, the primary users of the robot have been identified: autistic, mild mentally-retarded and severely motor-impaired children. All of them have difficulties in playing alone or with others but their difficulties require different types of support during play. For example, the autistic children have considerable difficulties in social interaction, in particular in understanding others' intentions and feelings, as well as gestures and facial expressions. They usually show little reciprocal use of eye contact and a tendency toward repetitive behaviour patterns. For these reasons it is important that the robot has a very simplified and unexpressive face, preferably with physically embedded parts like eyelids that can be manually opened or closed during play to reduce the expressivity, and that the games are repetitive with a clear sensory reward. In this respect, imitation and turn-taking games (Figures 1 and 6) are specifically suited to autistic children.

Mental retardation usually involves multiple dimensions, from retardation in intellectual abilities and adaptive behavior, to participation in social interactions. Children with mental retardation have reduced attention ability and might not understand the meaning of the proposed play. Therefore suitable play scenarios for them are coordination and sensory stimulation games (Figure 3 and 5).

Children with motor impairment are limited in their ability to play due to limitations in their movement, if they are able to move at all. Cause and effect games and pretend play are the most suited play activities for this user group (Figure 2 and 4). The expressivity of the robot plays a fundamental role in these kinds of games so it is desirable for the robot to be able to display a wide range of facial expressions.

THE DESIGN OF PLAY SCENARIOS

From the initial user studies a set of twenty play scenarios were defined in close collaboration with the expert panels [4]. The educational and therapeutic objectives of each scenario have been classified with reference to the World Health Organization's International Classification of Functioning, Disability and Health in the new version (2007) for Children and Youths.

Examples of play scenarios are:

Turn taking: an exercise play where two or more children exchange the robot in turn. The scenario can be played in "sensory reward mode" to augment expressivity and feedback with sounds and animated graphics. The main target users are autistic children and the educational objectives are to improve mobility, cognitive flexibility and basic interpersonal interaction.

Figure 1: Two variations of the *Turn taking* scenario

Make it Move: a cause and effect game where the robot's movement is controlled by clapping hands. The main target users are severely motor impaired children and the educational objectives are to improve the sense of self and the awareness of the child's own body and identity.

Figure 2: *Make it move* scenario

Follow-me: a coordination game that consists of playing with a robot that follows the child. Other children can compete to attract the attention of the robot in order to be followed. The primary educational objectives of this scenario are related to energy and drive functions and to improve motivation to act and to feel in control. The scenario aims to develop the understanding of cause and effect connections and to improve attention to mobility. The main target group are mildly mentally retarded children.

Figure 3: ***Follow me scenario***

Dance with me: an imitation and rule game where a child makes the robot 'dance' – i.e. either the child or the robot initiates a dance to the rhythm of pre-recorded music and the other imitates the choreography to 'dance together'. The scenario is addressed to severely motor impaired children with the objective of improving spatial awareness and the control of simple voluntary movements.

Figure 4: ***Dance with me scenario***

Get in contact: a sensory stimulation game played by one or more children. The adult has a supportive role during the activity to stimulate storytelling and to control the behaviour of the robot. The main target user group is represented by mildly mentally impaired children and the educational objectives are mainly related to the improvement of perceptual and emotional functions.

Figure 5: ***Get in contact scenario.***

Imitation: an imitation game where the adult operates the robot remotely and controls its behaviour. Once the child has practised all of the robot's possible movements, the adult asks the child to initiate similar movements for the robot to copy. After a while, the adult reveals that they are operating the robot, and the game continues. Because the child knows that actually they are playing with the adult through the robot, this might encourage the child to have more eye contact with the adult as well as sharing in the excitement and fun. The play scenario is mainly targeted to autistic children and has a number of educational and therapeutic objectives: to improve proprioception, to improve the sense of self and the awareness of one's own body and identity, to improve focusing, maintaining, shifting, dividing attention and joint attention and to stimulate basic interpersonal interaction like turn taking and gaze shift.

Figure 6: Imitation game

CONCEPT DESIGN

The design intentions in constructing the robot included the following:

- To develop a solution that provides the maximum number of features in order to address different types of play scenarios for different categories of users.
- To apply a modular approach that permits a high level of flexibility and specialization in the use of the robot and an easy adaptation to the child's abilities.
- To support the child's interaction with the robot in two main settings: one stationary (i.e. to be used on the table to enable different kinds of imitation games, see Figure 6), and the other one mobile, to emphasise the use of the free movement in the space and to enable different games like turn taking, coordination game, cause and effect games etc (Figure 2, 3, 4).

During the inspirational phase of the design, the main questions considered were related to the robot appearance and how the combination of the appearance with the visual language and behaviours could contribute to the definition and expression of the particular identity of the robot itself. Different possibilities have been explored to create a consistency between form, visual qualities and behaviours.

As a result of a series of iterations of specific play scenarios that can be enabled by different configurations, the final design choice was based on a modular robot that can be configured as a horizontal, mobile robot supporting movement and coordination games (a vehicle with a cartoon-like appearance) and as a vertical, stationary configuration to support mimic and imitation games (anthropomorphic, cartoon-like appearance). This solution allows us to obtain a broad flexibility in the play activities with the same robotic system.

From a structural point of view the final design is composed of three main typologies of elements (Figure 7):

- the mobile platform, developed by Robosoft (www.robosoft.fr)
- the interaction module, that can be easily plugged/-unplugged to the mobile platform following a "plug and play" philosophy. A connector interface serves as a mechanical locking system between the interaction module and the mobile platform and allows power and data transmission. The interaction module (developed by Profactor, www.profactor.at) is equipped with a high-level control system that provides editing of "play scripts" through the graphical user interface, by means of XML-description. It consists of a body, whose digital screen skin can display different visual effects, 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 to produce right-to-left (and vice versa) movements, or/and to simulate situations in which the attention of the robot is attracted towards a specific direction.
- some ADD-ONS and COATING elements (Figure 8) provide a rich level of interactivity and expressivity. The robot is also equipped with external control buttons.

Figure 7: The main components of the robot

The robot can be used in an autonomous or controlled way using external remote controls.

Figure 8: Add-ons and coating elements

In term of interactivity the mobile platform supports all the interaction patterns based on the physical movement of the robot in the space. The interaction module adds to the robot's movement three interaction layers:

- *Sound layer:* original sounds have been created to structure and articulate the play experience. They have been designed to give the impression of a living entity without any specific human or animal connotation. Sounds are used to assign a tempo to the activity, to structure spatial and proximity relations, to anticipate an intention to act, to underlie the effect of an action and externalise the robot's perception.
- *Physical actions layer:* allows movements of the interaction module in the stationary configuration, such as turning the head or performing some basic manipulation, such as grabbing and/or holding a small object. In the current implementation of the robot the arms have not yet been integrated.
- *Expression layer* (Figure 9) displays both the emotional status of the robot and dialogues with the users (action trigger and feedback). This layer is supported by the combination of visual representations on a digital display skin and on the head. The head performs different levels of facial expressions; the skin is a touch screen display whose main feature is to display both visual patterns for showing its emotional status and some controls that facilitate direct interaction with the robot.

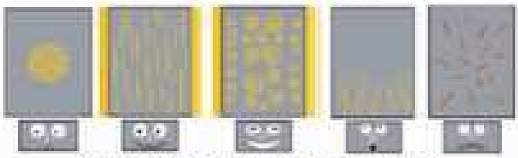

Figure 9: Robot's expressivity and emotions

Add-ons components

The *Add-ons* are simple passive components that can be added to the robot for emphasizing particular aesthetic and functional aspects. Different masks can be mounted on the head to hide parts of the face and to reduce the expressiveness (Figure 10). This feature is specifically designed for autistic children whose competence level in processing facial expressions can vary considerably in relation to the severity of the cognitive impairment. The combination of digital and physical components allows us to experiment with several setups, in order to find the solution that best fits the needs of the children.

Figure 10: The mask

Interactive coating modules

A set of interactive coating modules can be mounted on the robot's body to obtain different tactile and visual effects. The coating modules embed smart textiles that provide the robot with unusual visual, tactile and behavioural feedback resulting from material transformations.

Luminescent fabric modules

The Luminescent Fabric coating module (Figure 11) is made of coloured polyester and luminescent fibers. Different groups of luminescent fibers are weaved into the fabric and can have different colours. They can be managed independently – being controlled by one inverter each. The components are plugged into the sides of the robot and light up when the robot moves. Different light patterns can be obtained: the lateral modules blink fast together when the robot moves straight, only the right (left) module lights up when the robot turns right (left), a slow blinking appears when the robot is in waiting mode. This mechanism is used to reinforce the feedback on the robot status, in particular during movements and coordination games.

Figure 11: Luminescent fabric modules

Pressure sensitive textile module

A Pressure Sensitive Textile coating module (Figure 12) has been developed fixing a soft woolen cover on top of two metallic and conductive layers separated by an isolating layer. The conductive layers are made of steel wires while the isolating layer is composed of coloured polyester or transparent PA6 monofilament depending on the type of connection to the commutation. The fabric works like a switch: whenever the child strokes a sensitive area the robot laughs, emitting sounds. This module enables the "Tickling scenario" that consists of an exploration of the robot's body to discover where it is sensitive to tickling. The tickling zones change dynamically and children have fun in trying to guess where the robot is more sensitive. The game has been developed to improve perceptual functions such as auditory, visual, tactile and visuospatial perception as a basic form of communication in sensory stimulation games.

Figure 12: Pressure sensitive textile module

The interactive fur module

The "interactive fur" (Figure 13) is made of a soft woolen cover with static and moving hairs. The static hairs are knotted on a copper knitted fabric covering a dome-like fiberglass shell.

Figure 13: The interactive fur module

The moving hairs are fixed to the copper fabric, but their lower part is connected to a Nitinol spring (Figure 14).

Figure 14: The inner shell of the interactive fur with Nitinol springs

A total of 20 moving hairs are distributed on top of the shell. The central part of each Nitinol spring is connected to an electric wire wrapping around(?) the hairs. The Nitinol springs are fixed to the inner part of the dome shell by means of screws, and the electric wires are inserted through holes in the shell itself. When electricity passes from one extremity of the spring to the center, the other extremity contracts. In this way, the electric wire at the centre of the spring moves left and right together with the hair around which it is wrapped. The movement of the hair can be controlled in its timing, intensity and form. Since the hair is inserted in the copper fabric, which is not elastic, the movement of the lower part of the hair is transformed into a rotation of the hair, which in some cases can reach more then 100°. When half of the spring contracts, it is necessary to wait at least 20 seconds for it to cool down before the other half of the spring can contract. This makes the effect of the moving hairs seem quite natural, similar to the fur of an animal. Different implementations and controls of this module have been developed, embedding different kinds of sensors like proximity and sound sensors. When the child approaches the robot the fur moves, and the movement of the hairs correspond in timing and intensity to the movement of the person. If the child moves towards the robot quickly, it reacts with a fast movement of the fur. It the child crosses the robot from the right side, the fur reacts from the corresponding side. A similar behaviour can be obtained if the interactive fur is connected to audio sensors. If the child whispers to the robot from the right side, as she talks to the robot in the "right ear", the fur raises gently starting from the right side. It is usually more fun for children to shout in order to frighten the robot. In this case the fur reacts suddenly and the robot moves away. This module is used to reinforce the robot's behaviour in coordination and cause and effect games.

CONCLUSIVE REMARKS

The robot is currently being experimented with in primary schools and institutions in Spain, Italy, The Netherlands, Austria and the UK. Initial trials in a primary school in Siena (Italy) involved children with different cognitive and physical disabilities over a period of two months. All children involved in the trials, both disabled and typically developed, had fun playing together regardless of their different abilities. The play scenarios have been clearly understood and the children interacted appropriately with the robot, respecting the game rules, but also inventing new games. The robot played a fundamental role in mediating social relations among the children. Dynamics of peer-to-peer learning spontaneously emerged. The modularity of the robot was a key feature for stimulating creativity and symbolic play.

From a design viewpoint the robot has some distinctive qualities:

- Instrumental qualities – since the design choices reflect inclusiveness and social exchange.
- Aesthetic qualities – both in the robot appearance and expressiveness, thanks to the combination of digital and physical components.
- Innovation: the smart textiles produced and implemented in the additional modules are innovative and the related technology can be exploited in different domains.
- Ethical qualities and groundedness: the design process was centred on the children and their needs. Children, parents and teachers were involved from the very beginning and regarded not as *objects* of study, but as *active agents* within the design process itself.
- Impact: the modular design of Iromec can address the needs of a wide and variegated set of users. This feature increases the likelihood of the robot having a significant impact on current educational practices.

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9

CONCLUSIONS AND REFLECTIONS

The Design Cases presented in this thesis are the result of a long research activity I conducted from 2004 until 2011. Along these years the themes of aesthetic and embodied interaction slowly matured, and this thesis gave me the opportunity to reflect upon the influence they had on my work.

As said in chapter 4, the research was conducted combining Research-through-Design cycles with a user-centred design approach in order to stimulate reflection and understanding while trying to meet user desires and viewpoints.

Looking retrospectively to the Design Cases, a path of discovery through design practice was followed in seeking new understanding and generating novel research questions. In the first two Design Cases (Rolling Pins and Active Surfaces) the theme of Aesthetic of Interaction was not explicitly stated at the beginning of the design process. The projects were motivated by fuzzy problems without stable requirements. This somehow increased the initial complexity of the problem but at the end resulted in a more open design space where different themes could be explored and reflected upon. Typically this kind of problems are not expected to have right or wrong solutions but preferred situations that can be tried out and refined to increase the knowledge on the field and improve the (therapeutic) practice. In both Cases the projects were carried out to capture, analyse, explore and share solutions with different stakeholders (parents, teachers, therapists, nurses, doctors but also elderly and children who experimented with the prototypes). Once wealthy and experienceable prototypes were developed and the results of pilot tests were available, the theme of aesthetic interaction started to emerge posing new research questions on the relationship between design and disability. This relationship was explored as an iterative process in which experimental knowledge was generated through, and fed back in consequent cycles of designing, building, and experimentally testing experiential prototypes in the real-life settings. The effects of this iteration can be appreciated in the research questions addressed by Paper 2. This paper is a post hoc reflection on the design process and the concepts generated along the project. Paper 2 was published after Paper 1 that was more focused on the technology design and the experiment conducted within the home care context. The outcomes of that experiment and the continuous consultation with the experts, gave me the opportunity to reflect on the design process itself and make it more transparent and carefully documented. I went back to the literature review and the observational notes and produced the models of residual abilities that guided the generation of different concepts. Qualitative results of the experiments were included in Paper 2, which in turn disclosed new questions and shed light on new possibilities for the therapeutic practice. Paper 3 is a post hoc reflection on the user-centred approach adopted in the development of the Rolling Pins. The forms of participation of users in the design process were questioned and it was shown how they could vary from that presented as the prototypical UCD approach.

In Design Case 1 (Rolling Pins-RPs), the initial hypothesis was that embodied explorations can favour self and social awareness and promote shared intentionality. The hypothesis was generated from literature review, field observation and consultation of experts. By producing models of residual abilities of elderly with dementia, the design process was focused on providing a context for a social experience where the elderly can express themselves in an emotional and creative way using abilities that are not compromised.

The outcomes from field studies showed that the use of the Rolling Pins promoted a social ecology where therapist and patient could communicate empathically beyond the verbal exchange. Even if more extensive experimental results are necessary to provide fully validated results to evolve the exploratory use of the Rolling Pins in therapeutic protocols for people suffering from dementia, however the Rolling Pins can be regarded as an example of how a functional approach to accessibility can be effectively re-thought in terms of a more playful and aesthetic exploration of technologies supporting dementia care. The focus of empathic tuning was crucial to obtain positive and meaningful results, both in terms of efficacy of the therapeutic intervention and in terms of enjoyment, engagement and gratification of the elder.

A major intuition of Design Case 2 (Active Surfaces) was to design playful activities combining physical and cognitive rehabilitation in water. This intuition was generated by observing disabled children moving in the water. Water activities have a number of positive features: they stimulate children with proprioceptive and tactile input and offer a safe and supported environment. This environment does not only sustain the children making them autonomous in their movements, but also soothes and calms them, providing the necessary sensory input. Playing in water was regarded as a main vehicle to reduce the boredom and frustration of repetitive exercises and to exalt autonomy and self-confidence. The embodied interaction enabled by the Active Surfaces favoured the emergence of the exploration of body schemes and the control of spatial relations among the floating objects. This was a conquest for children not attributable to the simple mental access to these concepts. For the disabled children involved in the experiments, the exploration of body schemes and spatial concepts were mediated by the Active Surface that actually enabled the experience of their body in the world. Active Surfaces were not designed with the ultimate goal to allow the children to execute the tasks as defined by therapeutic protocols, but to provide a meaningful context for experience, where different cognitive and physical abilities can be tried out in a playful environment.

Design Case 3 (Premature Baby Care) was different from various respects. The conditions of the premature babies were often so precarious as to prevent any intervention or change in the environment that was not immediately functional to stabilize the health of the child. This was the reason why I tried hard to take advantage of the aesthetic focus on intimacy, fragility and (in)visibility without fully succeeding.

The priority of an accurate monitoring and a rapid and effective intervention on the baby in case of emergencies, precluded the implementation of all issues tackled in the concept generation. The theme of (in)visibility was only partially addressed. The presence of alarms, wires, tubes and complex displays was only partially reduced with the design of the sensitised mattress and the Bio-belt.

However the use of the mattress afforded emotional bonding between the parents and the child. The parents were aware that they could embrace the child without renouncing to constant monitoring of vital parameters of their baby. This made them more confident and keen to establish a direct contact with the child.

The focus on perceptual crossing in Design Case 4 (robot for kids) allowed for designing educational activities devoted to the acquisition of the mutual regulation of joint action in social exchanges. People inter-individually coordinate and reciprocally influence their movements in social interaction, and patterns of coordination dynamically influence the behaviour of the interacting partners. The robot, as an autonomous agent, represents a tremendous opportunity to experiment mutual regulation of joint actions. This is a social competence that children with relational or learning disturbances (e.g. autism) do not have. The focus on perceptual crossing allowed us to design the robot's behaviour without representing complex internal states and inferential mechanisms of shared intentionality. Shared intentionality was realised in a direct, non-mediated perceptual way, at the level of perceptual-motor skills.

In Design Case 4 the focus on aesthetic and embodied interaction fully matured. Aesthetic qualities were designed not only at the level of the playful experiential context offered by the robot but also at the level of interaction dynamics enabled by the use of smart materials. The coating modules of the robot embedded smart textiles to provide the robot with unusual visual, tactile and behavioural features. The research on smart materials started with the Design Case 3 and concentrated on the use of two different materials: a polyurethane gel with embedded sensors used for the mattress to record temperature, movements and interface pressures at specific anatomical points; and a cotton and lycra fabric used for the Bio-belt with embedded sensors and transducers for monitoring heart rate, breathing rate, body movements and temperature. The smart materials experimented with in Design Case 3 provided the opportunity to embody a kind of sensitivity in the design beyond the functional monitoring. The cotton fabric was soft, thin and pleasant to touch. It gave the possibility to eliminate adhesive sensors applied to the fragile skin of the baby that are usually harmful and part of the external wires. In fact replacement of the sensors causes skin irritation and the large number of wires contributes to engendering a sense of discomfort for the parents. The gel used for the mattress provided a delicate layer which embraced the child, sustained the baby's body and promoted direct contact with the parents.

The experience acquired with smart materials matured in Design Case 3 was precious for Design Case 4, where new and more challenging solutions were implemented and tested with children. A luminescent fabric was used to reinforce the feedback on the robot status, in particular during movements and coordination games. A pressure sensitive textile module was developed to enable the "Tickling scenario" consisting of an exploration of the robot's body to discover where it is sensitive to tickling. Finally the interactive fur was constructed to experiment dynamics of perceptual crossing. Designing with smart materials was a new challenge to improve the aesthetic qualities of the robot, matured from the reflection and the experience gained from the Design Case 3.

The Design Cases show a wide range of design challenges inspired by disability. Some of these may sound niche at first (e.g. perceptual crossing), but I believe they have a broad potential and a larger applicability also in other domains.

I do not consider that the different variations of design focus adopted in this thesis exhaust the potential of the aesthetic and embodied interaction in the design for disabilities. Nevertheless they contribute to answer the initial research questions in many respects.

Can therapeutic and rehabilitation aids be pleasurable and gratifying to use?
The prototypes described in the Design Cases offer a context for experience, rather being just rehabilitation aids. This experience is conveyed through embodied, tangible devices that stimulate feelings of engagement, emotional well-being and comfort during the therapy. Such experience engenders a positive attitude in the therapy and confidence of recovery making the activity itself pleasurable and gratifying.

Can disability be seen in terms of aesthetically-minded design rather than only in terms of accessibility legislation?
Throughout the dissertation, beauty is not seen as an isolated modality or property of an object/tool. It is related to the way in which the system behaves and responds over time in interplay with the person, and to the way in which it resonates with personal meaning and hopes of well-being. The therapeutic tools described in the Design Cases are surprising (Rolling Pins), playful (Active Surfaces), human-centred and respectful (Monitoring tools for premature babies), and rewarding (Robot for kids). They exalt a positive feeling of recovery providing a context for a rich and meaningful experience of care.

Can we set up an agenda with the seemingly reasonable goal of making therapeutic devices beautiful to use and pleasurable?
Therapeutic tools have the main objective to help people recovering from or maintaining specific abilities. A new agenda can be set up without negating this objective as a valid priority of therapeutic aids. However if this objective is adopted as the only priority, it can preclude that other fundamental qualities can inform the design.

A new design agenda should include societal and aesthetic sensitivity to make rehabilitation aids experiential and respectful of the person in the wholeness of his/her hopes and desires. The therapeutic devices should offer rich action-possibilities to compensate the loss of a specific ability. The designer should create a context for experience that is meaningful for the disabled person.

These values are lost during the therapy if a purely functional approach prevails. An aesthetically-minded design grounded in embodied interaction favours the re-appropriation of such values and restitutes dignity and naturalness at the therapeutic intervention.

9.1 Personal reflections

Applying the vision of aesthetic and embodied interaction to the field of disability was challenging. It was even more challenging and emotionally involving to try out and test all the developed prototypes in the real context of use.

I learned from people who spent their time and energy trying out the tools and making sense of them that sometimes their involvement in the design process may be very difficult to achieve and may even be undesirable. Domains like health care or rehabilitation are illuminating examples in this respect. The impairments of the users may limit the degree to which they can collaborate or express themselves appropriately.

Design activities involving people of differing abilities can run the risk of confusing a situated experience with a more systematic understanding of the problem at hand, thus leading to a potentially incorrect interpretation of real expectations and desires. The simple observation of people in these contexts is not only difficult but it is often improper and intrusive.

Also, apart from important ethical issues concerning the development, deployment and evaluation of systems in such settings, methods for eliciting needs, identifying opportunities and offering solutions in such a complex setting are relatively under-developed.

The methodological response I adopted to face these problems took a number of forms in the development of the Design Cases, as described in my publications. I turned my attention to a "light observation" of people's everyday life practices, putting most of my effort into participatory design with therapists and families combined with an analysis of relevant literature and modelling techniques to feed the conceptual design. The field observation resulted in a very naturalistic approach where I mainly used my senses, intuition and paid respect to the privacy of the people in the hosting institution (school, hospital, home care).

I tried to develop a sensitivity to the behavioural response of disabled people to simple external stimuli, to start generating concepts. I was struck by very basic sensory-motor patterns like grasping, rolling and pulling recurring in many of their activities (Design Case 1). I was impressed by the frustration of people in repeating boring and unnatural exercises in the swimming pool and by their excitement when moving autonomously in the water (Design Case 2). I was moved by parents of premature babies when perceiving the incubator as protection and barrier at the same time, and by their feeling of inadequacy when taking care of their baby (Design Case 3). I interpreted play as a fundamental right for disabled children and I looked for ways to let them discover play styles and get confident with their of possibilities (Design Case 4).

I realised that this sensitivity to the context could hardly find its expression in a functional approach to design and that the theoretical framework of aesthetic and embodied interaction could provide the ideal environment to unleash my intuition.

The next fundamental step of the design process was making. Physicality actually allowed me to think in a radically different way while exploiting to the fullest relevant domain issues and the opportunities offered by technology. Making was grounded in technology exploration.

Reflection was the next step. It was conducted in a "performance" way sharing the experience in context with elderly, children and their care givers. We reflected together on the opportunities offered by the final system, the potential impact on the current practices and the expected benefits.

Most of the prototypes presented in my Design Cases are still in use in home cares, schools and rehabilitation institutions. I consider this the best answer to my initial research questions.

10

SUMMARY

Aesthetic and embodied interaction is a central theme of this thesis and disability is the area chosen to challenge it.

Four Design Cases were developed to show the fundamental role that design could play in counteracting the impression of inconvenience of the disability condition that many rehabilitation aids inherently manifest. The ultimate objective was to exalt the beauty of interaction and satisfaction of recovery.

Central research questions guided my research:

Can therapeutic and rehabilitation aids be pleasurable and gratifying to use?

Can disability be seen in terms of aesthetically-minded design rather than only in terms of accessibility legislation?

Can we set up an agenda with the seemingly reasonable goal of making therapeutic devices beautiful to use and pleasurable?

These questions were addressed through the Design Cases which were illustrated in a collection of eight peer reviewed journal or conference papers that formed the core of the thesis.

The first part of the thesis clarified the context of research (chapters 1 and 2) and the theoretical and methodological approaches (chapter 3). The Aesthetics of Interaction was considered a new foundation for rich and embodied interaction which proved to be challenging since it was applied in contexts where perceptual and cognitive skills were reduced or impaired.

Throughout the dissertation, the term "beauty" was referred to as the experience of use that may lead to feelings of engagement, emotional well-being and comfort during the therapy. In this context the experience of beauty was enabled by therapeutic tools or systems that might engender a positive reflection and confidence of recovery. Therefore beauty was not seen as an isolated modality or property of an object/tool but it was related to the engagement and positive feeling of people during the therapy.

Aesthetic and embodied interaction came into play in the thesis by reflecting on the new challenges posed by complex technologies pervading our everyday living. New sensor-based and embedded technologies entailed a very different understanding than traditional interfaces, and required a novel and more 'ecological' appreciation of our relationship to technology.

The challenge was how to exploit these new technological possibilities for novel applications and experiences, which were inviting, playful and fascinating, and could improve life on an individual and societal basis.

The perspective of Aesthetics of Interaction adopted in response to this challenge was multifaceted and was explored in the domain of therapy and care along the following assumptions:

- Appreciated aesthetics engenders positive feelings which are of paramount importance to undertake a therapeutic path.
- Technologies should be experiential and respectful (Overbeeke et al. (1999) and designers should develop societal and aesthetic sensitivity when developing for disability support.
- The aesthetic interaction is enabled by the presence of rich action-possibilities (Wensveen, Overbeeke, Djajadiningrat, 2002) (Frens, 2006) involving the combination of different skills (not only the impaired ones) which makes the therapy more natural, intriguing and dignifying.
- The designer should aim at offering a context for experience, rather than just a beautiful product (Hummels, 2000).
- The aesthetic experience lies in playful narrative experiences (Dunne, 2005).

These assumptions were explored in the Design Cases with different focuses on aesthetic and embodied interaction.

Design Case 1 (Rolling Pins) was designed to support dementia care. Tangible interactive objects called Rolling Pins were developed to stimulate non verbal dialogues between therapists and elderly affected by dementia. In fact speech becomes increasingly inefficient with the progress of the disease. Progressive short-term memory difficulties and problems with new learning make conversations and other social interactions problematic.

The Rolling Pins embedded by design a concept of reciprocity and coordination. The focus on aesthetic and embodied interaction was based on emphatic tuning associated to choreographic movements and embodied playful exploration as pivotal concepts for design. The system allowed the elderly to explore expression modalities, establish emphatic relations and create a shared communication code with the therapist.

Design Cases 2 (Active Surfaces) was a system of floating tiles called Active Surfaces used to support aqua therapy for children with physical and cognitive disabilities. Therapeutic sessions were conceived as playful activities where children had to assemble the tiles into meaningful configurations defined by the therapist. The system design focused on play as a means to counteract the boredom of repetitive exercises and to combine motor and cognitive skills in the therapeutic practice. Moreover it addressed autonomy by exploiting the beneficial properties of the water including buoyancy that assists in supporting the weight of the person, viscosity that allows for muscle strengthening without the need of weights, hydrostatic pressure that improves posture awareness and the warmth that assists in relaxing muscles.

Design Case 3 (Premature baby care) discussed a fundamental concern deriving from the need to increase the focus on the social, emotional and intimate aspects in the design of technologies for the care of premature babies. The system was conceived as a soft and protective environment composed of foldable and sensitised components that gently embraced the baby to favour intimacy and emotional bond while monitoring his vital parameters in an unobtrusive way. It was an attempt to reconcile the viewpoints of different actors (parents, neonatal doctors, nurses) who played different roles in the premature baby care. In particular the Design Case showed how the design could bring together the functional/therapeutic view of neonatal doctors and nurses, with the parents' need of intimate contact and emotional bond with their baby. Issues of visibility, intimacy and fragility were considered as important as monitoring and control.

Design Case 4 (robot for kids) was a robot that engaged in educational games with children with different motor and cognitive disabilities. In order for the robot to be a believable playmate, it was designed to show intentional behaviour and express, pursue and share perception with the child during the game. Design Case 4 investigated the possibility of achieving by design a shared perception with the robot in order to enrich the experience of learning through play. For this reason, Design Case 4 had a focus on perceptual crossing (Auvray, Lenay, and Stewart, 2008) as a means to explore shared intentionality through mutual regulation of joint actions and perception.

The research along these four Design Cases was conducted through different research-through-design cycles performed in a diachronic, retrospective way, by reflecting on how the Cases evolved in time and which new topics and challenges emerged from practice in the field. Being inspired by the phenomenological orientation toward studying the human activity in context, research-through-design provided means and techniques to explore the mundane reality of everyday life of disabled people, their careers and the related socio-cultural milieu. It also allowed to develop design sensitivities that were used to focus on different aspects of aesthetic and embodied interaction.

During the research I spent time designing and exploring experienceable prototypes in the real context of use, reflecting back on the design process and the achieved results, and developing a set of research questions that guided the development of the next iteration of prototypes or projects. Research-through-Design cycles were combined with a user-centred design approach (Norman and Draper 1986). In fact in the development of the Design Cases I needed to constantly confront with potential users to understand problems and highlight opportunities to explore in the design. Users were involved in iterative design processes (Markopoulos, et a., 2008) even if the forms of participation were sometimes questioned and varied from that presented as the prototypical UCD approach (Marti, Bannon, 2009). User-centred design cycles as carried out in the Design Cases moved us away from simple user surveys or interviews and evaluations towards more active engagement of users in exploring the design space, experimenting with prototypes, contributing to a better understanding of the problems and also stimulating different viewpoints.

Chapter 9 presented my reflections on the four Design Cases, reconsidering the theoretical foundations of my research in light of the achieved results, as well as the methodological issues. The chapter concluded with the answers to the questions that motivated the research and some retrospective personal thoughts.

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CURRICULUM VITAE

Patrizia Marti was born on 19/08/1963 in Rome, Italy. After finishing the Liceo Scientifico in 1982, she studied Philosophy at the University "La Sapienza" in Rome, Italy. In 1987 she graduated on Artificial Intelligence and Automatic Natural Language Generation. In June 2010 she started a PhD project at Eindhoven University of Technology, The Netherlands of which the results are presented in this dissertation.

Since 1996 she is employed as Senior Researcher at the Communication Science Department, University of Siena, Italy where she teaches Interaction Design and Design of Learning Technologies. She is Rector's Delegate for Libraries at the University of Siena.

She has a long experience in fund raising at national and European level. He has been a Principal Investigator on 11 EU funded projects. She has been expert advisor to many EU and international bodies, including EU Commission, EU Future & Emerging Technologies Programme, EU Intelligent Information Interfaces, Eurocontrol, EU Disappearing Computer, UX group at University of Warsaw (Poland), Swedish Agency for Innovation Systems.

She is a Member of the Italian SigCHI chapter and ACM. She has been a Program Chair and Associate Editor for the CHItaly Conference and Ro-Man conference. She has served Scientific and Organizing Committees in various areas of HCI, ID and Information Systems, including ACM CHI, ACM IDC, ACM DIS, IEEE ICRA, IEEE IROS, IEEE ICORR.

She has been an invited keynote speaker at different European conferences in the UK (AISB), Italy (PD), France (LIFT), Tanzania (TEDC), Italy (LIFT).

She has been promoter of 7 PhD students, University of Siena and University of Firenze (I), (from 2004 until 2011), and External Examiner for Ph.D. candidates at Aalborg University, Denmark (2011), University of Hertfordshire, Hatfield, UK (2011), Aarhus University (2011).

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