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CONCEPTUAL FRAMEWORK FOR SOCIAL AND EMPHATIC BEHAVIOUR FOR ROBOT COMPANION

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Short description

This document describes the work carried out in WP2, Task 2.3: "Empathic behaviour and robot expressiveness", providing a conceptual framework for social and empathic behaviour for robot companion. The framework is articulated as a theoretical and design exploration through the development of prototype behaviour that have been implemented in the Care-O-bot platform. The design process was incremental and evolved through different cycles of evaluation and re-design of the different solutions. The outcomes of the design and evaluation activity were in turn used to reflect back on the theory and improve the solutions.

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1 Introduction

This deliverable describes the results of the research conducted in T2.3 on the behaviours that trigger empathic exchanges between an older person and the robot.

The report illustrates the theory that inspired the design process and the results of formative user evaluations of the empathic and expressive behaviours implemented in the Care-O-bot.

In more detail, we experimented with 4 concepts and related designs:

- Graphical User Interface (GUI)

- Dynamic mask and perspective taking

- Perceptual crossing

- Squeeze Me

Empathy is a controversial construct, evoking debate over its nature, definition and measurement in any context. It implies the apprehension of another's inner world and a joint understanding of emotions.

Notwithstanding its argumentative connotation, its beneficial effect on attitudes and social behavior is widely recognized. This is the reason why a growing number of applications of the concept have emerged in different fields. For example in HCI, Bickmore (2003) and Paiva et al. (2004) attempted to emulate empathy in virtual agents. In design research, Koskinen at al. (2003) developed methods and techniques as inspiration for design, to understand how people make sense of emotions. In the field of assistive robotics, Tapus and Matarić (2008; 2007) developed a model of empathic interaction based on verbal and non-verbal communication with robots.

Taking a phenomenological approach to action and perception, we believe that empathy is not a result of an internal judgment or a merely cognitive activity. It is a social product emerging dynamically as an outcome of the interaction whereby actions and perception of people synergize with one another.

In our approach, we take the human capabilities as central to achieving an empathic relationship. We aim at mapping the continuities of our being to the discreteness of machine. With this we mean that the way people are in the world is of continuous nature contrary to the discrete way machines are engineered.

Our research is guided preliminary by phenomenology of perception (Merleau-Ponty, 1962) and ecological psychology (Gibson, 1986) to study how people approach the world. We start from these theories as they centralize the subjective experience of people when they engage with the world. Both theories highlight the role of the body and its active perceptive nature while engaging. They claim that meaning is not in the world or in the 'mind' but that it emerges in interaction in between people and the world.

In the following we describe in detail four concepts and the related designs, each one incorporating the theory with different emphasis and nuances.

2 Graphical User Interface (GUI)

Over the past decades, GUIs have been grounded in several metaphors (such as the desktop-metaphor) in order to bridge our tangible world to the digital. Through the acknowledgement of embodiment and technological developments such as multi-touch, in the past years, natural interactions have been pushed forward as seen in actions like pinching-to-zoom and turn-to-rotate. Nonetheless, interface designs tend to stick to their desktop-metaphors and overlook the opportunity of an embodiment of action in the environment. In other words, through symbolic icons, hierarchies, menu structures and other procedures, the end-user faces a complexity only tackled with their cognitive skills. Psychologists and social scientists (Suchman, 1987) have argued that a technology-oriented interpretation does not properly address the full richness of socio-cultural, emotional and situated components of a context. In developing the GUI to control Care-O-bot, we aim to re-balance addressing all human skills by regarding the perceptual-motor, emotional and social skill as well as the cognitive ones.

In the following, we present the GUI that has been developed to interact with Care-O-bot. The design utilizes Gibsonian notions of affordance and intensity to provide access to contextual relevant functions within a smart environment.

2.1 Theory and design

Gibson (1986) suggests that perception concerns the tuning of our body (as our perceptual-system) to information, contrary to mentally capturing and storing information. We do so in holistic ways attuning to what is useful information through, what Shaw and McIntyre (1974) characterize as *attensity*, i.e., a measure of ecological significance of an object or event for an organism in a particular environment. For example, a musician develops his hearing capabilities; similarly, an obstetrician develops his/her sense of touch. Ecological Psychology thus stresses the unity of human and artefact and the attuning qualities of our effectivities, i.e. our bodies become sensitive to its environment to where it requires sensitivity. Essential notions are Gibson's concepts of affordance and effectivities (Norman, 1988), which encompass that we perceive the world in terms of what we can do in and with it, i.e., we perceive useful information in terms of action-possibilities. This basic notion is the starting point for our design for interaction between people and robot (Marti, Stienstra, 2013c).

A central idea of the GUI is the concept of action-possibility, that is, the potential for the robot to act in the world and execute tasks for people (Stienstra et. Al submitted). The GUI is dynamic since the action-possibilities change according to the interplay between the specific configurations of the environment, the person's potential needs and desires, and the likelihood of the robot executing a task. The action-possibilities are displayed on the GUI as simple icons, organized by relevance (Marti el al., 2013) (Figure 1).

Figure 1. The GUI with action-possibilities

The size of the icon indicates the possible action that is most likely to be performed. For instance, if the person did not drink for a few hours, the action-possibility "Bring me water" pops up to encourage the person to drink and avoid dehydration. This scenario is allowed thanks to a smart environment with a multi-angle camera fusion system and sensor network providing information about the living patterns of the older person and current states of tangible objects and the environment (Amirabdollahian, 2013).

With this GUI the user gets access to high-level functions of the robot such as 'bringing water', 'delivering a parcel', 'turning off the light' and so forth. As said above, these functions are presented in order of contextual relevance.

This means that the smart environment of the Care-O-bot assesses the likelihood of a functionality (action-possibility), whether it is possible (in the physical world) and desired (by the older person). Concretely, this means that the GUI will not present the function of 'switch off the light' while the light is off, and will not present the function 'make a coffee with milk' while the system assesses that the elderly person likes his coffee black.

The size of the functions, shown and clickable on the tablet, is mapped to the likelihood; if 'turning on the light' is more relevant than 'closing the curtain' the function will be shown bigger and thereby made more accessible for the elderly person. This likelihood is further used to make the Care-O-bot take initiative. In case the likelihood of drinking water (and the availability of clean glasses and water) exceeds an urgent threshold, Care-O-bot will propose or even perform supplying the elderly person with a much-needed drink.

This design for interaction provides ground for empathic relations to emerge. The Care-O-bot and elderly person are immersed in a common understanding of their specific context because of the interaction being shared. The higher-level assisting and collaborative functions of the Care-O-bot are empowered in the graphical user interface through contextual-personalisation. The elderly person is enabled to see what the Care-O-bot can do in the given context.

The system architecture and database (Figure 2) were initiated in the first year of the project, however the interface design went through several iterations that mainly tuned the graphics and choice of wording concerning the action-possibilities towards readability and fitting with the concept.

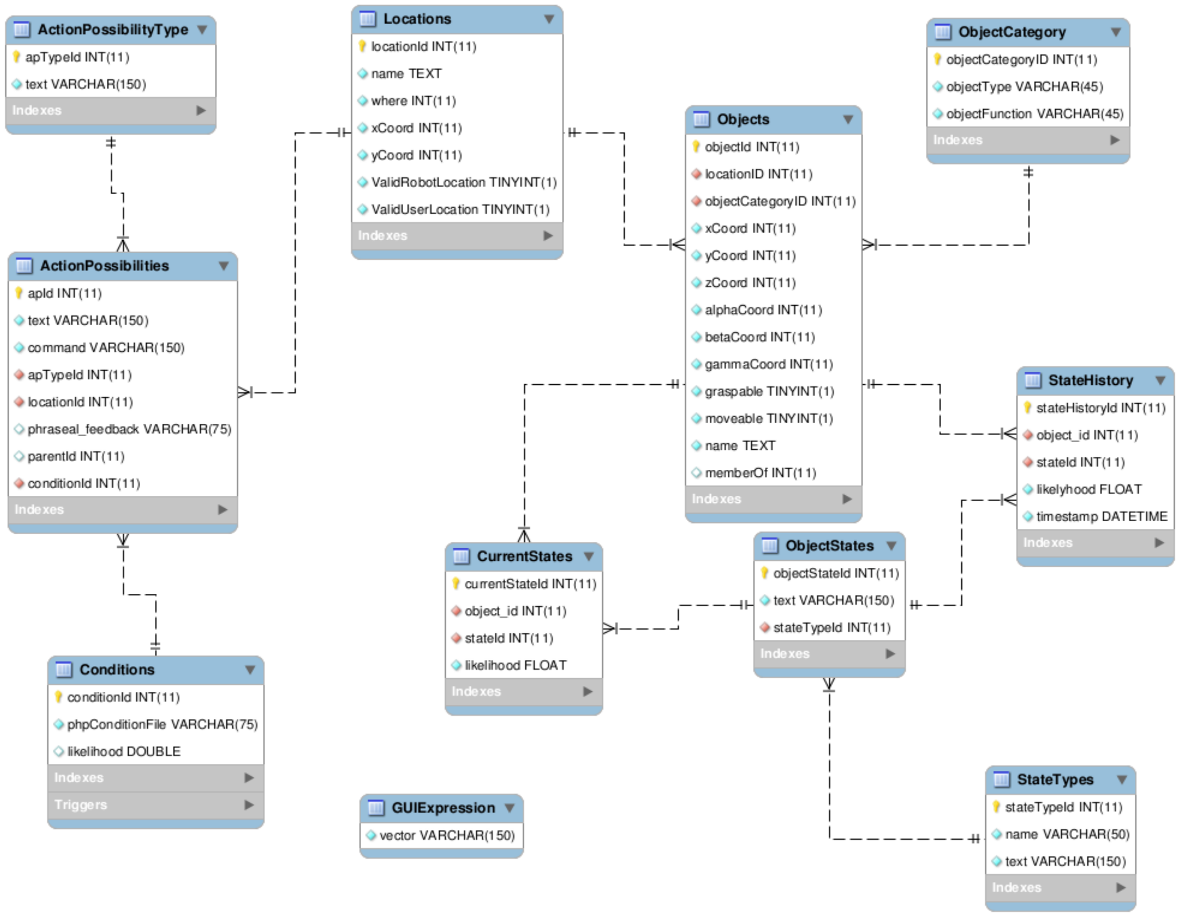

Figure 2. System architecture and database

2.2 Interaction Scenarios

The purpose of the GUI is to function as control for an assistive robot in a smart environment. Here we describe three scenarios to illustrate the diversity of opportunities the interface opens up and the way the system attunes to people's behaviour within interaction.

Scenario 1 "Lighting"

… After waking up early full of energy I was able to turn on the lights myself. But, now I found myself comfortable in the big chair enjoying the sunrise, I turn to the robot to turn off the lamp. Prominently available on the tablet is the action-possibility 'turn off the light'; turning it on is nowhere to be found. I decide to press the label and see the robot executing what I asked for. But still the sunlight keeps glaring in my face. It is going to be a bright day. Again I turn to the tablet in order to see what the robot can do for me. This time it shows me 'turn on the light' but not as prominently as 'partly close window-blinds'. When pressing this label the robot moves to the blinds and adjusts them to half open. On the interface a slider appears showing the window blind to be half open. I decide to open the blinds a bit more by moving the slider so I could enjoy the view outside. After a while, when it gets darker, the robot goes to the window again to adjust the blinds to keep me with enough light.

Within the lighting scenario three action-possibilities were addressed; 'turn off the light', 'turn on the light', 'partly close window-blinds'.

The likelihood for the action-possibility 'Turn off the light' is constructed as follows; [the current status of light should be on * (distance of person to lighted space + brightness in space in relation to the personal prefered)]. This first identifier functions as a condition. If the light is already off there would be no action-possibility that allows turning off the light at all. The second identifier raises the likelihood for 'turning off the light' when the light is left on when the room has been left. In more subtle ways, when the person moves through the space, the action-possibility on the GUI will change its size and location smoothly. The third identifier raises the likelihood when there is external lighting or decreases the likelihood if there is still not enough light for the person. The likelihood for the action-possibility 'Turn on the light' is constructed in similar manner; the current status of the light should be off and the relevancy increases when the light is needed by the person in the location. In case a person enters a room in the dark, the likelihood most likely surpasses a certain degree making the robot take initiative and turn on the light autonomously.

Within the scenario presented it was stated that the action-possibility 'partly close window blinds' is shown bigger, more centralized and thus more accessible than the action-possibility 'turn on the light'. This is caused by the status of the light in the space that influences the identifier 'brightness in space in relation to the personal preference' for the light which is somewhat absent because of the sunlight. In the case of the 'partly open or close window blinds' action-possibility the sunlight exceeding the personal preferred brightness in the space immediately raises its likelihood which is constructed on the basis of this identifier solely. The more sunlight and light from lamps, the higher its likelihood to be executed. The suggested shading of the blinds is offered in the reciprocal relation between what the blinds can do in order to achieve the preferred brightness.

When the user adjusted the window blind openness with the slider, the personal preferred brightness was adjusted. This did not modify the structure of the likelihood but merely a status (the database not the relevancy attunement) that influences it. We later give an example that actually adjusts the structure of the likelihood of action-possibilities.

Scenario 2 “Drinking water”

… It is getting dark, let me turn on the light. Maybe the robot can do this, I feel lazy right now. Good, the screen is filled with things the robot can do for me. Let’s see, ‘clean the floor’, ‘get me water’. Yes there it is, ‘turn on the light’... Isn’t this actor also in the Godfather, he is so familiar? Ohh, maybe the interface can help me out. On the middle of the screen the option to have more information about the current movie is given, next to it, slightly bigger than before ‘get me water’ is shown. Ahh well, first let me get more information about the actor… The robot comes driving up to me, carrying a glass of water on its tray. Almost obtrusively the drink is held in front of me. I should have been taking care of myself before...

We would like to highlight that the presented action-possibilities are merely suggestions. Within the scenario, drinking water is ignored for a long time. The likelihood increases on the basis of increasing thirst on the persons side. In the end of the scenario the likelihood is surpassed for the robot to take initiative. The likelihood of the ‘get me water’ action-possibility is constructed as [water available * clean glass available * sufficient robot-energy level * person’s thirst]. The first two identifiers of the likelihood are obvious conditions, without water or a clean glass it would be impossible for the action to be executed. Though the action-possibility ‘clean glass’ would have surpassed its threshold making the robot clean on its initiative. Water could for example be added to a shopping list when being absent. The sufficient robot-energy level condition brings about estimation whether the robot is physically able to perform the action-possibility, this identifier is present in most likelihoods and requires a complex real-time calculation.

While robot energy involves a robot-informer element in relation to the task to be executed, thirst is obviously depicted from the user and will most likely increase over time.

Scenario 3 “Preferred coffee”

… Settled behind the big table, the newspaper opened in front of me. I turn to the interface, there it is, ‘bring me a mild cappuccino’ centralized, surrounded by a series of smaller coffee variants...

As hinted at before, serving coffee depends on a variety of aspects such as the availability of cups, coffee, milk and sugar, clean coffee machine, reachability of materials and power levels of the robot. Different from the water example, coffee most likely does not depict on thirst solely. Coffee comes in many ways, whether it is an espresso, cappuccino or long one; whether it is with or without milk or sugar and so on. Each of these action-possibilities could have their personal preference relation which would make the one that has been drunk the most become the most relevant however this does not provide any information about whether a coffee is desired or not. Physiological measurements of thirst within behaviour could be feasible, yet physiological signs of a desire for coffee are harder to measure.

What we apply here is a different way of establishing a likelihood that requires learning. Besides the main likelihood informants coined before, the likelihood is computed taking into account all the variables that were present during previous times a certain coffee has been drunk. By doing this, in time the most relevant informers emerge thus leading to a dynamic contextual likelihood. Maybe it is the open newspaper, the bad night's sleep, the presence of a partner or the routine to drink every day at exactly three minutes past eight (from an embodied perspective we would stem this with the rising of the sun instead of the descartian framing of time) that coincide with our craving for a strong coffee. The challenge here is to filter to meaningless coincidences such as a door that is always left open or simply the light that is turned on or a chair that is in a specific location. Therefore likelihoods shape not only through looking at the statuses when action-possibilities are accessed but also when they are not.

2.3 Formative User Evaluation of the GUI

A formative user evaluation of the GUI was conducted in Siena through a Participatory Design (PD) process carried out in a Residential Home Care for self-sufficient elderly people in Siena. Six elderly participants (Male=2; Female=4) with a mean age of 83.17 joined the study.

The aim of the PD was to evaluate the GUI with different techniques and different supporting materials in order to involve elderly people in the design of future system. The aim of the study was also to evaluate the role of the GUI in engaging older people with empathic interactions with the robot.

We experimented with different techniques from video-based scenario evaluation to hands-on and gaming activity in which participants had to evaluate the dynamics of the GUI (Figure 3 and Figure 4).

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Figure 3. Older people engaged in the evaluation of the GUI through hands-on activities

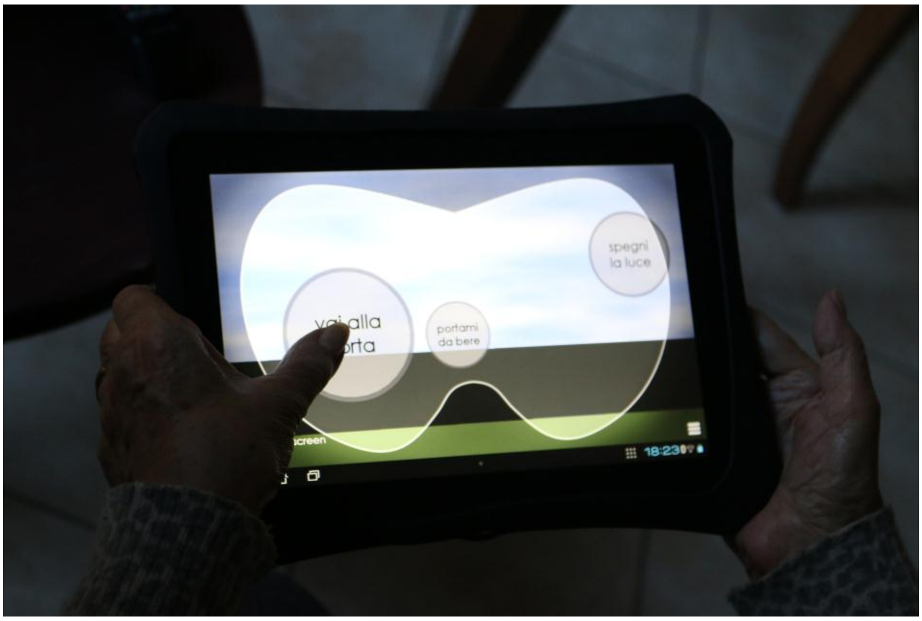

Figure 4. Walkthrough scenario

This permitted exploration of experiential elements of design, to reduce the need for the participants to engage in abstract thought and to collect insights on design solutions while having fun together.

The GUI was well accepted by the participants who declared to have understood the concept of action-possibility as well as the interface dynamics. During the scenario-based evaluation they were able to anticipate which action-possibility was the most likely to occur. A 91-year-old lady stated that the action-possibilities represented shared needs of the person and the robot itself. They were interpreted as something good for the person and for the robot as well. Indeed, the GUI only suggested actions that the robot could execute in a specific situation, so that it never looked foolish or unable to perform effectively.

During the evaluation, the facilitator stimulated the verbalisation of experiences of some personal significance in interaction with the robot to understand how the elderly could make sense of this relationship in ordinary everyday life. She encouraged description of first person accounts and invited narratives and reflection on personal experiences using metaphors and past memories. With this type of support, none of the participants showed difficulties during the interaction. Only two of them reported that the tablet was too heavy to handle, but in general the GUI proved to be easy to use and adequate in mediating an engaging relationship with the older person.

A detailed description of the protocol used during the evaluation and the outcomes of the evaluation sessions is contained in Iacono, Marti (2014). The paper is enclosed in Appendix 1.

3 Dynamic mask and Perspective taking

Since the GUI was designed for domestic use, there has been an effort to emphasize the experience of living with the robot, focusing on feelings of engagement and empathy, rather than solely on functional aspects. Therefore, on top of what the robot can *do*, that is represented by action-possibilities, we designed a graphical-user-interface layer, the emotional perspective, which shows how the Care-O-bot is *feeling*. We enriched the robot-view by a graphical layer representing the feelings of the robot (Stienstra et al., 2013, Marti, P. & Stienstra, J.T. (2013).

This view represents a mask that provides a sort of binocular vision superimposed over the iconic representation of action-possibilities. The mask helps focus attention on what the robot is looking at. We designed two constructs for expressive intentionality representation, the first one concerns internal feelings of the Care-O-bot while the second one concerns the reciprocal interplay with the direct surroundings (i.e., environment as well as elderly person's input) directing feelings.

Parameters taken as the internal feeling of the Care-O-bot are for example how full the battery is charged or the heat of the internal processor. Parameters taken as feelings of the Care-O-bot that are constituted through a reciprocal interplay with the environment or elderly person are for example the temperature and light intensity in the space (either by how the Care-O-bot perceives directly by its own sensors or provided by external environmental sensors). Feelings directly induced by the elderly person in interaction are for example the expressive way the interface is handled (subtle, polite, or aggressive), the ratio in which the elderly person ignores the Care-O-bot throughout the day or the amount of energy a task approached via the interface demands (once the task is being executed these will most likely be covered by the earlier mentioned internal feelings).

The *feelings* are not represented by values or icons *on top* of the view but via a dynamic layer *within* the robot-view constituted by a mask with shape-changing eyesight. The mask is the view's shape and size, it is like a goggle view with an adjustable shape. The shape-changing eyesight is defined by several dynamic lines (being the border of visible to non visible). They are separate eyelid-parts that together can constitute several expressive tensions such as angry, explorative, or surprisedness.

The mask is dynamic. It displays smooth transitions of the robot's view, thus pretending to express the robot's emotional state (Figure 5).

Figure 5. The dynamic mask

Whilst the action-possibilities indicate what the robot can do in context, the mask shows how the robot feels in order to share its internal states with the person on an emotional level. Expressions were designed drawing inspiration from Ekman's Six Basic Emotions (1999) and nuances found in the human face.

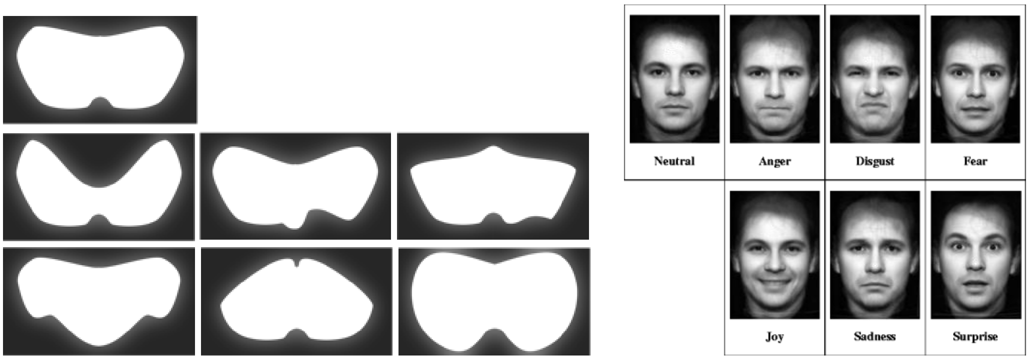

Figure 6. Designed expressions of the mask inspired by Eckman's Six Basic Emotions.

3.1 Formative User Evaluation of the dynamic mask

In order to evaluate the dynamic mask we designed four video scenarios depicting situations where the robot was asked by the participant to execute some tasks. Each scenario was shown in two versions: with a static robot-view and with the dynamic, expressive robot-view represented by the mask. Sixty people (M=33, F=27) were involved in the study.

The hypothesis of the study was that when robot's behaviour conforms to human social expectations, interactions are more likely to be found enjoyable and meaningful by people. Furthermore the expressivity of the mask is expected to result in empathic interactions with the robot and therefore to sustain rich and meaningful social exchanges.

The results of a questionnaire administered to the participants showed a preference for the people to interact with the dynamic expressive mask. Expressivity was a means to stimulate empathic concern and to facilitate perspective taking during the execution of the scenarios.

The outcomes of the study show that the use of the dynamic mask had a positive impact on the participant's ability towards empathic concern and perspective taking. The dynamic mask facilitated the comprehension of the scenarios. People felt emotionally involved with the robot as expressed in the qualitative comments reported in an open-ended section of the evaluation.

A man (18-35 years old) wrote that the empathic mask gave the impression that the robot was able to reflect on the situation at hand and react in a socially appropriate way.

Interestingly various participants reported a "learning effect" when watching the scenarios. Apparently it was easier to recognise the robot's empathic expressions after a while, usually in the last watched scenarios. The robot's behaviour became more familiar and the empathic expressions more meaningful and engaging.

Full details of the evaluation protocol and the qualitative and quantitative results of the study are described in Marti et. al, 2013b. The paper is enclosed in Appendix 2.

4 Perceptual Crossing

4.1 Theory

Perceptual-crossing as coined by Lenay and Auvray (Auvray, Lenay, & Stewart, 2009) (Lenay, 2010) and further explored by Marti (Marti, 2010) and Deckers (Deckers et al. 2011; 2012; 2012; 2013) in the field of interaction design boils down to the phenomenon in which two people look at each other and their eyes meet. It is the moment where I see you, seeing me. On itself this can be intensely experienced yet it does not convey functionality as such. Therefore perceptual-crossing is mainly applied to initiate 'conversation' as it does provide grounds for a shared context.

Perceptual-crossing is often extended with the phenomenon in which a person sees where the other person is looking. For example, I see in your eyes that things occur behind me.

The reason for studying perceptual crossing in human-robot interaction, is that through providing the artefact with shared perception in the interaction, the behaviour of the person can be changed. This relates to perceptual-crossing in a way that the person's actions are mapped to the actions of the artefact in a natural expressive way, providing ground for an engaging relationship (Marti et al., 2014b).

The paradigms of perceptual crossing seem to have similarities with synchronization, yet we would like to stress that perceptual-crossing is not about this. A following behaviour will create a 'mirror', but we could say that the figure in the mirror is not someone else, not another subjectivity to engage with. We aim to achieve that the user becomes immersed in an engagement with another subjective being; the Care-O-bot. Not to be a mirror, but an entity to empathise with.

Our research applies principles of perceptual crossing to achieve a mutual understanding for both entities (robot and human being) in order to immerse in a shared context and to grasp the intentions of the other. The '"grasping" and the acting upon in our paradigm go hand in hand. This work explores the reciprocal character.

4.2 Interaction Scenarios

The concept of perceptual crossing was implemented in three behaviour designs for a robot's movement that extend and explore qualities of the perceptual-crossing paradigm in relation to functional purposes. Within three simple scenarios, movement behaviour designs are applied that negotiate the behaviour of both actors in interaction. For instance, when a robot and a person face a door and they both intend to go through it, a designed behaviour negotiates who is to go first in appropriate manner, either the human or the robot.

The scenarios were firstly implemented in a prototype platform using Magabot, on which was mounted a shell similar to Care-O-bot, as described in D2.2: Low fidelity prototypes and mock-ups for perceptual crossing. In the third year of the project, the scenarios above were successfully integrated in the Care-O-bot platform by IPA.

Furthermore, UH implemented in the Care-O-bot platform, a fourth scenario of perceptual crossing, entitled “I See You Seeing Me”. The scenario pivots around a single point the Care-O-Bot will follow the elderly person when the latter is facing the Care-O-Bot.

In the following we describe three scenarios which were submitted to user evaluation as explained below.

Scenario 1 “Let’s move”

Alex (the human in the videos) and the robot are in a room. The robot is located in front of him. Alex has been sitting for a long time and now he needs to get up and walk. In the condition without perceptual-crossing, the robot stands in front of the person without doing anything. When the person stands up, it remains in the same position. In the condition with perceptual-crossing, the robot anticipates or provokes action from the person. The robot somehow blocks the way for the person but when the person begins to get up, the robot will make way for him. This initiation of movement also lies with the robot.

Scenario 2 “Walking together”

Alex moves to the next room. Suddenly he stops because he does not remember if he took his medicines. In the condition without perceptual-crossing, the robot continues to move, since it has been programmed to go from A to B. In the condition with perceptual-crossing, the robot stops when the person stops. It starts moving again together with the person, at the same pace, when he resumes walking.

Scenario 3 – "Let's cross paths"

Alex and the robot move to the next room through a door. Moving together from A to B might not always be exactly what is needed. This scenario shows how the person and robot switch sides along the route. In the condition without perceptual-crossing, the robot goes through the door first, actually preventing the person from going first. In the condition with perceptual-crossing, it makes room for the person to go through the door first.

4.3 Formative User evaluation of Perceptual Crossing

The scenarios of perceptual crossing were recorded as video clips, in two different conditions, with and without perceptual crossing, and submitted to 60 subjects who evaluated the videos in both conditions. The participants (M=30; F=30) aged between 18 and 92 years. Participants aged over 70 had a mean age equal to 82.92. The participants voluntarily joined the study. The elderly participants were recruited in a residential home for self-sufficient seniors in Siena, Italy.

Videos of scenario 1 are available at following links:

https://vimeo.com/86604601 (condition without perceptual-crossing)

https://vimeo.com/86611451 (condition with perceptual-crossing)

Videos of scenario 2 are available at following links:

https://vimeo.com/86687906 (condition without perceptual-crossing)

https://vimeo.com/86703123 (condition with perceptual-crossing)

Videos of scenario 3 are available at following links:

https://vimeo.com/87457361 (condition without perceptual crossing)

In the condition "without perceptual crossing", the behaviour works on the basis of discrete triggers and maintains predefined movement speeds. In the "walking together" scenario, for instance, in the condition with perceptual crossing, the robot walks along with the person with the goal of going from A to B; ; while in the condition without perceptual-crossing the robot moves from A to B at a fixed pace (which may, with luck, coincide with the person's pace).

The results of the experiment show that the scene with perceptual-crossing between robot and human is preferred to the one without perceptual-crossing. These results are particularly meaningful since they compare two age groups: between 18 and 35 years old and over 70, showing that the situation with perceptual-crossing is preferred by both younger and elderly participants.

Full details of the evaluation protocol and the outcomes of the study are described in Marti et. al. (2014b), including quantitative data and statistics. The paper is enclosed in Appendix 3.

5 Squeeze Me

5.1 Concept

Squeeze Me explores the emergence of empathic behavior between human and machine by sparking an expression-rich relation. The Squeeze Me is a squeezable device used to grab attention from a robot providing ground for expressive values to be shared. The expressions exerted on the mediating device by the human are mapped to expressive behaviors of the robot in the modality of motion in forthcoming interaction (Marti et al., 2014 a).

The aim of the Squeeze Me design is the constitution of empathy within a human and robot context, bringing together earlier work on empathy in the field of robotics with interaction design paradigms such as natural, rich and embodied interaction that build upon the emergence of meaning in the interaction.

We explore the emergence of empathy provided by coherently natural and moody responsiveness via a haptic input modality provided by Squeeze Me. With this input device the user, in our case an independent living elderly person, is enabled to request attention from a caregiving robot, the Care-O-bot. We just focus on attention requests from the elderly assume the robot can complete the following tasks described in the scenarios below:

Scenario 1 "Direct Interaction Mapping"

... just brushed my teeth, and surprisingly I was able to take a refreshing shower after yet another warm night. It is not easy facing the heat; it makes me tired, even more. Time to sit down and explore some tv channels, amusing myself by what the world is concerned with nowadays. Thirst is getting to me, perhaps the effort to shower myself took the best of me for the day. I need a drink, pff, getting out of this chair? No way, it is comfortable but I do not even

have the strength to get out if I have to move around all day with this sun pushing the energy out of me. No the sun is not what it used to be. Ok, focus, water ... Help, now what? Care-O-bot is there to assist me, but it is early. I didn't see him move around yet, perhaps he is still asleep. Well lets just wake him up to get me some water, after that I might have the strength to do some things on my own again ... his help is needed, I squeeze gently, it is merely a pinch in the remote. Would he have even felt it? Yes, slow but smoothly Care-O--bot turns towards me. Calmly driving in my direction. He is awake, and actually seems rather helpful today, perhaps not as grumpy as last night ...

Naturally Approaching

The Squeeze Me device is a simple (analog) force-sensing- resistor to which we directly map the values of the movement of the robot. The expressions exerted on the mediating device by the human are mapped to expressive behaviors of the robot in the modality of motion in forthcoming interaction. A short pinch results in a sturdy movement, a hard squeeze results in a quick movement and a gentle touch in a slow approach. This direct mapping inherently exhibits a natural relationship and maintains the richness exhibited by the user.

Scenario 2 "Moody Interaction Mapping"

... Care-O-bot has been helpful today, yes, life can be lazy. Living from my chair, and the more firmly I squeeze, I am attended more rapidly ... What is going on, he turns his back to me. That's not the way it is supposed to be, I will squeeze again! Listen! No? fine, I do it myself! ... ow come on, give me a hand. I simply do not have the strength for this. Maybe I shouldn't have used you as my slave today. Making you run around, for me to live like a king. Sorry, please, just take me to bed, I'll ask gently ...

Mood

On top of the directly mapped expressions of pinching to movement, interactions that inhibit a natural relationships, we here provide an amplifying and reductive mapping layer. This layer shifts the direct mapping towards a less expected mapping throughout the day (through interaction). The dynamic adjustments of expressive mapping, sometimes even inverting the input towards response provide a vivid and lively interaction. With a natural relationship as a reference, the moody interaction evokes denial, over-enthusiasm, stubbornness and require the elderly person to adjust their behavior in interaction. A relationship is constructed through these shifting interactions, we target for empathy through moodiness within a natural response.

The Squeeze Me aims at developing an empathy relation between the elderly user and robot through enabling expressive and rich interactions with a robot companion. The concept of empathic behavior is enabled by inherently meaningful and moody interactions implemented via prototypes and as part of an iterative design process.

5.2 Three cycles of incremental design

Squeeze Me has been designed and developed adopting an incremental and iterative process. We spent time exploring usable prototypes in the real context of use and reflected on the achieved results. The iterative design cycles were conducted by reflecting on how the different prototypes evolved in time and which new topics and challenges emerged from practice in the field.

5.3 First prototype

The first Squeeze Me prototype was a rigid plastic shell mounted on the tablet, the inner part of which hosted electronic components (Figure 7).

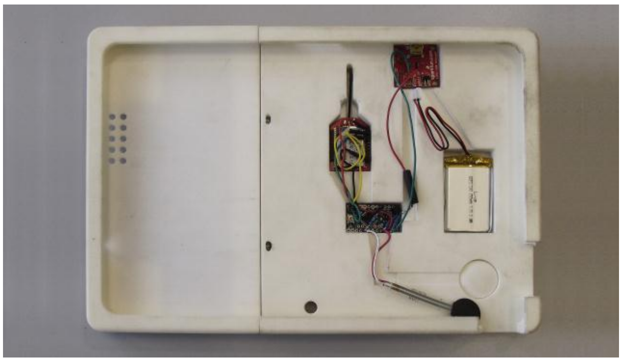

Figure 7. First prototype

The cover was 3D printed using a FDM plastic process. The electronics included the following components:

- Arduino Pro (Mini) 328 3.3V / 8 MHz
- FSR sensor
- Wifly module

• 3.7V LiPo Battery

• Battery Charger for LiPo

The design of the casing was simple (Figure 8). A button with FSR (Force Sensing Resistor) was placed on the top left side of the outer casing, to enable the user to easily and consciously access the functionality of getting attention from the robot. The button further was slightly hollowed with the intention to make it easily findable.

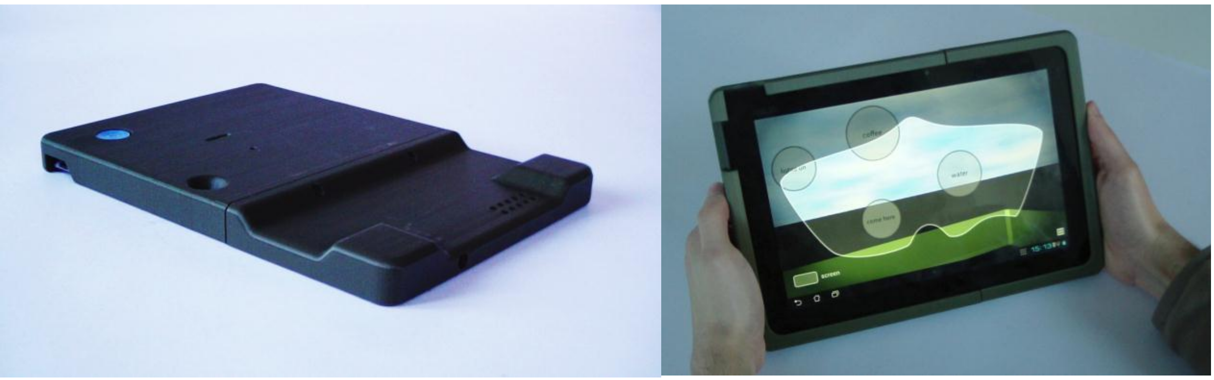

Figure 8. Casing of the first prototype

An Arduino Pro 328 3.3 V placed inside the cover took care of the data acquisition and interpretation in relation to the intensity of the pressure on the button. The data was sent via WiFi to a server that communicated with a scheduler designed to manage the action-possibilities to be taken by the robot.

5.3.1 Formative user evaluation of the first prototype

The first prototype was submitted to user testing at MADoPA. The test was undertaken in a smart home environment, equipped with the full robotic platform including Care-O-bot, and involved 18 older people with a median age of 73.8, 10 informal caregivers and 6 professional caregivers.

The participants were invited to evaluate the Squeeze Me by walking through a simple scenario, where the user gets a different reaction in movement of the robot, depending on the way of squeezing.

The outcome of the evaluation was primarily concerned with the material qualities of the casing and the feedback.

The main problems revealed during the evaluation were: Inadequate affordance of the button as a squeezing input modality.

The button was not visible to the user since it was placed behind the cover, was therefore difficult to locate because of unnatural positioning with respect to the handgrip.

The size of the button was too small. People often turned the cover to find the button, but then they had to turn it back to use the GUI. This made interaction unpleasant and ineffective.

The plastic was too rigid and made the tablet too heavy to handle.

The prototype provided for two kinds of feedback according the Wensveen's categorization (2004): functional feedback resulting in variation of the robot's speed, which was mapped to the pressure exerted on the button, and inherent feedback, related to the mechanical resistance of the button when pressed. When the button was pressed, the robot took time to start its movement. This disconnected the directness needed for achieving a sense of being in control while exerting pressure.

The mechanical resistance of the button made it difficult to detect the amount of pressure exerted by the user. The interaction was not smooth because of the inherent resistance of the material. The inadequacy of inherent feedback inevitably negatively impacted the functional feedback. Users were unaware of the pressure they exerted on the button and therefore they were unable to appreciate the cause / effect relationship between the variation of pressure and movement of the robot.

More details about the evaluation are contained in Marti et al., (submitted). The paper is enclosed in Appendix 4.

5.4 Second prototype

Taking the results from testing the first prototype into account, we built a second version of the system by improving it and enhancing all of its components. This process required complete redesign of the cover in terms of form, materials and electronics.

The second prototype was designed with a more ergonomic handgrip, to be handled with one or two hands, and pleasant to touch (Figure 9). The cover was made of soft rubber that can be squeezed to share expressive behaviour with the robot though continuous interaction.

Figure 9. The second prototype

The cover was 3D printed using the digital light processing technique (DLP), which uses a liquid polymer consolidated by exposure to an adiactinic light. This technique permits manipulation of soft plastic materials. Moreover, DLP printing allows for high-level definition of the object's details.

Two different plastic materials were used to print the cover. The black part was made of a dark malleable synthetic resin, whilst the white part was made of acrylonitrile-butadiene-styrene (ABS).

This harder plastic material was used to print the rigid central part of the cover, which provided both protection and room for allocating the electronics.

The main requirement for the electronics was to overcome the limitations imposed by the button contained in the previous prototype, and make the input surface much wider. The system was then implemented using the following components:

• Arduino mini 328 3.3v 8MHz

• Bluetooth modem BlueSMiRF Silver

• LiPo battery 3.7 V 1400mAH

• Printed circuit board (PCB)

• Specially designed textile analogous pressure sensors.

Even though detection and processing of data from the sensors remained within Arduino, in the same way as the first prototype, we transformed all the other components of the system. First, we replaced the FSR sensor with textile analogue pressure sensors designed by Plug&Wear (http://www.plugandwear.com). These sensors work as an analogue press button with the resistive principle.

The soft plastic and smart textile sensors improved the affordance of the cover toward squeezing.

The software controlling the cover was changed too. It consisted of an Arduino sketch that detected data through analogue readings of the sensor's resistance variation. Using 10kΩ pull-down resistors (1 for each sensor), it was possible to obtain an interval between 0 and 1023. This range was divided into different intervals, each of which was associated with a graphic transition of the mask. The intensity of pressure applied to the sensors permitted variation within this interval, and therefore different mask expressions.

The new software code also provided digital data smoothing; each sensor was read three times, and the values were stored in an array, from which the modal value was extracted. In this way we could minimise measurement errors caused by noise.

Moreover, in order to prevent sensors from being pressed inadvertently, the interaction design was implemented in such a way that it was necessary to pass a minimum pressure value simultaneously on both sensors. This means that the cover had to be squeezed with both hands to be effective. In other words, to avoid unconscious and accidental pressure, the design constrains its interaction paradigm by requiring two-handedness.

Below this value the system remained inactive. After the detection and smoothing phases, data were sent to the Tablet via a Bluetooth connection.

The software managing the expressive mask on the tablet was written in Java and had a twofold purpose:

To realize the “morphing effect” (transitions) among the various expressions of the mask.

To control the robot's speed according to the pressure applied to the cover by the person squeezing the device.

This implementation was used to enrich the system’s feedback. In addition to the functional feedback (the robot’s movement) and the inherent feedback (the kinaesthetic qualities of the soft plastic), we added an augmented feedback that was realised by integrating the pressure of the squeezing with the transition of mask expressions. This enriched the response of the system to the user’s action.

The tablet was connected to a database via WiFi, and with the cover via Bluetooth (serial communication). All the images related to the 9 basic expressions of the mask were contained in an external database. All changes in expression were realized through graphical transitions on the GUI. In order to achieve the morphing effect, different images were designed, the transition of which resulted in a pleasant, fluid experience. The software first checked if there was any input from the sensors inside the cover; if no input was detected (nobody was squeezing the cover), the GUI returned a neutral expression and the robot's movement was unmodified. On the contrary, when the person squeezed the device, the software retrieved the appropriate graphic transition, and the mask changed. The robot moved accordingly.

The cover was suitable for interaction with both hands and there was no longer a need to turn the tablet in search of a button, given that the entire surface grasped by the user appeared to be sensitive to squeezing.

We decided also to change the WiFi communication with the server that managed the robot's behaviour and implement local communication with the tablet via Bluetooth. This is because during testing of the first prototype, WiFi communication with the server had proven to be noisy and subject to interruptions due to high packet loss. Use of Bluetooth communication made the system much faster and more responsive.

The components were not connected to each other using cables but were soldered on a PCB specifically re-designed to suit the new cover. This allowed us to eliminate cables and the need to insulate electronic components.

5.4.1 Formative user evaluation of the second prototype

The re-design of the prototype in the material and interactive components greatly improved the experience for the users.

The second prototype was evaluated in Italy. We hypothesised that the new tablet would be much easier to use and would improve the user experience. .

Evaluation sessions were carried out in the form of a workshop held in a Residential Home Care for self-sufficient seniors in Siena. Six elderly participants (2 males and 4 females) with a mean age of 83.17 were involved. Since the real robot was not available, the activity was organized with the support of a simulation environment.

None of the participants showed difficulty during the interaction and in general all of them showed an open-minded, playful attitude during the evaluation.

They fully understood how the robot's expressions changed according to the situation, the emotional state of the robot and the way they influenced the emotional response through squeezing.

The augmented feedback provided by the graphical transition of the mask, mapped to the pressure exerted by the user, greatly helped comprehension of the system's behaviour.

Although the new Squeeze Me was generally well received by the participants, there were still some issues related to the weight of the tablet and the quality of feedback.

Two participants reported that the tablet was too heavy to handle and other participants did not clearly understand the mapping between the robot's movement and the pressure they exerted on the cover. Apparently the visual feedback of the dynamic mask was not sufficient.

They clearly understood the differences in the way the robot moved, and also the differences in the expressivity of the mask. However, they were not able to clearly relate them to their way of squeezing. In particular, they were unsure about how hard or gentle their squeezing was.

Furthermore, despite the improvement offered by the elasticity of the soft plastic of the second prototype to afford squeezing, beyond a certain level of pressure, the material reached its maximum compression and behaved as if it was rigid. This made it difficult to understand the intensity of the pressure applied to the cover since the kinaesthetic response of the material did not provide sufficiently clear inherent feedback.

More details about the evaluation are contained in Marti et al., (submitted). The paper is enclosed in Appendix.

5.5 Third prototype

In the light of the outcome of the second evaluation cycle we decided to improve the quality of tactile feedback by adding an augmented feedback to the inherent one afforded by the soft plastic. We embedded six small motors inside the cover that vibrated each time the pressure sensors were pressed. The greater the intensity of the pressure, the greater the perceived vibration. This was achieved in real time to stay ahead of the slightly delayed feedback of the robot's movement, which still takes a little time before it actually starts to move due to its physics.

The response after an informal user test of the use of vibration was positive, and the majority of people welcomed the addition of the new feedback, emphasizing the ability to perceive the intensity of the pressure without the need to look at the screen on the tablet.

6 Conclusion

In this report we provide a phenomenology-inspired design framework for social and emphatic behaviour for robot companions. Our approach aims at achieving an empathic relationship between the older person and the robot by providing continuous, expressive opportunities to allow interaction and meaning to emerge. We illustrate our approach with four different designs and several interaction scenarios and conclude this research reporting the result of formal evaluation cycles that fed the incremental design process.

To approach the empathic exchange with a bottom-up and "behaviour-based" design strategy, we adopted a phenomenological approach to action and perception. This approach proved to hold value for the interaction between an elderly user and robot in achieving an empathic relationship.

Four different designs were implemented and experimented on field trials with older people: a context-dependent GUI allowing meaning to emerge in interaction, a dynamic expressive mask allowing the user to share the perspective of the robot, perceptual crossing behaviours influenced by the way in which the user and the robot perceive each other, and the Squeeze Me, a graspable squeezable device that supports espressive communication between person and robot.

Our prototypes show that empathic demeanors in human-robot interaction can be achieved in a direct, perceptual way not necessarily mediated by the use of complex pre-planned behaviours to provoke an empathic exchange to emerge. In particular, the interaction design of the perceptual-crossing behaviour and the Squeeze Me rely on coupling and mapping actions and their effects through a continuous action-perception loop exploiting the richness and continuity of our embodied and social skills-defined procedures or sequences of actions. The proposed interaction designs do not require the representation of complex internal states and inferential mechanisms in the robot to provoke an empathic behavior to emerge. In particular, the interaction design of the perceptual-crossing behaviour and the Squeeze Me rely on coupling and mapping actions and their effects through a continuous action-perception loop exploiting the richness and continuity of our embodied and social skills.

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8 Appendixes

8.1 Appendix 1

Iacono I, Marti P, (2014) Engaging Older People With Participatory Design. In Proceedings of the 8th Nordic Conference on Human-Computer Interaction (NordiCHI), 2014 Oct 26-30, Helsinki, Finland.

8.2 Appendix 2

Marti, P., Iacono, I., Tittarelli, M., Stienstra, J. (2013b) Shaping Empathy Through Perspective Taking. In *Proc. RO-MAN2013*, (2013), ISSN :1944-9445, 751 – 756.

8.3 Appendix 3

Marti, P., Iacono, I., Stienstra, J., Tittarelli, M., (2014b) Exploring Movement Qualities in a Reciprocal Engagement, In Proceedings of the 4th International Conference on Development and Learning and on Epigenetic Robotics, Genova 13-16 October 2014.

8.4 Appendix 4

Marti, P., Stienstra, J., Sirizzotti, M., Iacono, I., (submitted) Expressive touch and materials in continuous-sustained interaction design, Submitted to TOCHI.

Engaging Older People With Participatory Design

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Abstract

We present a design case focusing on participatory design (PD) with older people. We experimented with PD techniques to foster engagement with participants in development of a graphical user interface (GUI) for controlling a robotic system in a smart home environment. The tenet of our approach is that to engage older people in the design of future systems, it is of paramount importance to increment and reinforce knowledge using different techniques and materials, and to create an empathic and trusted relationship between participants and designers. We experimented with different techniques for achieving this, from video-based scenario evaluation to hands-on and gaming activity in which participants had to evaluate the dynamics of a context-dependent interface using an expression-rich modality of interaction. This permitted exploration of experiential elements of design, to reduce the need for the participants to engage in abstract thought and to collect insights on design solutions while having fun together. The entire procedure implied incremental PD cycles in which knowledge was shared and consolidated through a learning process based on doing and playing together. The final reflections highlight a number of recommendations that demand consideration when undertaking research and design work with older people.

Author Keywords
Participatory design; older people; gaming; empathy.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
For many years older people have been excluded from design activities because they are considered resistant to technology [6], and this has also happened with PD projects. More recently a growing body of research has begun to emerge focusing on PD with older people [8]; [11]. Lindsay et al. [7] proposed an approach to PD with older people focusing on creation of a comfortable and relaxed environment. They emphasized the importance of establishing an emphatic and trusting relationship with participants, stating that the role of the facilitator becomes particularly crucial when working with seniors.
The design case presented in this paper describes PD sessions with older people, who were involved in envisioning the potential of a GUI to control a robot in a smart home environment. Different techniques were tried out to engage participants in the design activities, as well as to facilitate the creation of an empathic relationship between participants and facilitator. PD sessions developed in iterative cycles where previous knowledge was consolidated and shared among the participants, and reinforced through the use of different materials and content.

Design Case
The work presented in this paper is supported by ACCOMPANY (Acceptable robotiCs COMPanions for AgeiNg Years), a European project funded under FP7-ICT-2011-7. The project aims to facilitate independent living of seniors at home using an assistive robot, namely Care-o-Bot, in a smart home environment. The robot is equipped with omnidirectional drives, a seven degrees-of-freedom manipulator, a three-finger gripper and a tray that can be used to carry objects. Its 'head' contains range and image sensors enabling object learning and detection and 3-dimensional supervision of the environment in real time. It can autonomously move, can fetch, carry and manipulate objects. A major challenge of the research is to explore rich and natural ways for interaction with a focus on engaging relations between human and machine [9].
A GUI on a tablet is the main means of interacting with the robot. It was developed using a person-centred approach that pivots upon the uniqueness of older people's skills by providing continuous and expressive opportunities for interaction and meaning to emerge [13]. A phenomenology–inspired design was adopted to define the GUI [12]. In particular, we focused on the role of context and affordances in shaping our perception. A key point of the approach is the uniqueness of the relationship between our lived experience and the environment, which is personal and dynamic. It is affected by the affordances offered by the environment [5] and refers to the meaning that objects assume for the person who makes sense of them. Taking these tenets from phenomenology and ecological psychology, we developed a dynamic and context-dependent GUI to be used by the elderly at home to control an assistive robot.
A central idea of the GUI is the concept of action-possibility, that is, the potential for the robot to act in the world and execute tasks for people. The GUI is dynamic since the action-possibilities change according

Figure 1. Graphical User Interface

to the interplay between the specific configurations of the environment, the person's potential needs and desires, and the likelihood of the robot executing a task. The action-possibilities are displayed on the GUI as simple icons, organized by relevance [10] (Figure 1). The size of the icon indicates the possible action that is most likely to be performed. For instance, if the person did not drink for a few hours, the action-possibility "Bring me water" pops up to encourage the person to drink and avoid dehydration. This scenario is allowed thanks to a smart environment with a multi-angle camera fusion system and sensor network providing information about the living patterns of the older person and current states of tangible objects and the environment [1].

Since the GUI was designed for domestic use, there has been an effort to emphasize the experience of living with the robot, focusing on feelings of engagement and empathy, rather than solely on functional aspects. For this reason, the GUI contains a robot-view, so that the person can see what Care-o-bot is looking at, as if the older person can see through the eyes of the robot. This view is displayed as an additional graphical layer. It represents a mask that provides a sort of binocular vision superimposed over the iconic representation of action-possibilities. The mask helps focus attention on what the robot is looking at. This encourages the person to take the robot's perspective, share its viewpoint, and likely guess the reason why a task might be difficult to execute. Perspective taking is indeed a typical social behaviour that leads to manifestations of empathic exchanges [3]. The mask is dynamic. It displays smooth transitions of the robot's view, thus pretending to express the robot's emotional state (Figure 2). Whilst the action-possibilities indicate what the robot can do in context, the mask shows how the robot feels in order to share its internal states with the person on an emotional level. Expressions were designed drawing inspiration form Eckman's Six Basic Emotions [4] and evaluated by older people involved in the PD process.

The PD process

The PD process was carried out in the form of a workshop held in a Residential Home Care for self-sufficient elderly people in Siena, Italy. Six elderly people (2 males and 4 females) with a mean age of 83.17 were involved. The activity was organized in four phases (Figure 3): familiarization; envisioning and evaluation; playing together; performance with a simulated scenario. The phases were entirely video recorded. Open questions were used to evaluate scenarios of use, concept and dynamics of the action-possibilities and the mask's expressivity, but also to obtain insight into the experience of living with a robot at home. Different supporting materials were used during the sessions: a video scenario, images on paper, coloured pens, a photo camera, and a simulation environment with a digital version of the robot.

Familiarization

During the first phase, the facilitator presented a video scenario showing Care-o-Bot in interaction with an older person in a home-like environment. The scenario developed in two scenes. In the first scene the person sat on the sofa. The doorbell rang, suggesting that someone was waiting outside the door. The robot's view was transferred to the GUI on the tablet. A surprised expression of the mask was displayed together with a new action-possibility "Move to the door", bigger than the other possible actions on the GUI. The person selected the biggest action and the

Figure 2. Dynamic mask. From top to bottom: neutral, joy, fear and sadness.

robot slowly moved toward the door. The postman delivered a parcel and put it on the robot's tray. A new action-possibility, "Bring me the parcel", appeared on the GUI; the person selected it and the robot moved toward the sofa, offering the parcel and bowing very politely. The second scene started with the robot moving toward the sofa. The person had not drunk for hours and it was time to have some water to avoid dehydration. The expression of the robot was sad until the person agreed to go to the kitchen together: the action-possibility "Go to the kitchen to take a drink" was the biggest icon on the screen. As the person selected it, the mask's expression changed from sad to happy, and the robot moved aside to let the person pass first. In this way, Care-O-bot manifested its intention to execute the task together, so that the person could walk a bit and stay active.

The facilitator invited the participants to comment on the video, trying to balance the interventions of confident and shy participants. She paid attention to make all participants feel like equal partners in the activity. The elderly were asked about the role of the robot, what it was supposed to do in the home environment, and how they could engage in interaction. The scenes were considered clear by all participants. Notwithstanding the subtleties of some interactions, the participants focused on the robot's functionality. Most of the dynamics and context-dependent behaviour of the GUI remained unnoticed or unexplored.

Envisioning and evaluation

The second phase of the session repeated the same scenario using a different technique. People were invited to walk through a photo storyboard bearing different scenes. Each participant received a copy of the photo storyboard and a coloured pen to draw on it. The facilitator recalled the scenes, encouraging the elderly to use the images freely. This hands-on activity completely changed their perception of the GUI. They managed to trace the mask's contours, highlighting the expressions with different colours. They fully understood how the robot's expressions changed according to the situation and the emotional state of the robot. A 91-year-old man, when looking at a joyful expression of the mask, said: *"I can see its eyes… I can see the joy … its eyes are smiling…"*. Then he started drawing the robot's eyes, nose and mouth, sharing his reflections with the other participants.

The group also showed an empathic attitude toward the robot. They felt sorry when it was sad, and were keen to help. Most of the subtleties of the robot's behaviour that had remained unnoticed in the previous phase were more clearly appreciated, like the one in the second scene, when the robot moved aside to let the person pass first. Furthermore, participants succeeded in understanding the dynamics of the action-possibilities, anticipating which of them was the most likely to occur. A 91-year-old lady stated that the action-possibilities represented shared needs of the person and the robot itself. They were interpreted as something good for the person and for the robot as well. Indeed, the GUI only suggested actions that the robot could execute in a specific situation, so that it never looked foolish or unable.

Playing together

The third phase of the session involved a playful activity. Other researchers have used games in PD activities. Games, in fact, allow the participants to use their skills and preferences in a collaborative and non-competitive way, exploring different design possibilities [2]. In order to reinforce the knowledge generated in

Figure 2. PD activities (From top to bottom) familiarization; envisioning and evaluation; playing together, performance with a simulated scenario.

the previous phase, the facilitator randomly distributed images of the mask's expressions and different labels naming them on the table. The game consisted in associating the right label with the corresponding mask. The game was over when all participants associated the labels with the expressions. The facilitator played an important role during the game. She actively contributed by creating a playful atmosphere in which people could guess the combinations without any fear of making mistakes. Interestingly, only two people made a mistake. They all enjoyed the activity and collaborated to reach the final goal. At the end of the game, the facilitator proposed mimicking the different expressions and posing beside the image of the robot's mask (Figure 4). Then she took photos that generated hilarity and fun. This greatly contributed to maintaining a friendly, relaxed atmosphere.

Performance with a simulated scenario

The final phase in the session was used to practice with the knowledge acquired in the previous phases and to try out the GUI with a simulation environment, since the real robot was not available. A 3D representation of a home environment similar to the one depicted in the video scenario was projected on a large screen. The participants sat in front of it, taking turns trying out the GUI. The same scenario as was presented in the familiarisation phase was tried out. A digital version of the robot responded to the commands entered on the GUI by the participants. The GUI was fully working, so that the elderly could try alternative paths. The facilitator stimulated the verbalisation of experiences of some personal significance in interaction with the robot to understand how the elderly could make sense of this relationship in ordinary everyday life. She encouraged description of first person accounts and invited narratives and reflection on personal experiences using metaphors and past memories. With this type of support, none of the participants showed difficulties during the interaction. Only two of them reported that the tablet was too heavy.

Lessons learned

Involving elderly people in PD was challenging and insightful at the same time. PD sessions were used in the project to improve the look and feel of the GUI, and to generate new scenarios for use. The design case was also illuminating in deriving lessons about how to make older people feel engaged, and in identifying the activities best suited to their skills, the materials which are most versatile, and the roles they can play with the support of the facilitator. The outcomes of our design case can be regarded as recommendations that demand consideration when undertaking PD with older people.

- *Knowledge is not acquired by older people once and for all.* Learning how to use an interface is a slow process that requires intermediate steps. Knowledge has to be reinforced using different media and materials.
- *Video-based evaluation is less effective than hands-on experience.* People need to make sense of an experience by appropriating content and transforming it through practical activities.
- *Playing together is an effective means of participation.* Through the game, the elderly confronted issues that are not really close to them, and that could be considered abstract or unlikely. The game encouraged an open-minded, playful attitude.
- *The role of the facilitator is essential.* She has to create an empathic and trusted relationship as well as a

Figure 4. Elderly people mimicking expressions of the robot mask

relaxed atmosphere and a family environment. She has to spend time just listening in a respectful way and suspending judgement. She has to adopt a clear and understandable language that is accessible for all participants.

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- *Concepts must be reinforced by proposing alternative views and different representations of them.* This is fundamental, particularly when working with people with memory deficiencies.

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Shaping empathy through perspective taking

Patrizia Marti, Iolanda Iacono, Michele Tittarelli and Jelle Stienstra

Abstract— **This paper describes an explorative study to evaluate a dynamic expressive mask associated to a remote robot-view used to control an assistive robot. The mask is generated by a graphical-user-interface platform displayed on a tablet used to control the robot in a smart home environment. The hypothesis of the study is that when robot's behaviour conforms to human social expectations, interactions are more likely to be found enjoyable and meaningful by people. Furthermore the expressivity of the mask is expected to result in empathic interactions with the robot and therefore to sustain rich and meaningful social exchanges. In this study we compared four scenarios of interaction between a robot and a person at home. The scenarios depicted scenes where the robot was asked to execute tasks. Each scenario was showed in two versions: with a static robot-view and with a dynamic, expressive robot-view. The results of a questionnaire administered to 60 persons showed a preference of people to interact with the dynamic expressive mask. Expressivity was a means to stimulate empathic concern and to facilitate perspective taking during the execution of the scenarios.**

I. Introduction

In this paper we describe our design approach to develop a graphical-user-interface platform to control an assistive robot, namely Care-o-Bot, in a smart home environment.

Care-o-Bot is a mobile robot with a machine-like appearance able to assist older persons at home. The robot is equipped with an arm manipulator, a three-finger gripper and a tray that can be used to carry objects. The body contains range and image sensors enabling object learning and detection and 3-dimensional supervision of the environment in real time. The robot can detect, fetch, carry and manipulate objects.

Care-o-Bot is part of a larger system including an intelligent home environment enhanced with a multi-angle camera fusion system and sensor network. This equipment provides information about the living patterns of the older person, current states of objects present in the environment and the environment itself.

The smart environment including the robot has been developed in the context of ACCOMPANY (Acceptable robotiCs COMPanions for AgeiNg Years), an European project funded under FP7-ICT-2011-7 (http://accompanyproject.eu). The project aims to facilitate independent living of older persons at home. A major challenge of the research is to explore rich and natural ways for interaction, focusing on empathy as a means to enable meaningful and engaging relations between human and machine.

Empathy is a fundamental feature of human being that enables us to reach out and connect with others, to know what another person is thinking or feeling and to actually feel another's emotional state [1]. Recently the research on empathy has experienced a renewed attention and the advancements in particular in the field of social psychology and neuroscience research have inspired other fields of research including technology design. For example, different projects have been developed to establish empathic interactions with synthetic characters to enhance cooperation, specifically on educational, training and counseling/helping perspectives [2, 3, 4]. Rodriguez et al [5] proposed a model of empathy for virtual characters that aims to enable emergent empathic interactions between them, in a way that is perceived by users as well. Other researchers [6] explored in empathy in socially assistive robotics building on the findings of different psychologists who showed that empathy plays a key role for therapeutic improvement (e.g., [7]) and their assumption that empathy mediates pro-social behaviour [8].

In particular in the field of assistive robotics, the majority of robots strive to advance the state of the art in technological fields such as planning, object handling, autonomous movement, language processing etc.. In the ACCOMPANY project we aim to develop a robot with social skills to enrich the interaction and prolong it beyond the initial encounter.

This challenge is explored through the design of innovative concepts of empathic interaction embodying the perspective of the robot companion using dynamic and context-dependent graphical interface. With our work we hope to inspire user-interface designers to utilize *emotional* and *social skills* by shifting from purely functional, and hierarchical, to expressive rich, contextualized and continuous-sustained paradigms for interaction.

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II. DESIGN

A context dependent and personalized graphical-user-interface capitalized within perspective taking is one of the concepts of social behaviour that we have been developing in the project. Through a tablet interface (“Fig.1“), the person can see action-possibilities that can be performed by or with the robot at the moment of interaction [8]. The action-possibilities are organized by relevance. In time, the older person’s usage of action-possibilities will influence their relevance with respect to a specific context of use.

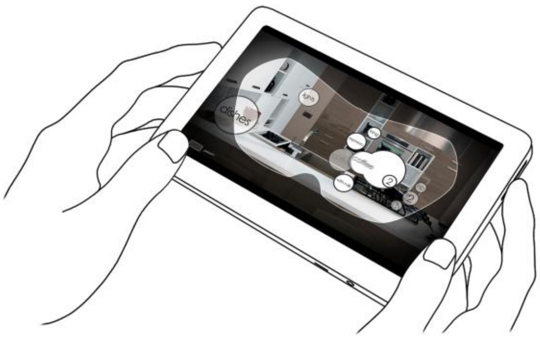

Figure 1. Seeing through the robot’s eyes: context depending action possibilities, varying in size depending on their likelihoods.

While selecting a desired action-possibility through clicking the Care-O-Bot will start performing. The elderly persons can see how the task is performed from the Care-O-Bot’s eyes. On completion of the task, the displayed action-possibilities are updated as the context has changed through the task executed by the robot (e.g. after closing the door, ‘closing the door’ is most likely not actionable anymore and has been substituted by another action-possibility namely ‘open the door’).

The robot-view displays what the Care-O-Bot is looking at. This view is covered with a mask indicating a clear vision in the centre and cloudy one outside the centre. As if looking through the robot’s eyes. Whilst the action-possibilities show what the robot can do in context, the mask shows how the robot feels in order to share its internal states with the person on an emotional level. To this aim we developed an emotional-perspective platform to display expressions through a dynamic mask [9].

We design two constructs for expressive representation, the first one concerns internal feelings of the Care-O-Bot, while the second one concerns the reciprocal interplay with the direct surrounding (i.e. environment as well as person’s input) directing feelings. Examples of parameters taken as internal feelings of the Care-O-Bot are the battery level or the heat of the internal processor. Examples of parameters taken as feelings of the Care-O-Bot that are constituted through a reciprocal interplay with the environment or person are the temperature and light intensity in the space. An example of feelings directly induced by the person in interaction are for the ratio in which the person ignores the Care-O-Bot throughout the day. Details about how parameters are used to generate expressions are described in [10]. Mapping these parameters to the robot’s expressions generate changes in the robot-view on the tablet. A typical scenario may be when the sound-scape around the robot becomes annoying (e.g. when an object falls down or a door slams). In this scenario the mask will retract as if the eyes get smaller. Metaphorically, the Care-O-Bot closes its senses to the overload of information.

The robot’s feelings are expressed via two dynamic layers within the robot-view: 1) using graphical filters; and 2) through a continuous shape-changing eyesight (mask). The graphical filters are for example continuous-scaled blur, saturation, opacity and gamma. The shape-changing eyesight expressions shows expressions in relation to Ekman’s basic expressions [11] and nuances found in the human face.

III. EVALUATION

In order to evaluate the two modalities of expressing feelings through the robot-view interface, we designed the following scenarios.

Scenario 1 “The vase falls down“

The window is open and a sudden wind makes a vase falling down. The mask displayed on the robot-view interface shows that the robot is scared about this noise. The robot moves toward the source of noise and looks at the plant laying on the floor. The mask changes again showing sadness. The scenario contains two expressions, fear and sadness depicted in frame 6 and 8 in “Fig. 2“.

Figure 2. The “Vase falls down“ scenario

Scenario 2 “The rotten apple“

Ann would like to have a snack. She asks the robot to bring her an apple entering the command through the interface. The robot moves to the kitchen and looks at a basket containing apples. It focuses on a rotten apple. Ann can see from the interface on the tablet that the mask changes to express disgust. The scenario contains only one expression, the disgust, depicted in frame 7 in “Fig. 3“.

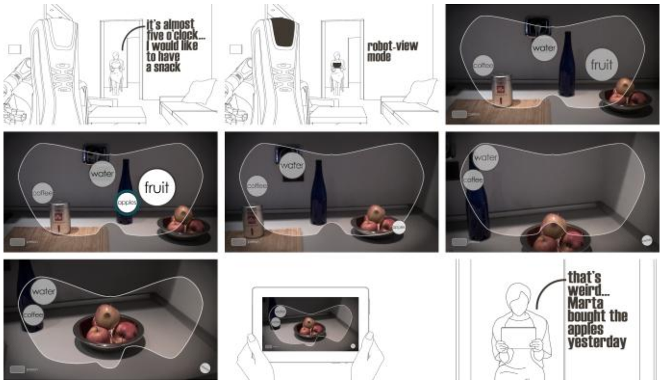

Figure 3. “The rotten apple“ scenario.

Scenario 3 “Someone at the door“

Ann is waiting for her friend Marta, who is supposed to arrive in a few minutes. The doorbell rings three times. The robot expresses surprise. Ann knows that Marta is used to ring three times to advice about her arrival. Ann selects the action “Open the door“ from the robot-view interface. The robot moves toward the door. The mask changes from surprise (frame 7, “Fig. 4“) to basic (frame 1, 2, 3, 4, “Fig. 4“).

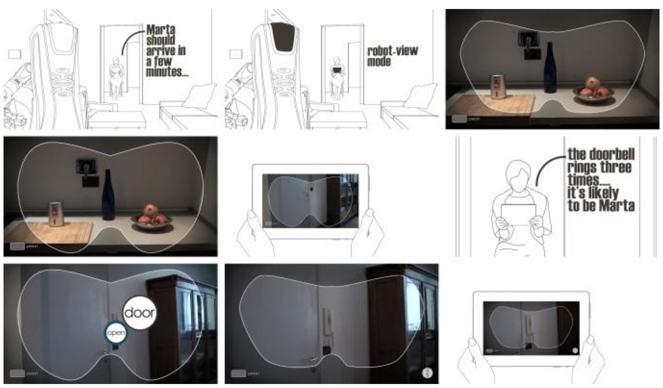

Figure 4. “*Someone at the door*“ scenario.

Scenario 4 “Sleepiness“

Ann asks the robot to turn off the lamp by selecting the action “switch off the light“. The robot seems to be unable to perform the requested action because is running out of battery level. The robot-view gets darker to show the robot’s sleepiness.

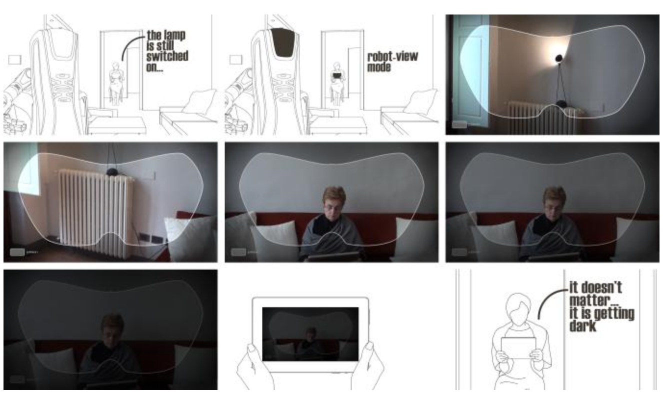

Figure 5. “*Sleepiness*“ scenario

In this scenario the robot’s feeling is expressed using a graphical filter rather than the changing mask.

IV. Procedure

The previously described scenarios were presented in form of videos in two different conditions: with empathic expressions (changing mask in scenarios 1, 2 and 3; and graphic filters in scenario 4), and without empathic expression (using a static mask).

Sixty people (M=33, F=27) were involved in the study (Table 1).

TABLE I.

Gender	**18-35 years old**	**36-55 years old**	**56-70 years old**	**After 70 years old**
Male	19	8	4	2
Female	17	8	1	1

Subjects divided by age and gender

They were asked to watch the scenarios in both conditions: without empathic expression (condition A), with empathic expression (condition B). The scenarios in both versions were randomly administered. Before watching the videos the subjects were asked to fill in the Interpersonal Reactivity Index (IRI) developed by Davis (1983) [12]. IRI is used to evaluate empathy as a multidimensional construct constituted by affective/emotional and cognitive aspects. The original version of IRI is composed of 28-items answered on a 5-point Likert scale ranging from “Does not describe me well“ to “Describes me very well“ divided into 4 subscale. For the purposes of our study, we used two IRI subscales related to perspective taking and emotional concern. Davis describes *perspective taking* as the tendency to spontaneously adopt the psychological point of view of others, while the *empathic concern* is defined as the assessment of “other-oriented“ feelings of sympathy and concern for unfortunate others. Each subscale is composed of 7-item. Since the subjects who participated to the survey were Italian, we used the Italian version of IRI (Indice di reattività interpersonale) validated by Albiero et al. (2006) [13].

The subjects were asked to watch the video-scenarios. After observing the assigned video each participant answered the questions included in the Scenario Evaluation questionnaire. This questionnaire contained 5-items on a 5-point Likert from “never“ to “always” It was administrated to each subject twice, after the scenario in condition A and after the same scenario in condition B randomly assigned. A second questionnaire, the Comparison questionnaire, was administrated once the scenario was watched in both conditions, to compare the videos presented in condition A and B. This questionnaire was composed of 5 items and contained close-ended and open-ended questions. The procedure was repeated for all the scenarios. The process is sketched in “Fig. 6“. All questionnaires were anonymous.

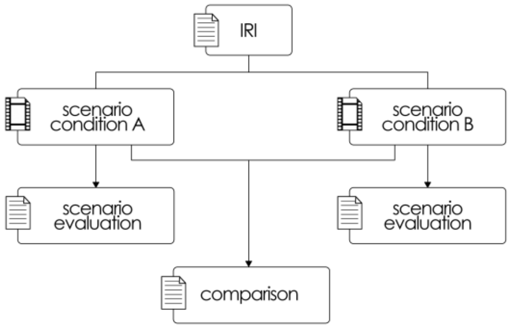

Figure 6. Evaluation procedure

V. Results

The scenarios 1 and 4 were evaluated by 59 subjects, scenario 2 by 56 subjects, and scenario 3 by 42 subjects. The results obtained from the IRI questionnaire are showed in Table II below.

TABLE II.

IRI's subscale	Male (33 subjects)		Female (27 subjects)	
	Mean	***Ds***	***Mean***	***ds***
EC	25,81	3,62	26,67	3,46
PT	24,30	2,69	28,81	3,84

Results of the IRI questionnaire

The results of the IRI questionnaire show the mean value and the standard deviation with respect to the Empathic Concern (EC) and the Perspective Taking (PT) of the interviewed subjects.

All subjects understood the scenes depicted in the videos as shown in “Fig 7“. The “Fig. 7“ reports the mean value of answers to the question “*Did you find it difficult to understand the situation showed in the video?*“, included in the Scenario Evaluation questionnaire.

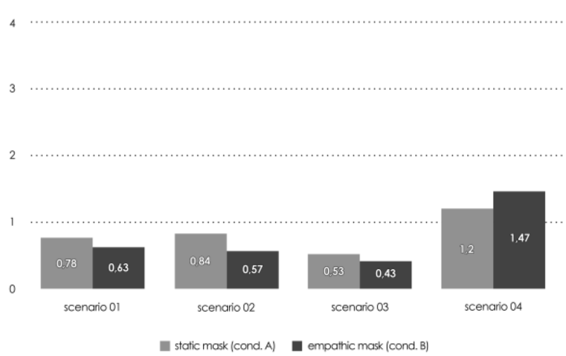

Figure 7. Mean value of answers to the question: “Did you find it difficult to understand the situation showed in the video?“.

The main difficulties were related to scenario 4 “Sleepiness“. This result is discussed later.

“Fig. 8“ shows the total answers to the question “*Which version of the scenario did you like most?*“ included into the Comparison questionnaire.

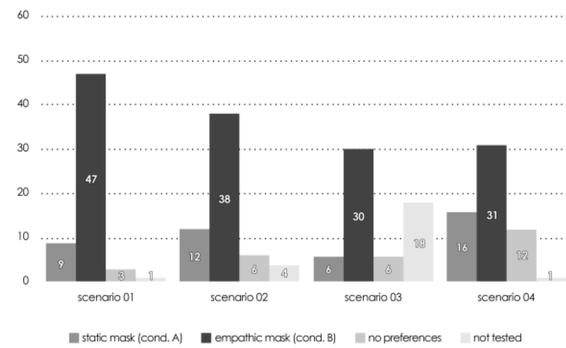

Figure 8. Preferred scenarios in condition A (static mask) and B (empathic mask).

The interviewed subjects preferred the condition B (empathic mask) for all scenarios. People commented that the scenarios in condition B were more engaging compared to the ones in condition A. Scenario 1: “*The vase falls down*” was the most appreciated. This scenario is more dynamic with respect to the other ones since the mask changes twice from the basic expression to fear and sadness. In the other three scenarios, beside the basic expression, only one more expression is displayed. Our interpretation is that when the mask shows only one expression in addition to the basic one, the changes in the shape are more difficult to notice. This happens in particular in Scenario 3 -*“Someone at the door“* where the basic expression (“Fig. 4“, frame 3) is very similar to surprise (“Fig. 4“, frame 4). The subjects did not clearly notice the changes in shape of the mask

Scenario 4 “*Sleepiness*“ was the least appreciated. In this scenario we adopted a different design strategy. Instead of using a dynamic mask inspired by Ekman’s basic expressions, we used graphical filters to convey empathy. In particular in Scenario 4 “*Sleepiness*“ we changed the opacity modifying the transparency level of the scene. This solution created a “darkness effect” that the subjects did not easily attributed to the robot’s sleepiness. They were more oriented to attribute the effect to the light conditions of the environment. This results requires to experiment more with graphical filters, trying out those effects that might be more clear and appropriate.

“Fig. 9“ shows the mean value of answers to the question “*The scene is showed through the robot’s eyes. Did taking the robot's perspective help you to understand its* *intentions?*“ included in the Scenario Evaluation questionnaire.

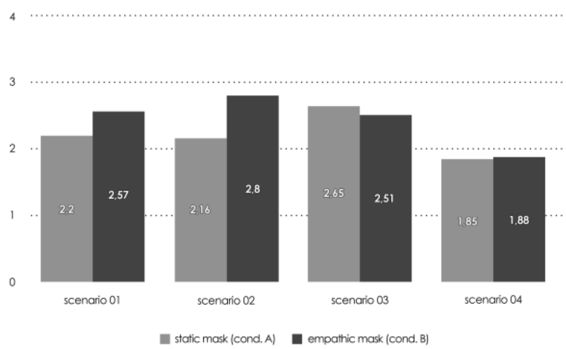

Figure 9. Mean value of anwers to the question: “The scene is showed through the robot’s eyes. Did taking the robot's perspective help you to understand its intentions? “

In this case the difference between condition A and B is not meaningful. Subjects answered positively in Scenario 1 and 2 and the opposite in Scenario 3 (variance = .14). For Scenario 4 the variance between condition A and B is very low, variance = .03, and therefore not meaningful.

“Fig. 10“ shows the mean value of answers to the question “*Did taking the robot's perspective help you to share its mood?*“ included in the Scenario Evaluation questionnaire.

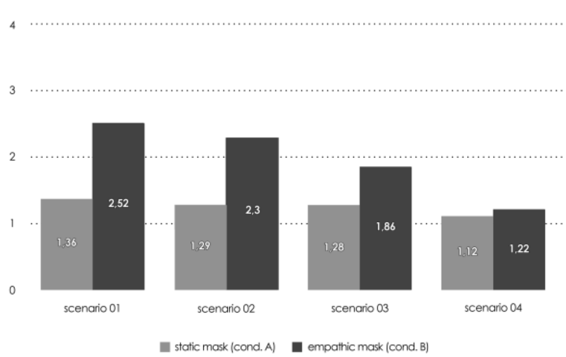

Figure 10. Mean value of anwers to the question: “The scene is showed through the robot’s eyes. Did taking the robot's perspective help you to share its mood? “

“Fig. 11“ shows the mean value of answers to the question “*During the scene did you feel emotionally involved with the robot?*“ included in the Scenario Evaluation questionnaire.

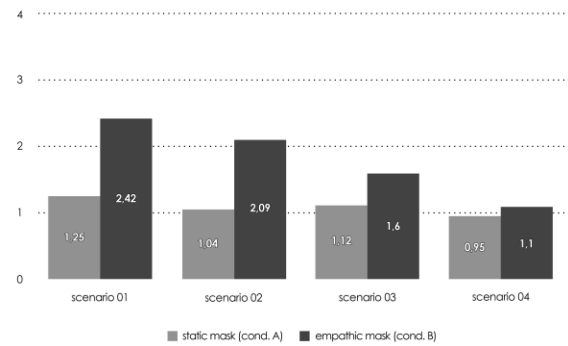

Figure 11. Mean value of anwers to the question: “During the scene did you feel emotionally involved with the robot? “

“Fig. 12“ shows the mean value of answers to the question “*Was the robot able to clearly express its emotional states?“* included in the Scenario Evaluation questionnaire.

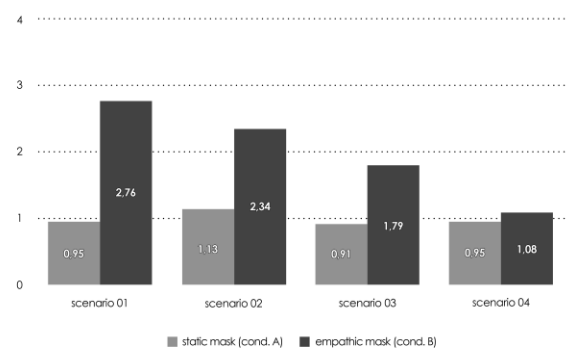

Figure 12. Mean value of answers to the question: “Was the robot able to clearly express its emotional states? “

The results showed in “Fig. 10“,“Fig. 11“ and “Fig. 12“ show that the subjects the emotional concern and perspective taking is more effective in condition B rather than in condition A. More in detail, the variance between condition A and B is meaningful in Scenario 1, 2 and 3 while it is very low and therefore not meaningful in Scenario 4.

VI. Discussion and Conclusive Remarks

The outcomes of the study described in this paper show that the use of the empathic mask had a positive impact on the subject’s ability of empathic concern and perspective taking. More in general, the empathic mask facilitated the comprehension of the different scenarios. People preferred Condition B that resulted more clear and engaging than Condition A.

Their ability to feel emotionally involved with the robot was expressed in the qualitative comments reported in the open-ended section of the questionnaires as well as their preferences for the Condition B.

For example, a lady (18-35 years old) wrote that in Scenario 3 "*Someone at the door*" the robot behaved as a human being who was interrupted while doing something. The robot's eyes opened wide to show surprise toward the doorbell ringing. This was an effective way to represent the robot's feeling toward an unexpected event.

A man (36-55 years old) reported that in Scenario 2 "*The rotten apple*" the robot simulated an expression of regret toward the rotten apple that was very similar to the observer's state of mind. It was very simple for him to share the robot's concern since this was very close to his own concern.

A man (18-35 years old) wrote that the empathic mask gave the impression that the robot was able to reflect on the situation at hand and react in a socially appropriate way.

Interestingly various subjects reported a "learning effect" when watching the scenarios. Apparently it was easier to recognise the robot's empathic expressions after a while, usually in the last watched scenarios. The robot's behaviour became more familiar and the empathic expressions more meaningful and engaging. This remark is encouraging since it shows a certain availability of the subjects to interact with the robot and learn from its behaviour.

Regarding the proposed design strategies for the empathic mask, that is the use of graphical filters vs the shape-changing eyesight expressions similar to the human face, the results of the test seem to show a preference toward the shape-changing expressions. In fact Scenario 1, 2 and 3 were more clearly understood than Scenario 4. People seemed to associate more easily the empathic behaviour to the robot's expression when they were represented with the shape-changing mask. Empathy conveyed through the use of graphic filters was less clear and easy to understand. We will investigate this aspect more deeply and will test different design solutions to assess which one works better in our scenarios of use.

As said above, we involved 60 subjects in our study. However, the majority of the sample was constituted by people between 18 and 35 years of age. Only 3 subjects were more than 70 years old, whilst only 5 subject were between 56 and 70 years of age. Even if the number of over 56 subjects was very small, it is important to notice that these subjects, and in particular the over 70, reported a certain difficulty in understanding the scenes as well as the robot's feelings. In the next iteration of design we have planned a new evaluation cycle of the empathic mask. The evaluation will be carried out using the same protocol described in this paper but we will involve only elderly people. In this way we hope to collect data that can help us to design more expressive solutions for our target population.

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Exploring Movement Qualities in Reciprocal Engagement

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***Abstract*— In this paper we present three behaviour designs for a robot's movement that extend and explore qualities of the perceptual-crossing paradigm in relation to functional purposes. As defined by [1], perceptual-crossing is related to the perception of how the behaviour of an entity/object and its perception relate to interacting entities/actors. Within three simple scenarios, movement behaviour designs are applied that negotiate the behaviour of both actors in interaction. For instance, when a robot and a person face a door and they both intend to go through it, a designed behaviour negotiates who is to go first in appropriate manner, either the human or the robot. The work is presented on the level of both theoretical and practical application, followed by an experimental activity. With this work we hope to inspire design thinking to shift from discrete, procedural design mechanisms to continuous and action-driven mechanisms when addressing interaction between humans and systems.**

***Index Terms*— Perceptual crossing, human-robot interaction, engagement, movement.**

I. Introduction

This paper explores the possibility of achieving negotiated interaction with a robot in a home environment, with the aim of empowering empathic relations between robot and person and enriching the experience of use as an emergent and dynamic outcome of the interaction. In exploring this notion of negotiated interaction with the robot, the concept of 'perceptual-crossing' is taken as a main source of inspiration for design. Perceptual-crossing is recognition of an object of interaction that involves 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 other's eye, in the case of mutual touch, kinaesthetic or acoustic interactions (proto-conversation with babies, dialogue, choral singing etc.), and resonance of movements.

A theoretical background is provided to frame the concept of perceptual-crossing and to investigate the possibilities of exploring it in the field of human-robot interaction. The study is conducted using three simple interaction scenarios in the context of human-robot interaction. The scenarios were performed thanks to different behaviours that were implemented in the robot. The three situations were recorded as video clips, in two different conditions, with and without perceptual crossing, and submitted to 60 subjects who evaluated the video scenarios in both conditions.

The results of the experiment show that the scene with perceptual-crossing between robot and human is preferred to the one without perceptual-crossing. These results are particularly meaningful since they compare two age groups: between 18 and 35 years old and over 70, showing that the situation with perceptual-crossing is preferred by both younger and older people.

The study was developed in the context of Accompany (Acceptable robotiCs COMPanions for AgeiNg Years), a European project funded under FP7-ICT-2011-7 under grant agreement n°287624 (http://accompanyproject.eu). The project aims to facilitate independent living of older persons at home. The Care-O-Bot robot is the main vehicle for research in this.

II. Theoretical background

Perceptual-crossing, as coined by [1], [2] and further explored by [3] and [4], [5] in the field of interaction design, boils down to the phenomenon in which two people look at each other and their eyes meet. Work on perceptual-crossing is rooted in the phenomenology of perception by [6] who highlights the reciprocal nature of our perception (e.g., perception requires action) in the emergence of meaning. Perceptual-crossing may occur visually as well as in other ways, such as touching and movement coordination. This itself may be experienced intensely, but does not convey functionality as such.

Perceptual-crossing therefore is applied primarily to initiate a ‘conversation’, as it does provide grounds for a shared context. Perceptual-crossing is often extended with the phenomenon in which a person sees what the other person is looking at. For example, I see in your eyes that something is happening behind me. In social sciences this is referred to as joint visual attention. With respect to perceptual-crossing it thus expands the spatial context of a negotiated interaction.

Research into perceptual-crossing in the psychological field of enactive approach to social cognition [7], [8], [9], [10], [11] focuses on one and two dimensional simulation models in which uncertainties are avoided. In these simulation models, the moving behaviour of a single actor is simulated. Users validate whether perceptual-crossing with these behaviours can be achieved in certain dimensions, such as speed, direction, geometry of movement and modality. The simulations are focused on defining the limitations of non-holistic systems.

[1] carried out experiments in which subjects were able to distinguish animate objects from inanimate ones with the same appearance and movement only by perceiving very simple tactile stimuli. 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. A fundamental insight we can draw from these experiments for the design of empathic interaction is that an important clue in interaction is its interwoven nature, which must be shared between the subjects.

Paramount in achieving this perceptual-crossing is continuous interaction, and this occurs in time, preferably without latency between the ‘action and reaction’ [4], [12], in order to have the parties engage in the same context. We thus aim for merging of action and reaction. Contrary to static symbolism, interactive materiality concerns active and perceptive ‘material’ capable of interaction that is designed to persuade for behaviour change.

The Interaction Frogger Framework [12], [13] provides practical handles for designing such interaction. Artefacts as such can perceive as well as act; this may be in the visual field or in the tangible. Through providing the artefact with behaviour in the interaction, human behaviour can be persuaded. This relates to perceptual-crossing in that the person’s actions are mapped to the actions of the artefact in a natural, expressive way, providing grounds for an engaging relationship [14].

[4] investigated perceptual-crossing with artefacts. They designed and built PeP, “Perception Pillar”, with different perceptive behaviours in the form of a dynamic light design. PeP is able to detect a person’s presence, perceptive action and expressivity. It allows for reciprocity, in which the subject is able to perceive the perceptive activity of the artefact. PeP was experimented under the hypothesis that if perceptual-crossing occurs between the subject and object, the subject’s feeling of involvement 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 user’s feeling of involvement.

Perceptual-crossing predominantly explores subject – object relations (transforming the object to have subjective qualities), yet third party (the context of action, the intentions of both subjects towards the environment) plays only a minor role here. We see an opportunity in pushing the *perceptual-crossing paradigm* to a *contextual resonance* paradigm in which two entities (person and artefact) go beyond an awareness of sharing context and come to share intentions (understanding and acting upon them). Our work extends the research on perceptual-crossing with functionality (in our case the increase of empathy through togetherness), integration of contextuality and multiplicity of intentions. In other words, we contextualize the paradigm and allow the subject and object to assess and act upon intentions that are of functional value in the context.

The paradigms of perceptual-crossing seem to have similarities with ‘synchronization’ and ‘joint attention’, yet we would like to stress that perceptual-crossing is not about this. A synchronization behaviour will create a ‘mirror’, but we could say that the figure in the mirror is not someone else, not another subjectivity to engage with. We aim to achieve engagement of the (elderly) person *with* another subjective being: the Care-O-bot. Not to interact with a reflection of oneself, but with an entity to empathise with.

The research presented in this paper applies principles of perceptual-crossing to achieve mutual understanding. This is relevant for both entities (robot and person) to immerse in a shared context and to ‘grope’ the intentions of the other. The ‘groping’ and the acting upon in our paradigm go hand in hand. They happen at same time in the active-perception-loop.

III. Scenarios

Three interaction designs were developed to explore several layers in achieving perceptual-crossing. All of them intend to empower an empathic relationship between the person and the robot, but they differ in their contextual resonation with the person. The three scenarios are chosen for their feasibility to be implemented in the robot, and carefully defined building one upon another. They take perceptual-crossing as point of departure and intend to push the status quo from initiating interaction [4] to functional purposes such as negotiation, initiative and empathy.

The first scenario explores initiation of behaviour: a robot’s behaviour is capable of persuading a person to move, or the other way around. The second scenario explores how a perceptual-crossing can be sustained over time (i.e., maintained within a mutual understanding while walking). The third scenario thus explores how the continuous empathic relation can be used to negotiate who (robot or human) takes the lead in interaction. The scenarios push the reciprocal engagement between robot and person with a functional purpose (moving away to instantiate acts, providing support and a sense of togetherness, and negotiating decisions when objectives do not correspond), which lies beyond the contact-making of perceptual-crossing.

The scenarios were implemented in form of low-fidelity prototypes using Magabot, which mounted a shell similar to Care-O-bot “Fig. 1”.

Figure 1. Alex and the Magabot with the shell

The Magabot platform and the shell are equipped with five distance sensors on the front and three distance sensors on each side to detect the person walking in front or next to the robot. Even though the Magabot platform is very limited and equipped with few sensors, the scenarios were successfully implemented and tried out. The main idea of implementation is the direct loop of perception and action; if the person moves the robot responds as promptly as possible. Furthermore, the behaviours are not predefined beyond the just stated action-perception loops. The robot is thus never fully static, always responding to its ever-changing environment. The value of this implementation does not rely on the software developed, but on the insights we obtained to feed the theory and provide input about the scenarios to implement, at a far richer level, on the Care-O-bot.

A. Scenario 1 - *"Let's move"*

Alex (the human in the videos) and the robot are in a room. The robot is located in front of him. Alex has been sitting for a long time and now he needs to get up and walk. In the condition without perceptual-crossing, the robot stands in front of the person without doing anything. When the person stands up, it remains in the same position. In the condition with perceptual-crossing, the robot anticipates or provokes action from the person. The robot somehow blocks the way for the person but when the person begins to get up, the robot will make way for him. This initiation of movement also lies with the robot.

B. Scenario 2 - *"Walking together"*

Alex moves to the next room. Suddenly he stops because he does not remember if he took his medicines. In the condition without perceptual-crossing, the robot continues to move, since it has been programmed to go from A to B. In the condition with perceptual-crossing, the robot stops when the person stops. It starts moving again together with the person, at the same pace, when he resumes walking.

C. Scenario 3 - *"Let's cross paths"*

Alex and the robot move to the next room through a door. Moving together from A to B might not always be exactly what is needed. This scenario shows how the person and robot switch sides along the route. In the condition without perceptual-crossing, the robot goes through the door first, actually preventing the person from going first. In the condition with perceptual-crossing, it makes room for the person to go through the door first.

IV. EVALUATION PROCEDURE

The scenarios were presented to the subjects in the form of videos (https://vimeo.com/user22680386). The videos show two conditions of perceptual-crossing for each scenario. Whereas the conditions are the same, such as, for example, conflicting objectives, the designed behaviours differ. Simply said, there is one behaviour without perceptual crossing (condition A) and one with (condition B) for each context. Practically this means that in the condition "without perceptual crossing", the behaviour works on the basis of discrete triggers and maintains predefined movement speeds. In the "walking together" scenario, for instance, the robot walks along with the person with the goal of going from A to B in the condition with perceptual-crossing, while in the condition without perceptual-crossing it moves from A to B at a fixed pace (which may, with luck, coincide with the person's pace).

Sixty participants (M=30; F=30) aged between 18 and 92 years old were involved in the study.

Gender	**Age**			
	18-35	***36-55***	***56-70***	***Over 70***
Male	16	5	5	4
Female	15	4	2	9

a. Subjects broken down by age and gender.

b.

The people aged over 70 have a mean age equal to 82.92.

The subjects voluntarily joined the study. The elderly people were recruited in a residential home for self-sufficient seniors in Siena, Italy. They were asked to watch the video-scenarios in two conditions: without perceptual-crossing (condition A) and with perceptual-crossing (condition B). The conditions were randomly assigned.

After looking at a video, a Scenario Evaluation questionnaire was administered. The Scenario Evaluation questionnaire contained a statement on the robot's attitude, to be answered on a linear continuous scale with 4 adjectives coupled with their opposites: rude/kind; distracted/focused; individualist/altruist; indifferent/emphatic. Participants were invited to assess the robot's attitude, from 0 to 4. The questionnaire also contained statements to be answered on a 5-point Likert scale from 0 to 4. The participants were asked to respond to each statement in terms of their own level of agreement or disagreement: 0=strongly disagree; 1= disagree, 2=undecided, 3= agree, 4=strongly agree.

In order to compare the two conditions, with and without perceptual-crossing, a second questionnaire, the Comparison questionnaire, was administrated in the end, after the subject had watched both videos. The Comparison questionnaire was composed of 2 closed-ended questions. The evaluation procedure was repeated for all scenarios and for all subjects, as shown in "Fig. 2".

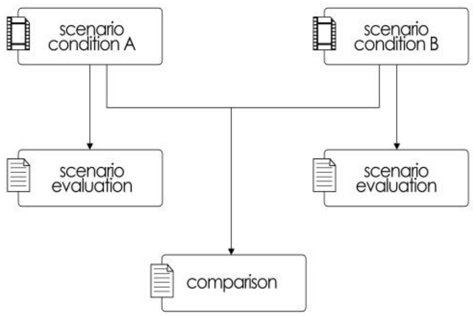

Figure 2. Experimental Procedure.

V. RESULTS

All subjects declared they clearly understood the scenes depicted in the videos. Below we show the results of the experiments related to the groups aged 18-35 and the over 70, in order to highlight the differences between young and older people in evaluating perceptual-crossing with the robot.

"Fig. 3" shows the frequencies of answers of people aged 18-35 for the questions *"In which video is the robot's behaviour socially acceptable?"* and "*Which version of the scenario did you like most?*" contained in the Comparison questionnaire.

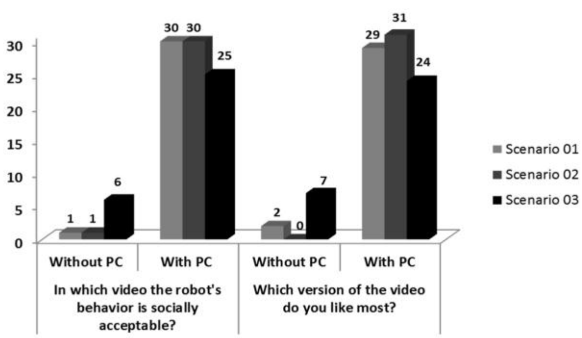

Figure 3. Results of the Comparison Questionnaire (Group 18-35).

"Fig. 4" shows the answers to the same questions contained in the Comparison questionnaire for the group aged over 70.

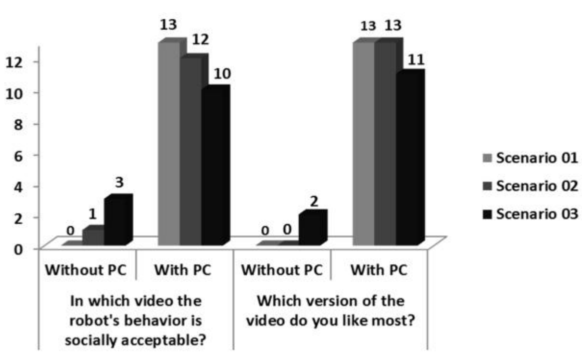

Figure 4. Results of the Comparison Questionnaire (Group over 70)

Both groups preferred condition B (with perceptual-crossing) for all Scenarios. The robot's behaviour that is considered socially acceptable is the one with perceptual-crossing. The differences between the two conditions are less evident in Scenario 3, "Let's cross paths", for both groups. The older participants reported that the scene described in this scenario could have different interpretations. For example, if the person is autonomous, it is better if he goes through the door first. However, if the person is not fully autonomous and needs assistance, it is better for the robot to go first, in order to be able to help if needed.

We conducted the Wilcoxon Signed-Rank Test to assess whether there were statistically significant differences between the two conditions. The test was used to compare the scores of respondents for both conditions to all the statements included in Scenario Evaluation Questionnaires based on the Likert scale.

A. *Group 18-35*

The Wilcoxon Signed-Rank Test revealed a statistically significant difference ($\alpha < 0.01$) between the two conditions for all the statements related to Scenario 1 and Scenario 2. For Scenario 1, we obtained the following results: statement 1 "The robot understood Alex's need to get up" (z= -4,414; p=0,000); statement 2 "The robot influenced Alex's decision to get up" (z= -4,234; p=0,000) and statement 3 "The robot behaved in a socially acceptable manner in relation to Alex's behaviour" (z= -4,842; p=0,000). Regarding Scenario 2, the test produced the following results: statement 1 "The robot moves with Alex to the next room" (z= - 3,329; p=0,0001); statement 2 "The robot moves independently from Alex's movement" (z= - 4,648; p=0,000). The results show that the condition B with perceptual-crossing was considered the most acceptable.

Regarding Scenario Evaluation Questionnaire 3, the test showed a statistically significant difference only for the statement 2 "The robot moves independently from Alex's movement" (z= -4,412; p=0,000), whilst for statement 1 "The robot moves with Alex to the next room" no statistically significant difference was found (z= -2,219; p= 0,045). Indeed, the median value was 3.0 for both conditions. In particular, 7 participants assigned the highest score to the condition without perceptual-crossing, and 9 participants assigned the same score to both conditions.

B. *Group over 70*

The Wilcoxon Signed-Rank Test for the group over 70 showed a statistically significant difference ($\alpha < 0.01$) for all the statements related to the Scenario 1, whilst no significant difference were found for one statement about Scenario 2 or for any of the statements regarding Scenario 3.

We obtained the following results for Scenario 1: statement 1 "The robot understood Alex's need to get up" (z= -2,871; p=0,004); statement 2 "The robot influenced Alex's decision to get up" (z= -2,844; p=0,004) and statement 3 "The robot behaved in a socially acceptable manner in relation to Alex's behaviour" (z= -3,126; p=0,002). In relation to Scenario 2, the test revealed a significant difference for the statement 2 "The robot moves independently from Alex's movement" (z= -

2,694; p=0,007), and no significant difference for the statement 1 “The robot moves with Alex to the next room” (z= -1,980; p=0,048). In this case, 5 people evaluated both conditions with the same score. The median value was 1.00 for the condition without perceptual-crossing and 3.00 for with perceptual-crossing. Regarding Scenario Evaluation Questionnaire 3, the test showed no statistically significant difference for any of the statements. No statistically significant difference was found for Statement 1 “The robot moves with Alex to the next room” (z= -,463; p= 0,643); Statement 2 “The robot moves independently from Alex’s movement” (z= -,782; p=0,434) was scored the same by 5 people while 5 other people expressed agreement with the condition without perceptual-crossing.

In short, the results show that both groups expressed agreement for Scenario 1 and 2, but not for Scenario 3.

“Fig. 5” shows the total answers to the question “In order to behave in a socially acceptable way, the robot would...” related to the 18-35 age group for Scenario 2 and Scenario 3.

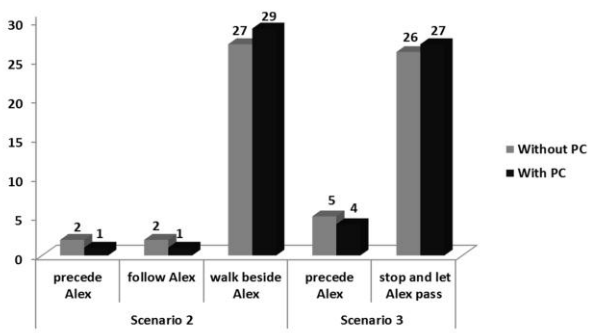

Figure 5. Frequency of answers to the question:
“In order to behave in a socially acceptable way, the robot would...” related to the Scenario 2_“Walking together” and Scenario 3_“Let's-cross-paths” (Group 18-35)

The results show a clear preference for the answer “Walk beside Alex” (Scenario 2_”Walking together”) in both conditions, and for the answer “Stop and let Alex pass” (Scenario 3_”Let’s cross-paths”).

“Fig. 6” shows the total answers to the question “In order to behave in a socially acceptable way, the robot would...” (Scenario 2 and Scenario 3) for the group over 70.

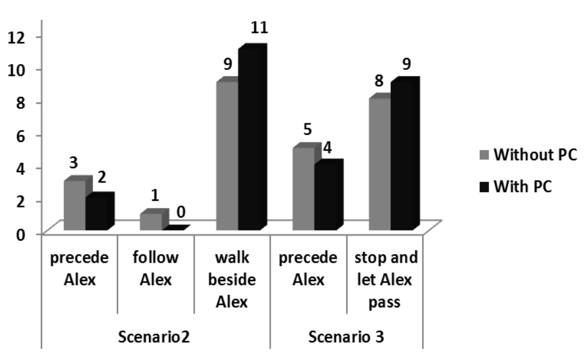

Figure 6. Number of answers to the question: “In order to behave in a socially acceptable way, the robot would...” Scenario 2 “Walking together” and Scenario 3_ “Let's-cross-paths” (Group over 70)

The results are similar to the one obtained for the other group. They show a clear preference for “Walk beside Alex” (Scenario 2_”Walking together”) in both conditions. Interestingly, among older participants, 38.46% considered the behaviour of preceding Alex acceptable in the condition without perceptual-crossing, while 30.77% saw the behaviour of preceding Alex in the condition with perceptual-crossing acceptable. They reported that Alex might have felt safer with the robot always preceding him, so that if he needed any support he could take advantage of the robot.

“Fig. 7” shows the mean value of the robot attitude scale for the three Scenarios related to the group 18-35.

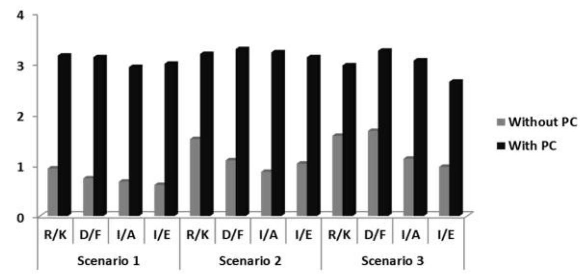

Figure 7. Mean value for the robot attitude scale:
“The robot's behaviour was:...” rude/kind; distracted/focused; individualist/altruist; indifferent/emphatic (Group 18-35)

Comparison of condition A and condition B is strongly meaningful for Scenario 1 and 2, and less significant for Scenario 3 (that was judged ambiguous).

“Fig. 8” shows the mean value of the robot attitude scale for the three Scenarios for the group over 70.

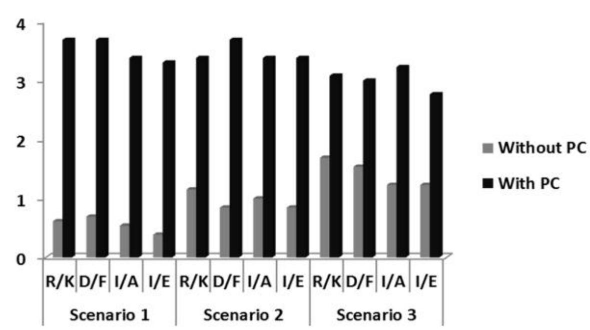

Figure 8. Mean value of the robot attitude scale:
“The robot's behaviour was:...” rude/kind; distracted/focused; individualist/altruist; indifferent/emphatic (Group over 70).

Also in this case, the difference between condition A and condition B is strongly meaningful for Scenarios 1 and 2 and less significant for the Scenario 3, for the reasons explained above.

VI. Discussion and Conclusion

The results of the study show that the scenarios with perceptual-crossing were the most appreciated by all subjects, including both young and older participants.

We are aware that videos are not easily assessed from the perspective of a third party. Perceptual-crossing is about engagement and thus benefits from actually experiencing it. However, this evaluation provided grounds for further development of the idea in the real robot platform of the Accompany project. This was not done at an earlier stage as the action-perception loop has fundamental consequences for the system architecture of the Care-O-Bot, which is preliminarily driven by a discrete paradigm of planning conflicting with the required continuous paradigm of perceptual-crossing. As mentioned above, a direct action-perception loop is paramount to achieving perceptual-crossing. The interaction design shall not have the robot moving in a pre-programmed way but *attune* its pace and movement to the pace and movement of the person. Following direct mapping between the action of the person and the action of the robot, expressive qualities in the movement are consolidated.

The results of the experiment described in this paper show that perceptual-crossing can positively influence the robot's behaviour in interaction with a young or older person. The outcomes are currently used in the Accompany project to guide implementation in human-robot interaction, which is holistic and ensures that the robot's actions meet the person's expectations.

The next step will be to assess if the results of the video-based experiment can be confirmed in a situation in which the person and the robot actually interact. Interaction takes place where the action is; experiencing the crossing is thus better grasped in interaction rather than in viewing interactions from another point of view. We thus expect, as we have actually experienced perceptual-crossing with the robot ourselves, that the rich interaction between the robot and the person with perceptual-crossing will be highly valued. Yet, it might feel so natural that the work goes unnoticed.

Our experiment, and design cycle, pointed out that nuance in movement is paramount. In order to have a direct feedback loop and for people to have a sense of direct experience (needed to make valuable judgements of the robot's intentions), the interaction should occur in real time on the sense/actuate and system architecture levels. Pre-programmed computing does not allow for the interactions we achieved in the present experiment.

The ambiguous role of initiative that lies with the robot or human raises ethical questions. Is it the robot or human that should go first or take the initiative? In our designed interaction paradigms this is negotiated *in* interaction based on shared or conflicting objectives (e.g., going through the same opening, that does not allow both to pass at the same time). We are aware that some situations demand a clear initiative on the part of either robot or person, but we also believe that there are situations in which interaction between robot and human benefits from a negotiation that strengthens the empathic relationship. Alternatively, the interaction paradigm embedded in the robot is easily extended with an intentional preference to be submissive or to lead the way in interaction with people.

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Expressive touch and materials in continuous-sustained interaction design

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Squeeze Me is an interactive tablet cover enabling expression-rich human-robot interactions. The pressure exerted by the person is mapped to expressive behaviours of the robot. This comes in the form of the robot's motion, as well as expressions on a graphical interface used to control the robot. In the paper, the Squeeze Me design is described in terms of how the real world manipulation afforded by the device is mapped to the graphical interface on the tablet, providing a means for expressive and continuous interaction between the person and the robot. We discuss our designs in terms of a scenario of use, the user's actions, and the real-time feedback provided by the system. Our implementation decisions and trade-offs that impacted the interaction design are then elaborated upon. Finally, we discuss the outcome of three conducted evaluation cycles followed by their implications for future work. A major contribution of the research is the shift in design from representational and discrete to expression-rich and continuous-sustained interaction paradigms with tangibles. Continuous interaction exploits direct mapping, which closely maps input (pressure on the cover) to output (the robot's movements and interface) in a continuous and expressive manner.

Keywords: Touch-based interaction, continuous-sustained interaction, expressivity, tangibles, squeezable device.

Categories and Subject Descriptors: H.5.1 [Multimedia Information Systems**]**General Terms: Design

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1. INTRODUCTION

Within the panorama of Gestural Interfaces, Tangible User Interfaces (TUI) have become popular to allow intuitive embodied manipulation of information through the

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sense of touch. From the seminal work of [Ulmer et al. 2001], who defined tangible interfaces as a means of augmenting the physical world by coupling digital information to everyday physical objects and environments, to the more recent work of [Ishii, 2008], the field of TUI has evolved significantly, offering a full record of designs exploring touch-based gestural interaction. In 2004, Fishkin [Fishkin, 2004] proposed a taxonomy of TUI based on the notion of embodiment and metaphor to define the degree of tangibility of an interface. He proposed six characteristics of embodiment, from full embodiment, in which the output device is the input device, to distant embodiment, in which the output is located in a place other than the place where the action is executed (e.g. a TV remote control). This kind of embodiment implies that the user's attention switches back and forth between the input (e.g. the remote control) and the output (the TV screen). Intermediate types of embodiment are nearby embodiment, in which the output takes place close to the input object (e.g. the user moves physical objects on an augmented tabletop to control the display on that tabletop); and environmental embodiment in which the output is "around" the user (e.g. the user translates physical avatars representing users of a chat system, and the audio from that user is adjusted accordingly).

Below we present the design of a squeezable device allowing touch-based interaction to support expression-rich communication between human and robot. This device incorporates different types of embodiments, from full to environmental.

The novelty of the design lies in the quality of interaction design supported by the device, which focuses on continuity in interaction and expressivity to promote natural and rich interaction possibilities.

2. CONTINUOUS INTERACTION AND RICHNESS OF EXPRESSION

Following a phenomenological perspective, people interact within the world in a continuous way. Even though our thoughts seem to be jumpy, our body is as it is in the world. The body that we use to be in the world exists, and does not allow us to disappear suddenly or move from one point to another without crossing what is in between. We are subjected to the sustained-continuous transitions that the world and our body provide us. Unlike our approach, most of the intelligent systems that we use every day address us in a discrete, state-changing manner. This utilizes our cognitive skills and leaves our embodied skills underused.

In order to illustrate the value of a continuous interaction, we focus on our design of a touch-based interaction between person and robot, in an ongoing interaction where action and reaction converge, directly allowing for meaning to emerge *in* the interaction.

Continuous interaction as means of achieving natural interaction has been explored in several projects. In the Augmented Speed-skate Experience, Stienstra et al. [Stienstra et al. 2011] created an augmenting movement sonification that allowed the speed-skater to hear particularities of the movement technique that are not felt through proprioceptive channels. The speed-skater was enabled to assess and adjust his or her speed-skate technique real-time as the meaning emerged in the interaction, making a system assessment redundant. Ross' Fonckel lamp (fonckel.com) [Ross et al. 2010] provided an embodied interaction for controlling light, exploiting the sustained-continuity of our body mapped to control a continuity of light dimensions. His work illustrates the opportunities of continuous interaction in a former discrete (on/off) application of control (i.e. replacing the switch).

Wensveen et al. [Wensveen et al. 2004], explored how skills can influence each other and in particular how *emotional skills* can be addressed via our *perceptual-motor*. Their Interaction Frogger framework allows analyses of interaction and syntheses of interactions to be experienced as 'natural', by exploiting *direct mapping*, which closely maps input to output, continuously and expressively.

They identified six aspects of natural coupling of action and function, which may be applied directly to allow for intuitive interaction (i.e. utilizing the skills that we use in everyday life to such an extent that it feels natural). Most of the time interaction employs kinaesthetics:

- Time: the product's reaction and the user's action coincide in time; there should therefore be no delay between the user's action and the system's response.
- Location: the reaction of the product and the action of the user occur in the same location, as when the paper is cut where the scissors touch it.
- Direction: the direction or movement of the product's reaction (e.g. up/down, clockwise/counter-clockwise) is coupled to the direction or movement of the user's action.
- Dynamics: the dynamics of reaction (e.g. speed, acceleration, force) is coupled to the dynamics of the action (e.g. speed, acceleration, force).
- Modality: the sensory modalities of the product's reaction are in harmony with the sensory modalities of the user's action (e.g. when the blades touch and cut the paper this can be seen, heard and felt).
- Expression: the expression of the reaction is a reflection of the expression of the action (e.g. when the user is in a hurry, the resulting action will probably be imprecise and hurried).

In electronic products, natural coupling is closely determined by the quality of feedback produced by the system. In addition to the six aspects of natural coupling between the user's action and the system's response, [Wensveen et al. 2004] identify three types of possible feedback from the system.

- Functional feedback, defined as information generated by the system when performing its function (e.g. pressing a button to switch on the TV).
- Augmented feedback, which refers to information not coming from the action itself, but from an additional source (e.g. when pressing a button on the TV, a red light appears to indicate that the button has been pressed).
- Inherent feedback, which is the information provided as a natural consequence of performing an action. It arises from the movement itself (e.g. when we press a button we feel the friction of the material and the kinaesthetic properties of the button).

To take a step further in continuous-sustained interaction, we place high value on the richness of expressiveness incorporated within the continuity of interaction, as emphasized in the sixth aspect of coupling: expressivity.

In order to facilitate interactions that allow someone to explore what is personally meaningful, good, suitable, inconvenient or bad, we believe that design should allow for expression in a rich way. Most interaction paradigms exploit expression in addressing emotions, and this is in most cases achieved through discretely coupling an input to a predefined output. For example, a user's gestural movement can be recognized and trigger a predefined reaction representing a mood (happy or sad movement or graphics), symbol or function. Again, this results in exploitation of our cognitive skills and underuse of our embodied skills.

Our approach to achieving richness of expression in interaction mainly builds on the Interaction Frogger Framework [Wensveen et al. 2004] mentioned earlier, in which action is mapped to reaction in a direct, coherent and convergent manner, as described in the scenario below.

3. CONTINUOUS-SUSTAINED AND EXPRESSION-RICH TANGIBLE INTERACTION: A SCENARIO OF USE

Ann (the user in our scenario) lives in her smart home with Care-O-Bot, a mobile robot that is part of a smart environment to facilitate her independent living at home. The home is equipped with a complex network of sensors that monitors meaningful objects and activities [Amirabdollahian et al. 2013].
Ann is sitting on the sofa right after lunch (Figure 1).

Fig. 1. The user and Care-O-bot

She would like to have a cup of coffee. She takes the tablet and looks at the action possibilities displayed. Without hesitation she selects “Coffee” and adjusts her choice by adding sugar. She then enters the command (Figure 2).

Fig. 2. The user selects the action-possibility “Bring me the coffee”

The Care-O-bot goes into action and slowly moves to the kitchen to get a cup of coffee. After a while, Ann checks what the robot is doing in the kitchen. The Graphical user interface (GUI) on the tablet allows her to see through the robot's eyes.
Apparently the robot is taking quite a lot of time to complete the task. The coffee is ready. If the robot doesn't speed up, she will have a cold cup of coffee! Ann therefore grabs the tablet with both hands and gently squeezes it (Figure 3). The mask displayed on the tablet turns from neutral to a surprised expression.

Fig. 3. The dynamic mask

The robot's behaviour changes too. The Care-O-bot puts the cup on the tray and moves towards Ann slowly, so as not to spill the coffee. The irresistible smell of the coffee makes Ann impatient. She squeezes the tablet again, more firmly. The mask on the tablet turns to neutral and the robot moves more rapidly….but not rapidly enough for Ann…who keeps squeezing the tablet.
The mask changes from neutral (Figure 4) to angry, and the robot slows down for a short while…it is a bit moody…

Fig. 4. Change in expression

This is a little joke, a ritual between them. The mask changes again, from anger to joy (Figure 5), and the robot quickly delivers the coffee. Ann enjoys her coffee and smiles to the Care-O-bot (Figure 6).

Fig. 5. The user releases the Squeeze Me

Fig. 6. The user takes the coffee from robot's tray

This scenario is enabled by a rich robot platform that is described in the following sections.

4. THE TECHNOLOGICAL SYSTEM ENABLING THE SCENARIO ERFORMANCE EVALUATION

4.1 Care-O-bot and the smart environment

Care-O-bot is a mobile robot conceived to support seniors at home. The robot has a machine-like appearance. It is equipped with omnidirectional drives, a seven degrees-of-freedom manipulator, a three-finger gripper and a tray that can be used to carry objects. Its "head" contains range and image-detection sensors enabling object learning and detection and 3-dimensional supervision of the environment in real time. The robot can move autonomously and fetch, carry, and manipulate objects.

Care-o-Bot is part of an intelligent home environment enhanced with a multi-angle camera fusion system and sensor network providing information about the senior's living patterns, the current state of objects present in the environment (e.g., a dirty coffee cup) and the environment itself [Amirabdollahian et al. 2013].

A number of objects that 'can be manipulated' by the robot are traced on several aspects and accessed through layered functions (e.g. a cup can be used for coffee or tea). For instance, the action 'Bring me a cup of coffee' requires the robot to know where the user is located (so as to bring the coffee to them), whether the user is thirsty (so as not to provide coffee over and over again) as well as information about the environment and the objects involved: whether there are empty clean cups, sufficient coffee, a clean coffee machine and so on.

4.2 GUI and the dynamic mask

A Graphical User Interface (GUI) on a tablet is the main means of interacting with the robot. It was developed using a person-centred approach that pivots upon the uniqueness of seniors' skills by providing continuous and expressive opportunities for interaction and meaning to emerge [Stienstra et al. 2012]. A central idea in the GUI is the concept of *action-possibility*, that is, the potential for the robot to act in the world and execute tasks for the person. The GUI is dynamic since the potential for action changes according to the interplay between specific configurations of the environment, the person's potential needs and desires, and the likelihood of an action being executed. The action-possibilities are displayed on the GUI as simple icons and are organised by relevance (Figure 7).

Fig. 7. Action-possibilities on the GUI

The size of the icon indicates the action-possibility that is most likely to be performed. For instance, if the person has not had a drink for a few hours, the action-possibility “Bring me the water” pops up to encourage the person to drink and thus avoid dehydration.

The likelihood of an action-possibility also depends on previous preferences and rituals between the robot and the person.

The objective of the GUI is to provide the person with the means to access functions that can be performed by the robot alone or in collaboration. Action-possibilities are thus defined as what the robot can do in a specific context with the objects in the smart environment. Therefore, the GUI requires information about the state of the objects to be handled by the robot, the state of robot itself and the environment, as well as the state of the user and his or her unique approach to the world. In other words, it requires a vast, articulated picture of the context.

Since the GUI was designed for domestic use, there has been an effort to emphasize the experience of living with the robot, focusing on feelings of engagement and empathy, rather than focusing solely on functional aspects. For this reason, the GUI contains an additional graphical overlay displaying a mask that provides a sort of binocular vision superimposed over the iconic representation of possible actions [Stienstra et al. 2013]. The mask helps focus attention on what the robot is looking at. This encourages the person to take the robot’s perspective, share its viewpoint, and likely guess or empathize with the reason why a task might be difficult to execute. Perspective is indeed a typical social behaviour that leads to manifestations of empathic exchanges [Davis, 1983].

The mask is dynamic. It displays smooth transitions of the robot’s view, thus pretending to express the robot’s emotional state (Figure 8).

Fig. 8. Transition of expressions on the mask

Whilst the action possibilities indicate what the robot can do in context, the mask shows how the robot feels in order to share its internal states with the person on an emotional level. Expressions were designed drawing inspiration form Eckman's Six Basic Emotions [Ekman, 1999] and evaluated by older people during participatory design sessions [Iacono et al. 2014].

5. SQUEEZE ME

The Squeeze Me device is an interactive cover, mounted on the tablet (Figure 9), enabling expression-rich communication between the person and Care-O-bot [Marti et al. 2014].

Fig. 9. The Squeeze Me prototype

By detecting pressure on the cover, we directly map the values of the robot's movement as well as the expressions on the GUI.

In greater detail, the pressure exerted on the device by the person is mapped to expressive behaviours of the robot in the modality of motion in the forthcoming interaction, as well as mapped to the appropriate expressions of the mask. A short pinch results in a sturdy movement, a hard squeeze results in a quick movement and a gentle touch in a slow approach. Each movement is mapped to the dynamic behaviour of the mask. This direct mapping inherently exhibits a natural relationship while maintaining the richness exhibited by the user.

The device has been designed and developed adopting an incremental and iterative process. We spent time exploring experience able prototypes in the real context of use and reflected on the results achieved, leading us to post a set of questions for research which guided development of the next iteration of prototypes or projects. The iterative design cycles were conducted by reflecting on how the different prototypes evolved in time and which new topics and challenges emerged from practice in the field.

5.1 First prototype

The first Squeeze Me prototype was a rigid plastic shell mounted on the tablet, the inner part of which hosted electronic components (Figure 10).

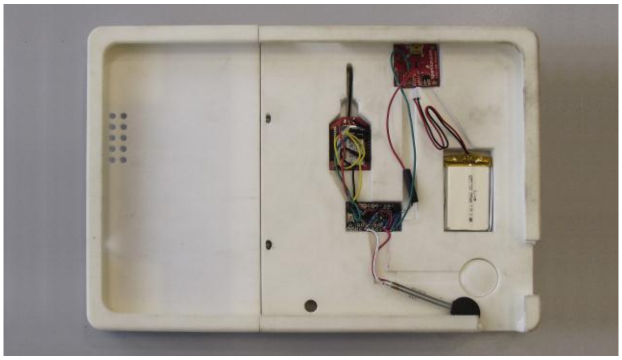

Fig. 10. Initial prototype

The cover was 3D printed using a FDM plastic process. The electronics included the following components:

- Arduino Pro (Mini) 328 3.3V / 8 MHz
- FSR sensor
- Wifly module
- 3.7V LiPo Battery
- Battery Charger for LiPo

The design of the casing was pretty simple. A button with FSR (Force Sensing Resistor) was placed on the top left side of the outer casing, to enable the user to easily and consciously access the functionality of getting attention from the robot (Figure 11). The button further was slightly hollowed with the intention to make it easy findable as a button.

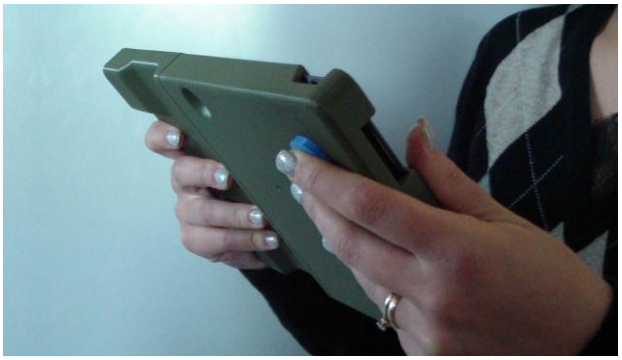

Fig. 11. Detail of the Squeeze Me button

An Arduino Pro 328 3.3 V placed inside the cover took care of the data acquisition and interpretation in relation to the intensity of the pressure on the button. The data was sent via WiFi to a server that communicated with a scheduler designed to manage the action-possibilities to be taken by the robot.

This prototype was submitted to user testing at MADoPA, a centre that provides home healthcare assistance in France. The test was undertaken in a smart home environment, equipped with the full robotic platform including Care-O-bot, and involved 18 older people with a median age of 73.8, 10 informal caregivers and 6 professional caregivers.

The participants were invited to evaluate the Squeeze Me by walking through a simple scenario similar to the one described above.

The outcome of the evaluation was primarily concerned with the material qualities of the casing and the feedback.

The affordance of the button as a squeezing input modality was inadequate for different reasons. First of all, the button, which was not visible to the user since it was placed behind the cover, was therefore difficult to locate because of unnatural positioning with respect to the handgrip. The size itself was too small. People often turned the cover to find the button, but then they had to turn it back to use the GUI. This made interaction unpleasant and ineffective. Furthermore, the plastic used to print the cover was too rigid and made the tablet too heavy to handle. The mechanical properties of the material, its stiffness and lack of formability, contrasted with the very idea of a squeezable surface. The button did not invite continuous interaction, but rather discrete, on/off use.

In addition to problems involving the material the cover was made of and the positioning of the button, a number of issues were related to the feedback provided. The prototype provided for two kinds of feedback according the Wensveen's categorisation [Wensveen et al. 2004]: functional feedback resulting in variation of the robot's speed, which was mapped to the pressure exerted on the button, and inherent feedback, related to the mechanical resistance of the button when pressed. When the button was pressed, the robot took time to start its movement. This disconnected the directness needed for achieving a sense of being in control while exerting pressure.

The mechanical resistance of the button made it difficult to detect the amount of pressure exerted by the user, which was made unnatural because of the stiffness of the button. The interaction was not smooth because of the inherent resistance of the material.

The inadequacy of inherent feedback inevitably negatively impacted the functional feedback. Users were unaware of the pressure they exerted on the button and therefore they were unable to appreciate the cause / effect relationship between the variation of pressure and movement of the robot.

The low quality of inherent feedback provided by the device make the touch-based interaction discrete, fragmented and unnatural.

A 95-year-old lady had serious problems using the Squeeze Me button because of her numb fingers, which she had trouble controlling, as she would have liked to. It was very difficult for her to position the finger on the button without looking at it and exert some pressure. Notwithstanding this problem, she was enthusiastic about the idea of squeezing the device to communicate with the robot, despite never managing to use it properly. She asked the evaluator if she could adjust the robot's speed directly from the GUI. She was somehow puzzled about focusing the attention on the "hidden" button and the robot's behaviour.

5.2 Second prototype

Taking the results from testing the first prototype into account, we built a second version of the system by improving it and enhancing all of its components. This process required complete redesign of the cover in terms of form, materials and electronics.
The second prototype was designed with a more ergonomic handgrip, to be handled with one or two hands, and pleasant to touch (Figure 12). Its cover was made of soft rubber that can be squeezed to share expressive behaviour with the robot though continuous interaction.

Fig. 12. The second prototype

The cover was 3D printed using the digital light processing technique (DLP), which uses a liquid polymer consolidated by exposure to an adiactinic light. This technique permits manipulation of soft plastic materials. Moreover, DLP printing allows for high-level definition of the artefact's details.
Two different plastic materials were used to print the cover. The black part was made of a dark malleable synthetic resin, whilst the white part was made of acrylonitrile-butadiene-styrene (ABS). This harder plastic material was used to print the rigid central part of the cover, which provided both protection and room for allocating the electronics. During the design process we paid special attention to the modularity of all the cover components. This made it easier to assemble the components and to fix potential malfunctioning of a single component.
The main requirement for the electronics was to overcome the limitations imposed by the button contained in the previous prototype and make the input surface much wider. The system was then implemented using the following components:

- Arduino mini 328 3.3v 8MHz
- Bluetooth modem BlueSMiRF Silver
- LiPo battery 3.7 V 1400mAH
- Printed circuit board (PCB)
- Specially designed textile analogous pressure sensors.

Even though detection and processing of data from the sensors remained within Arduino, in the same way as the first prototype, we transformed all the other components of the system. First, we replaced the FSR sensor with textile analogue pressure sensors designed by Plug&Wear (http://www.plugandwear.com). These sensors work as an analogue press button with the resistive principle (Figure 13). The have a very high resistivity when not pressed, but their resistance decreases when pressed.

(http://www.plugandwear.com/datasheet/Datasheet_PW073_PW074.pdf).

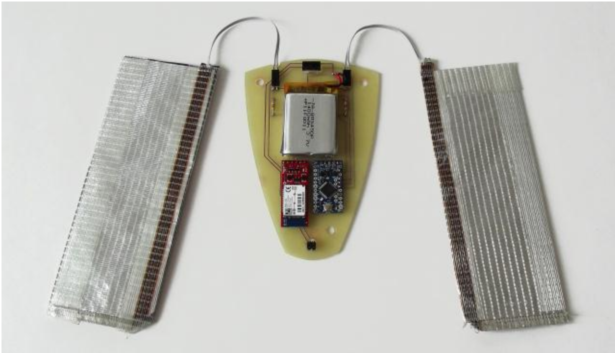

Fig. 13. Smart textile analogue pressure sensors and electronic components

The soft plastic and smart textile sensors improved the affordance of the cover toward squeezing.

The software controlling the cover was changed too. It consisted of an Arduino sketch that detected data through analogue readings of the sensor's resistance variation. Using 10 Ω pull-down resistors (1 for each sensor), it was possible to obtain an interval between 0 and 1023. This range was divided into different intervals, each of which was associated with a graphic transition of the mask. The intensity of pressure applied to the sensors permitted variation within this interval, and therefore different mask expressions.

The new software code also provided digital data smoothing; each sensor was read three times, and the values were stored in an array, from which the modal value was extracted. In this way we could minimise measurement errors caused by noise.

Moreover, in order to prevent sensors from being pressed inadvertently, the interaction design was implemented in such a way that it was necessary to pass a minimum pressure value simultaneously on both sensors. This means that the cover had to be squeezed with both hands to be effective. In other words, to avoid unconscious and accidental pressure, the design constrains its interaction paradigm by requiring two-handedness.

Below this value the system remained inactive. After the detection and smoothing phases, data were sent to the Tablet via Bluetooth connection.

The software managing the expressive mask on the tablet was written in Java and had a twofold purpose:

- To realize the “morphing effect” (transitions) among the various expressions of the mask.
- To control the robot's speed according to the pressure applied to the cover by the person squeezing the device.

This implementation was used to enrich the system’s feedback. In addition to the functional feedback (the robot’s movement) and the inherent feedback (the kinaesthetic qualities of the soft plastic), we added an augmented feedback that was realised by integrating the pressure of the squeezing with the transition of mask expressions. This enriched the response of the system to the user’s action.

The tablet was connected to a database via WiFi, and with the cover via Bluetooth (serial communication). All the images related to the 9 basic expressions of the mask were contained in an external database. All changes in expression were realized

through graphical transitions on the GUI. In order to achieve the morphing effect, different images were designed, the transition of which resulted in a pleasant, fluid experience. The software first checked if there was any input from the sensors inside the cover; if no input was detected (nobody was squeezing the cover), the GUI returned a neutral expression and the robot's movement was unmodified. On the contrary, when the person squeezed the device, the software retrieved the appropriate graphic transition, and the mask changed. The robot moved accordingly.
The cover was suitable for interaction with both hands and there was no longer a need to turn the tablet in search of a button, given that the entire surface grasped by the user appeared to be sensitive to squeezing.
We decided also to change the WiFi communication with the server that managed the robot's behaviour and implement local communication with the tablet via Bluetooth. This is because during testing of the first prototype, WiFi communication with the server had proven to be noisy and subject to interruptions due to high packet loss. Use of Bluetooth communication made the system much faster and more responsive.
The components were not connected to each other using cables but were soldered on a PCB specifically re-designed to suit the new cover (Figure 14). This allowed us to eliminate cables and the need to insulate electronic components.

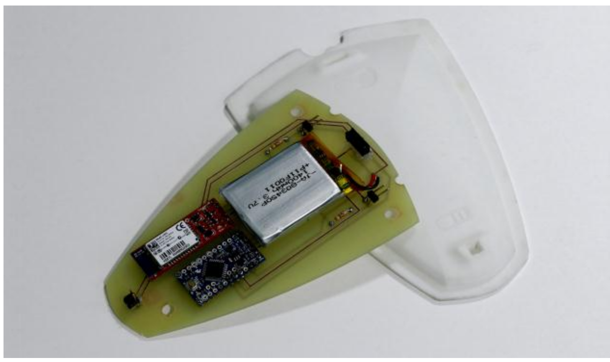

Fig. 14. Detail of the PCB

The re-design of the first prototype in the material and interactive components greatly improved the experience for the user(s).
The second prototype was evaluated in Italy. Evaluation sessions were carried out in the form of a workshop held in a Residential Home Care for self-sufficient seniors in Siena. Six elderly people (2 males and 4 females) with a mean age of 83.17 were involved. Since the real robot was not available, the activity was organized with the support of a simulation environment. A 3D representation of a home environment similar to the one depicted in the scenario described above was projected on a large screen. The participants sat in front of it, taking turns trying out the GUI and the Squeeze Me. A digital version of the robot responded to the commands entered on the GUI by the participants. The GUI was fully working, so that the elderly could try alternative paths. Open questions were used to evaluate scenarios of use, concept and dynamics of the action possibilities, the mask's expressivity and the Squeeze Me, but also to obtain insight into the experience of living with a robot at home and interacting with the proposed device. The facilitator stimulated the verbalisation of experiences of some personal significance in interaction with the robot to understand how the elderly could make sense of this relationship in ordinary everyday life. She encouraged description of first person accounts and invited narratives and reflection

on personal experiences using metaphors and past memories. None of the participants showed difficulty during the interaction and in general all of them showed an open-minded, playful attitude during the evaluation.

They fully understood how the robot's expressions changed according to the situation, the emotional state of the robot and the way they influenced the emotional response through squeezing.

The augmented feedback provided by the graphical transition of the mask, mapped to the pressure exerted by the user, greatly helped comprehension of the system's behaviour. Participants could check the intensity of their way of squeezing by observing the dynamics of the mask on the GUI, in addition to the variation in movement of the robot.

A 75-year-old person said that he liked to be kind to the robot, and he also appreciated that the robot was kind to him. The squeezing allowed him to be kind and to have a kind reaction in return. When exploring the Squeeze Me, he wondered what might happen if he continued to squeeze all the time. He tried and then commented that the robot refused to move towards him, since from the way he squeezed the cover, the robot likely understood that he was angry and therefore preferred to avoid him. So the robot evidently did not like to be squeezed too much… .

This short excerpt of the interview demonstrates that participants focused on the quality and texture of experience rather than on identification of conventional usability issues.

However, although the new Squeeze Me was generally well received by the participants, there were still some issues related to the weight of the tablet and the quality of feedback.

Two participants reported that the tablet was too heavy to handle and other participants did not clearly understand the mapping between the robot's movement and the pressure they exerted on the cover. Apparently the visual feedback of the dynamic mask was not sufficient. They clearly understood the differences in the way the robot moved, and also the differences in the expressivity of the mask. However, they were not able to clearly relate them to their way of squeezing. In particular, they were unsure about how hard or gentle their squeezing was.

Furthermore, despite of the improvement offered by the elasticity of the soft plastic of the second prototype to afford squeezing, beyond a certain level of pressure, the material reached its maximum compression and behaved as if it was rigid. This made it difficult to understand the intensity of the pressure applied to the cover since the kinaesthetic response of the material did not provide sufficiently clear inherent feedback.

Users were inclined to stop interacting when the sensitive surface became excessively rigid.

5.3 Third prototype

In the light of the outcome of the second evaluation cycle we decided to improve the quality of tactile feedback by adding an augmented feedback to the inherent one afforded by the soft plastic. We embedded six small motors inside the cover which vibrated each time the pressure sensors were pressed. The greater the intensity of the pressure, the greater the perceived vibration. This was achieved in real time to stay ahead of the slightly delayed feedback of the robot's movement, which still takes a little time before it actually starts to move due to its physics.

The response after an informal user test of the use of vibration was positive, and the majority of people welcomed the addition of the new feedback, emphasizing the ability to perceive the intensity of the pressure without the need to look at the screen on the tablet.

The Squeeze Me is currently undergoing a new design, including its material components, to minimise the problems related to weight and the rigidity of the material when squeezed hard.

The new design concerns both use of alternative materials and new sensors and electronics. We are evaluating the possibility of using particular types of polyurethane to achieve the desired sensitivity in the cover. Polyurethane, in addition to being soft, pleasant to the touch and lightweight, combines the advantages of flexible elastomers with those of viscoelastic materials (e.g. delayed recovery after compression) (Figure 15). These features could allow us to overcome the limitations of rubber and plastic and obtain an inherent feedback that effectively implements the paradigm of continuous interaction.

Fig. 15. Sample of polyurethane material

6. FINAL REMARKS

Our interaction design relies on mapping between action and reaction, in our case between the pressure exerted, the movement of the robot and the expressive mask. In this light we seek to map emotions or expressions to expressional output, thus seeking functionality in the emotional empathy-building realm. What we have learned is (a) that it is difficult to go beyond the discrete paradigm towards the continuous, (b) that time is of essence in continuous-sustained interaction and that even if the mapping is within it, the interaction seems quite promising, and (c) the (lack of) details of the material can disrupt the good intentions.

In order to address one's embodied skills in a continuous fashion, it is paramount to avoid the "if and else" paradigm, which draws the designer back into categorisations. In order to fully achieve a paradigm that allows for meaning to emerge *in* interaction, it is crucial to stick to the closest loop in time (e.g. it is not possible to relate one's actions back to a reaction that comes too late, and if a nuanced movement is reduced to option D in a discrete manner it is also not possible to deduce what actually caused what). As we've seen in the paper, we easily return to these predefinitions, which may not enable users to fully exploit their skills. Users deserve to be treated with respect for their skills, not to be grouped into three pre-set movements or expressions. This is an issue that goes beyond the desire of the designer to aim for continuous interaction. System architectures do not easily allow for this; they profoundly utilise the "if, else and then" paradigms in both programming (control of the robot's movement on a systemic level) and theory (Eckman's six basic emotions are reduced categorisations which do not leave much room for all the expressions in between, which should have been addressed).

In principle, not much has changed in the interaction paradigm over the three iterations of the Squeeze Me presented; the actions are coupled to the reaction as directly as possible. The main area of exploration and conclusion of the work presented is that the material in the interaction should also support the interaction paradigm (i.e. the interaction that is guided must allow for the richness of expression that the movement of the robot requires). In order to overcome delayed feedback (the robot starts to move after a delay) or categorised feedback (the mask has 6 predefined emotions), the casing itself, with its material qualities and vibration sensors, play a crucial role in the direct feedback loop. In other words, by providing the feedback loop with a layer that is direct (real-time) and expressive over its full scale (real-time and frequently updated feedback), the technical inconveniences that currently prevent designers from applying a direct action-perception loop can be overcome and overshadowed. The expressivity and directness of this feedback covers the others as it 'speaks to' the dynamics and expressiveness in the continuity of people's skills.

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