Chapter 2
A Motivational Case Study in Social Robotics

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Abstract Different social environments have been used, in recent times, as contexts for interaction by social robotics such as children in hospitals or classrooms with positive results. Recently, the MOnarCH project explored the formation of social relations between a robot and users, namely children, in the Pediatrics ward of an Oncological hospital. This robot can navigate autonomously in the available free space, interacting with basic verbal and non-verbal utterances, explicitly when someone is recognized or touches it. The chapter shows the design process of MOnarCH which is carried out in three phases: Conceptual, Production, and Deployment and Evaluation. The main intention is to understand how the system can be designed to best suit the people and the society who need to use it and include the necessary flexibility for a posteriori behavioral adjustment. Annotated video recordings and micro-behaviors that were used in some of the experiments asserts that MOnarCH is simply a playmate for a physically and emotionally fragile population, a new experience that does not replace healthcare professionals. The empirical evidence suggests that the vast majority of children surveyed had the correct perception that the robot was not alive. Nevertheless, children acknowledged the robot's presence in the Pediatrics ward and the liveliness features implemented positively.

Keywords Social robot · User-centered design · Design process · MOnarCH

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2.1 The Dawn of Social Robotics

By acquiring mobility and becoming robots, computers are nowadays required to engage in complex interactions with humans. The resulting momentum developed into social robotics, a blossoming area in the wide field of Robotics. Pragmatic economics, the aging of the population, and the intrinsic desire for a better Quality of Life (QoL) have been the underlying leitmotifs of this development.

Initially conceived to perform repetitive actions where human instructions were given a priori, robots are now starting to be assigned socially complex tasks. Creating artificial intelligence systems capable of acting as active partners, either being engaged in cooperative activities in a working environment or as coactors in multiple social contexts, is a highly complex endeavor. Its complexity challenges robotic engineering to go beyond primary concerns with the correctness of functional performance and compliance with basic safety rules, maximizing well-being and taking into account the specificities of the user, their needs, their expectations, and the way they feel and react to technology. In other words, as happens with all other artifacts, appliances or services, the figure of the user has come to play a central and determinant role throughout the design and production process.

Human-robot interaction is the natural follow-up to the initial stages of human-computer Interaction. People's perceptions of a robot resemble those involved in human–human interaction, with the distinctive feature that the robot still has a long road to go to achieve human-like sentiency.

Nevertheless, the growing integration of robots with social skills in society is leading to a worldwide expansion of the social robotics' field. Different social environments have been used as contexts for interaction by social robotics, e.g., children in hospitals (Shibata et al. 2001; Dautenhahn 2003; Dautenhahn and Werry 2004; Marti et al. 2013; Liu et al. 2008), children in classrooms (Tanaka et al. 2007; Kanda et al. 2009), adults in institutions and/or domestic scenarios (Turkle et al. 2006a, b), with positive results. Moreover, the existence of numerous projects targeting a diversity of populations shows the importance of the field (see a selection of projects in Table 2.1). All of these projects share common goals: well-being, moving robots outside labs, multimodal HRI, long-term HRI, understanding social environments, etc.

The number of projects in Table 2.1 is evidence of the maturity of robotics technologies, namely when operating in social contexts. The majority of these projects focus on (i) elderly people as end users and (ii) helping functionalities. Some of the robots in this summary have a dual purpose, as it is proposed they target different users (the elderly and children). The suggested bias toward the elderly population may be due to the fact that most elderly people like robots (Martín et al. 2013).

Studies have been carried out to discover elderly people's preferences regarding the design and features of a robot. The current results have shown that elderly patients prefer a robot that is smaller and with less humanoid features (Wu et al. 2012).

Zoomorphic robots have mostly been used to interact with elderly patients and results have been similar to those obtained with domestic animals (Bernabei et al.

Table 2.1 A summary of social robots and application domains

Link	Project Acronym	Robot/Application	End users
www.monarch-fp7.eu	MOnarCH	Edutainment for inpatient children in an Oncological hospital	Children
www.softbankrobotics.com	NAO	Humanoid robot of child size and full anthropomorphic features	Misc
www.softbankrobotics.com	Pepper	Humanoid robot, with anthropomorphic features, for generic people assistance	Misc
http://www.parorobots.com/	PARO	Seal cub robot with basic interaction capabilities and no locomotion	Elderly
www.aliz-e.org	Aliz-E	Artificial Intelligence for small social robots that interact with children using the NAO robot	Children
www.giraffplu.eu	GIRAFFPlus	Telepresence robot for remote monitoring	Elderly
www.chrisfp7.eu	CHRIS	Safe Human-Robot interaction within selected application domains	Misc
www.lirec.eu/project	LIREC	Building long-term relationships with artificial companions (lirec.eu/project)	Misc
www.cogniron.eu	Cogniron	Development of cognitive robots to serve as companions to humans	
humavips.inrialpes.fr	HUMAVIPS	Endow humanoid robots with audiovisual abilities such that they exhibit adequate behavior when dealing with humans (uses an NAO robot)	Misc
perso.ensta-paristech.fr/~tapus/HRIAA	HRIAA	Robot with social abilities and personality and emotions, using verbal and non-verbal and para-verbal communication (uses an NAO robot)	Misc
www.squirrel-project.eu	SQUIRREL	Human-robot interaction in a cluttered scene	Children

(continued)

Table 2.1 (continued)

Link	Project Acronym	Robot/Application	End users
strands.acin.tuwien.ac.at/	STRANDS	Long-term deployment of intelligent mobile robots in dynamic human environments. Understanding spatiotemporal structure of environment in different time scales.	Misc
www.dream2020.eu	DREAM	Autistic children (uses the NAO robot)	Children
www.companionable.net	CompanionAble	Personal assistant, for remote monitoring and aide memory services	Elderly
www.mobiserv.info	Mobiserv	Personal assistant, with some anthropomorphic features	Elderly
www.aal-europe.eu/projects/alias	Alias	Personal assistance in domestic and care homes	Elderly
www.aat.tuwien.ac.at/ksera/index_en.html	KSERA	Remote health monitoring robot	Elderly
rehabilitationrobotics.net/cms2/	Accompany	Personal assistant robot, for domestic use	Elderly
hobbit.acin.tuwien.ac.at	HOBBIT	Personal assistant robot for domestic use, with anthropomorphic features including manipulation	Elderly
mrl.isr.uc.pt/projects/socialrobot	SocialRobot	Personal assistant, with anthropomorphic features	Elderly
www.robot-era.eu	ROBOT-ERA	Personal assistant with anthropomorphic features	Elderly
rapp-project.eu	RAPP	Software platform for robotics apps	Elderly
www.ramcip-project.eu	RAMCIP	Personal assistant for domestic use, with dextrous manipulation and empathic communication capabilities	Elderly
http://www.growmeup.eu	GrowMeUp	Personal assistant using cloud computing and machine learning techniques. It is able to learn people needs in order to establish positive long-term relationships	Elderly
http://www.enrichme.eu	ENRICHME	Personal assistant for long-term monitoring and interaction	Elderly

(continued)

Table 2.1 (continued)

Link	Project Acronym	Robot/Application	End users
www.mario-project.eu	Mario	Personal assistant to address loneliness, isolation, and dementia effects.	Elderly
http://cordis.europa.eu/poject/rcn/206414:en.html	MoveCare	Personal assistant, using AI and machine learning, to propose exergames to people and detect risks	Elderly
http://cordis.europa.eu/project/rcn/206852_en.html	CARESSES	Robot able to autonomously re-configure their way of acting and speaking to match customs and etiquette of the person it is assisting	Elderly
https://www.heykuri.com	Kuri	Personal assistant with anthropomorphic features and lovable personality to play with children	Children
http://joyforall.hasbro.com/en-us	Joy For ALL	Robot pups (dog or cat) for companionship	Misc
http://www.aal-domeo.org	DOMEO	Personal Assistant for domestic use	Elderly

2013). Results show an increase in social activity, and less aggression and agitation, as well as fewer depressive symptoms (Giusti and Marti 2006; Šabanovic et al. 2013; Wada et al. 2013). Nutritional intake was also improved and the overall need for medication and medical follow-ups was reduced. At this moment, studies have not yet shown clear effects on patients' cognitive function.

In 2009, the U.S. Food and Drug Administration (USFDA) approved the PARO (see Chang et al. 2013; Moyle et al. 2013) robot as a class 2 medical device, for use with the elderly. This robot is currently being used in various countries, such as Germany, Denmark, and Japan.

In a pediatric hospital context, PARO has been used with children aged 2–15, whose communication improved as a result of the interactions between children and robot (Shibata et al. 2001). Another study measured brain activity in young adults through Functional Near-Infrared Spectroscopy (fNIRS) during interaction with this seal robot and the subsequent resting periods. Results showed that activity around the motor cortex decreased when PARO was turned off (meaning participants had no motivation to interact with it voluntarily), and there was also a decrease in the left frontal area activity after having interacted with PARO while it was turned on. This means that the area related to the recognition of emotional gestures as well as positive emotions had been activated while interacting with the robot (Kawaguchi et al. 2012).

Friedman et al. conducted a study with Sony's AIBO, the first consumer robot of its kind to be offered to the public (Aibo 2017). They looked into understanding people's relationships with AIBO, by analyzing the spontaneous postings in online AIBO discussion forums. The results showed that AIBO psychologically engaged this group of participants, particularly by drawing conceptions of technological essences, life-like essences, mental states, and social rapport (Giusti and Marti 2006; Friedman et al. 2003).

The companion robot cat from Hasbro (2017) has been used with people suffering from dementia and Alzheimer's in care homes. The social skills of the cat do not include walking, which is an important part of the animal's social behavior.

Current social robots include several commercial prototypes, some of which have already been used in real environments. The Chelsea and Westminster Hospital has been using an NAO robot "to assess whether these robots could help combat the social isolation experienced by many inpatients in hospital wards" (see NAO 2017).

The case of SoftBank Robotics' Pepper, used as auxiliary staff/receptionist at Ostend Hospital (see NAOb 2017) is an interesting example of technology that is still under development but, nonetheless, is profiting from its public usage. Pepper has also been "employed" in a maternity ward at a Belgium hospital, as an attempt to improve healthcare and putting a smile on patients' faces NAOb (2017). Other applications of this robot include very simple receptionist tasks in commercial environments.

Social robots are challenging the dichotomy between apparent living beings/artificial objects (at least from an epistemic point of view): people tend to recognize the robots as intentional agents even knowing they are not living entities, as a consequence of the natural human tendency to attribute intentional states to artificial objects (Giusti and Marti 2006).

2.2 A Case Study: The MOnarCH Project

Recently, the MOnarCH project explored the formation of social relations between a robot and people, namely children, in the Pediatrics ward of an Oncological hospital.

The MOnarCH robot (see Fig. 2.1) has an appearance consistent with the robot stereotype identified in a survey conducted with a set of children of ages up to 16 years old (Sequeira and Ferreira 2014). The robot is capable of navigating autonomously in the available free space, interacting with basic verbal and non-verbal utterances, namely when someone is recognized or touches it (see Fig. 2.2). It can also play simple games, such as a variant of the popular Flow Free commonly available in cell phones adapted to the slow dynamics of the inpatient children. It was assumed that adults (visitors and staff) could also be involved in casual interaction.

The paradigm underlying the MOnarCH project is that, even with technological limitations, a close human-like interaction mimicking some human communication features can be created. This is achieved by regulating the robot's activity/liveliness level according to the environment.

A typical scenario will be that of a robot wandering in open spaces, such as corridors or common rooms, socializing through various forms of greeting (e.g., Fig. 2.3 where the interaction with a child is depicted), until it is called to execute specialized tasks triggered by healthcare specialists.

Fig. 2.1 Young child exploring the robot (Credits: Exame Informática, 2016)

Fig. 2.2 Pre-teen interacting with the robot (Credits: Agência Lusa, 2015)

Fig. 2.3 A common reaction to the robot by a child in a hospital (Credits: José Oliveira and Revista Visão)

Fig. 2.4 The blueprint of the Pediatrics ward; the areas marked “classroom”, “playroom”, and “main corridor” can be used by the robot

2.3 The MOnarCH Environment

The environment accessible to the robot is essentially a flat area made up of a long corridor, a playroom, and a classroom (see Fig. 2.4).

During the project, video cameras were installed in static positions. These were used to estimate people’s positions in the ward, specifically the position of the children playing the Flow Free game variant (see Sequeira et al. 2015).

The areas accessible to the robot form a well-structured environment, where state-of-the-art localization techniques yield good results. Even in the presence of obstacles, the laser range sensors installed at the front and rear of the robot can acquire measurements that easily match an a priori defined map of the environment (see Ventura and Ahmad 2015 for details).

2.4 Designing a Social Robot—A User-Centered Framework

The term user-centered design was coined by Donald Norman and Stephen Draper in 1986 (Norman and Draper 1986) focusing the particular field of ergonomics in human–computer interaction. The approach explicitly highlighted the need, throughout the design process, to be aware of the potential user and the specificities of their physicality, as well as the nature of their experience using it. User-centered approaches have been reported, for example, in Wu et al. (2012).

The rich multidisciplinary framework involved in the process led some authors (e.g., Steen 2012; Giacomin 2012) to propose the term “Human-Centered Design” as more suitable for covering all aspects of what being a human means and not only those specifically concerned with usability. However, both user-centered design and human-centered design highlight the fact that all artifacts, including technological artifacts, are determined in their function and form by the anatomy and physiology of the user, by their psychology and life experience, by their expectations of technology, as well as by the specificities of the particular context of use.

Consequently, rather than expecting people to just adapt to a new technological artifact, learning how to handle or interact with it, robotic engineering has to be capable of thinking and anticipating how the system can be designed to best suit the people and the society who need to use it, or include the necessary flexibility for a posteriori behavioral adjustments.

In order to achieve this aim, one needs to identify the assumed end user and design for the variability represented in the population, spanning such attributes as age, size, strength, cognitive ability, prior experience, cultural expectations, and goals, thus optimizing performance, safety, and well-being.

Acknowledging the essential role played by the explicit understanding of the nature, status, and context of end users, the International Organization for Standardization has defined the six essential procedures to be followed throughout the production process (see ISO 9241-210 2010):

1. The design is based upon an explicit understanding of users, tasks, and environments.
2. Users are involved throughout design and development.
3. The design is driven and refined by user-centered evaluation.
4. The process is iterative.
5. The design addresses the whole user experience.
6. The design team includes multidisciplinary skills and perspectives.

2.4.1 The Definition of the User's Referential Framework

The particular characteristics of the users, all with their own special circumstances; the specific civilizational/cultural environment and the communicative context and conditions of use in the definition of the overall system and its expected performance play an essential part. This has therefore called for the definition of what we have designated the **User's Referential Framework—URF**.

The following factors, in some cases subsuming a small set of features, can be identified as constituting this referential framework:

1. Function/role to be performed by the system.
2. Universe of users.
3. Nature and Status.
4. Typical Environment: Scenario and Context of use.
5. Interaction Lifespan: Frequency and Duration.

Function/Role is determinant when conceiving an artifact. Whether it is technological or not, the overall architecture and all the design options are dependent on the function being performed.

Universe refers to the number of individuals supposed to interact with the artifact on regular terms. This interaction can involve a single individual, as in the case of an elderly person who has a service robot at home; or a multiple universe, as in the case of a service robot performing in a domestic environment and being assigned various tasks by the different family members, e.g., educational interaction with children, assisting adults in cleaning tasks, or entertaining grandma playing games.

Universe can consequently correspond to **a single individual or to multiple individuals**.

Nature and Status subsumes the variants (i) Age, (ii) Gender, (iii) Civilizational/ Cultural Context, and (iv) Particularities.

The age of the user and the specificities of their physicality are fundamental. Is the robot meant to interact with children, with adults or with both? The answer to this simple question will determine the dimensions of the robotic structure, the type of interfaces available, the overall appearance of the robot, and the materials to be used.

Besides the individual physical/chronological constraints when defining the system's architecture, designers have to be aware of important cultural differences in communities and societal groups that may determine the consumers' preferences in terms of the robot's appearance. For instance, it is well-known that the uncanny valley effect—the feelings of eeriness and revulsion experienced by most human beings when interacting with near-realistic humanoid objects (Mori 2012)—seems to be prevalent in the choice of a robot's appearance in western countries, though its effect is not so significant in the east (MacDorman et al. 2008).

One has to acknowledge the possible relevance of **Gender**, but we consider that this factor really places no constraints, although its specification just contributes to a possible customization of the artifact.

The Particularities factor relates to specific physical and mental user constraints that have to be considered by the design, for instance, any kind of physical impairment or psychological/mental condition.

Typical Environment: Scenario and Context of Use relates to the physical environment in which the system will be integrated, as well as the social atmosphere where it is going to be embedded and which it has to be responsive to. It involves questions such as Where is the robot going to operate? In the open air as, for instance, an agriculture aid? Will it operate indoors? For example, in collaborative contexts within industry; in institutional spaces and collaborative contexts such as assistive and care tasks; or in the domestic environment in edutainment activities for all the family? All these different options determine fundamental differences in terms of its overall architecture, namely, its physical robustness, mobility, perceptional awareness, navigation performance, as well as variations concerning interface definition and the forms of interaction available.

When we talk of **Interaction Lifespan**, we are assuming that every HRI taking place in a virtual timeline can vary according to its **frequency**, i.e., the number of times it occurs and according to its **duration**, i.e., how long it keeps going on. Regarding its **frequency**—it can be either **occasional**, such as the interaction between a robot and a museum visitor, or it can be **recurring**, as with a service robot in a domestic environment and the people that live there. Regarding **duration**, interactions can be either **short-** or **long-termed**. In a way, we can say that all occasional interactions are short-termed, while recurrent interactions are necessarily long-termed. The differences in interaction frequency and duration pose distinct problems. Occasional interaction, such as people suddenly coming face to face with a robot in a shopping center, requires the platform to swiftly attract and engage people, because the chance to interact happens in a snapshot. On the other hand, interactions that have a durative character, especially those that are long-termed, test the system's capacity for keeping the recipient's interest in the interaction. It must surprise them with new approaches/activities so that it doesn't become predictable and boring.

Table 2.2 sums up and organizes the main factors defining the User's Referential Framework.

2.4.2 The URF in the MOnarCH Project

The design of the MOnarCH robot is fully compatible with a user-centered design approach. Though it is anticipated that the robots might, and probably will, also interact with adults; children are the primary end users. Their interactions will be generally recurrent, though not necessarily long-termed, as the duration of the children's stay in hospital will vary.

Considering the relevant factors defining the User's Referential Framework (URF) as shown in Table 2.2, the following previous definition of the MOnarCH's end user profile is displayed in Table 2.3.

According to this referential framework the users, as mentioned above, will multiple, constituted by children and/or teenagers, mainly European and African. The interaction, either short- or long-termed (Ferreira and Sequeira 2015) according to the individual situations, will take place in the Pediatrics ward of a hospital, involving edutainment activities. The interactions will be generally recurrent though not necessarily long-termed, as the time span children are hospitalized will vary.

The activities included (i) helping to maintain the children in socially interesting dynamics and (ii) playing with the children. The assumption is that adults (visitors and staff) could also be enrolled in casual interaction.

The Pediatrics ward in MOnarCH is regulated by social norms established to preserve healthcare efficiency and the children's well-being. These norms implicitly limit the spatial areas a robot can use, and the admissible interactions. Consequently, specific behavior has been adapted to different areas of the ward. In a playroom, for example, the robot is able to play an interactive Flow Free game with a child; whereas in the main corridor of the ward, the robot can play catch-and-touch or simply wander around greeting people it recognizes.

Table 2.2 User's Referential Framework

Universe		Nature and status				Typical environment/scenario			Interaction lifespan			Functional role(s)
						Open air	Indoor					
Singular	Plural	Age	Gender	Particularities	Civilizational/ cultural context	Physical space	Institutional space	Domestic space	Frequency	Duration		
Individual user	Multiple users	Child -teenager	Gender specific, not gender specific	Disabled, other	European, Asian, American…	Public spaces, open institutional spaces, industry, agriculture	School, library, hospital, care house, industry	Flat, detached house	Recurrent	Short termed	Long termed	Edutainment, assistive and care, collaborative work

Table 2.3 MOnarCH URF

Universe		Nature and status				Typical environment/scenario	Interaction lifespan			Functional role(s)
						Indoor				
Singular	Plural	Age	Gender	Particularities	Civilizational/ cultural context	Institutional space	Frequency	Duration		
~~	Multiple users	Child-teenager	Not gender specific	Inpatient children with severe physical condition	Mainly European	Hospital	Recurrent	Short termed	Long termed	Edutainment

2.4.3 *The Design Process*

The design process was carried out in three phases: Conceptual, Production, Deployment, and Evaluation. For the purpose of the present chapter, brief descriptions are given here of only the first two.

In Phase 1—the Conceptual Phase—the process started with an inquiry conducted in two public schools (to about 120 children and teens) of the suburban area of Lisbon in order to verify (i) the existence of a prototypical mental image corresponding to the concept of robot and (ii) the semantic consistency of this concept among children and teens.

Identifying the children's assumptions in terms of visual image (Fig. 2.5) and their expectations concerning the functions to be performed by a robot provided design guidelines that were important when defining an engaging and stimulating application capable of enhancing a fluent child/robot interaction.

As regards the visual image, the results of the above-mentioned survey pointed to a nearly generalized preference for anthropomorphic forms relative to all possible others, and a multi-functional capacity that body forms always reflected. Features such as eyes, mouth, and arms were present in most of the children's drawings (98%) and a particular emphasis was given in a significant percentage (35%) to a supplementary "tablet-like" interface on the chest area. As to the expected functionalities,

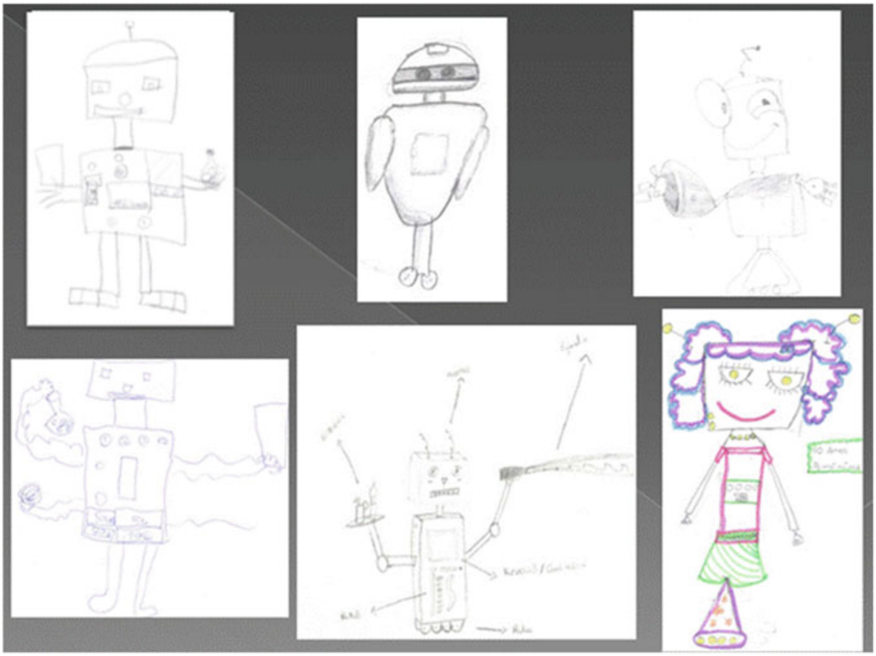


Fig. 2.5 Sample of children's drawings from the survey

edutainment and helping with domestic tasks, such as tidying up the bedroom were prevalent.

Some of the elements identified by the children were used by the design team. A set of preliminary drawings, shown in Fig. 2.6, was discussed by the MOnarCH team.

A merging of the options # 2 and # 3 features (Fig. 2.6, top left) was chosen, namely, because of their rounded, smooth surfaces, interface area in the belly zone, and expressive potential of the facial area.

The robot is 1.15 m tall, about the height of an 8–11-year-old child, in order to keep interaction with the children as close to eye level as possible (see Fig. 2.7). The robot weighs around 45 kg, fitting for a child's companion. It is equipped with a variety of sensors, including laser range finders and touch sensors (bumpers and soft touch). These enable the robot to estimate its localization with accuracy, so as to avoid obstacles and interact with the children.

The robot has an omnidirectional motion with linear velocities of up to 2.5 m/s, and is thus capable of walking beside a person at a moderately fast pace. The empirical evidence collected throughout the project suggested that there was no need for higher velocities. For some expressive capacity, the robot has got two 1-dof arms and a 1-dof neck, variable luminosity eyes and cheeks, a LED matrix for a mouth, loudspeakers, microphone, touch sensors placed in strategic places of the body shell, and a RFID tag reader. The 1-dof arms do not aim at any form of manipulation. Instead, they are useful, for example, to convey the perception of body movement when the robot circulates.

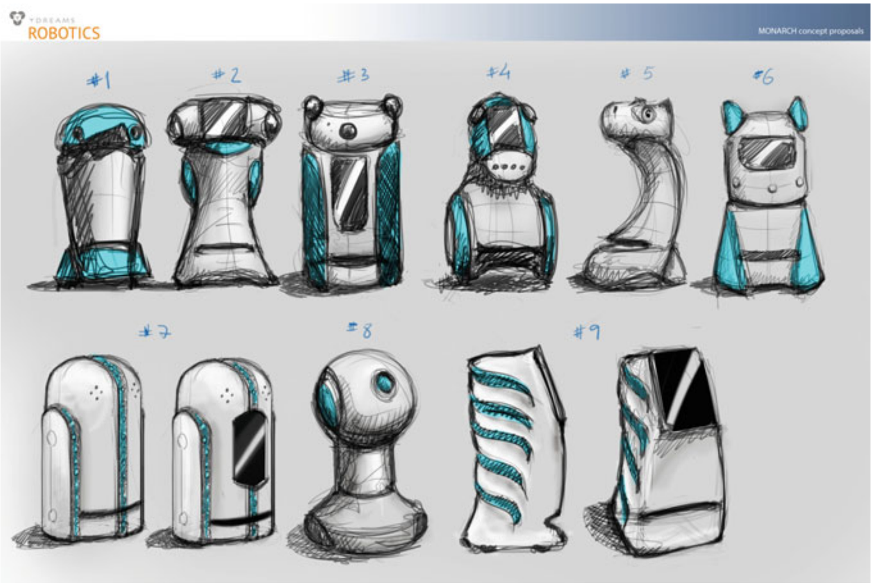


Fig. 2.6 The MOnarCH robot's appearance: initial studies conducted by one of the project partners

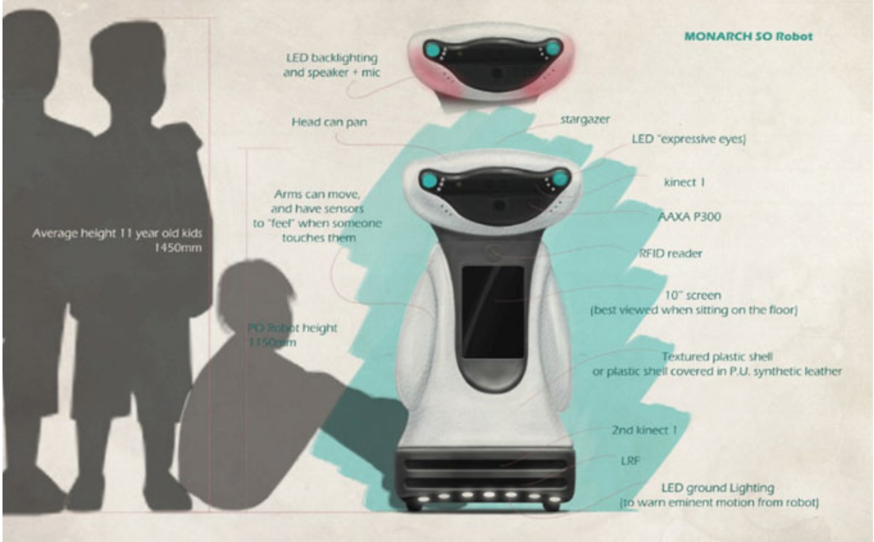


Fig. 2.7 Main features of the MOnarCH robot final version

Movement can be perceived by living organisms as expressive, in the sense of being meaningful, and body movements are generally interpreted among different species in specific ways. Just the way one walks carries a multitude of data comprehending for the observer: such different features as psychological state/attitude, mood, intention and also physical condition, or age.

The MOnarCH robot tries to convey the idea of lightness and cheerfulness with its soft and swift movements. Moreover, the smooth motion of the robot's body can sometimes be seen as "dancing" (see Fig. 2.8). This is just an example of expressive motion that contributes to the liveness of the robot. Similarly, when playing Flow-

Fig. 2.8 The MOnarCH robot using a "dancing" movement for expressivity (the sequence evolves from left to right)

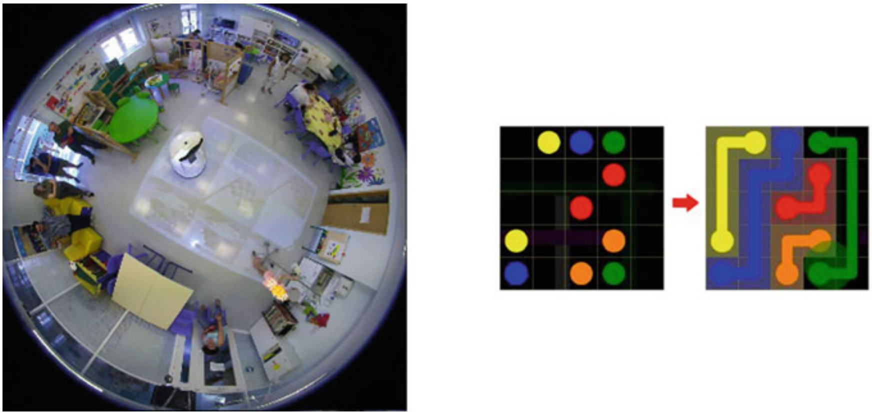


Fig. 2.9 Child playing the Flow Free interactive game with the robot (cell phone sample game on the right image)

Free (see Fig. 2.9) it is important to include small movements to convey a perception of liveness.

The two 1-dof arms are used to improve liveliness. A simple balancing of the arms, while the robot is moving, can easily convey the perception that the robot has a focus while moving or a goal location (as, for example, when playing "catch-and-touch"—see Fig. 2.10).

Also, the fact that the neck can rotate right or left (1-dof neck) conveys the feeling that it is looking at whoever it is interacting with or that it has a clear focus of attention, which contributes to interaction fluency (relevant in scenarios such as the Flow Free game of Fig. 2.9).

2.5 Technologies

The omnidirectional platform supports two laser-based range sensors, for obstacle avoidance and localization, with one computer in charge of the navigation and another to handle the interaction devices. These are the touchscreen in the chest, two LED eyes with color and intensity control, a LED matrix mouth, two RGB-D cameras, and a RFID reader inside the head. Touch sensors are available at the tip of the arms and around the shoulder area.

The laser range finders located at the front and at the back of the robot, at approximately floor level, provide 360° coverage around the robot with a 0.5° angular separation. Figure 2.11 shows the location of the robot in the ward (left-hand image) and the LRF measurements in the neighborhood of the robot (right-hand image). Regions of measurements (the red and blue points) aligned along with line segments, corresponding to walls in the corridor, are visible in the right-hand image. The dots in the close neighborhood of the front part of the head correspond to people

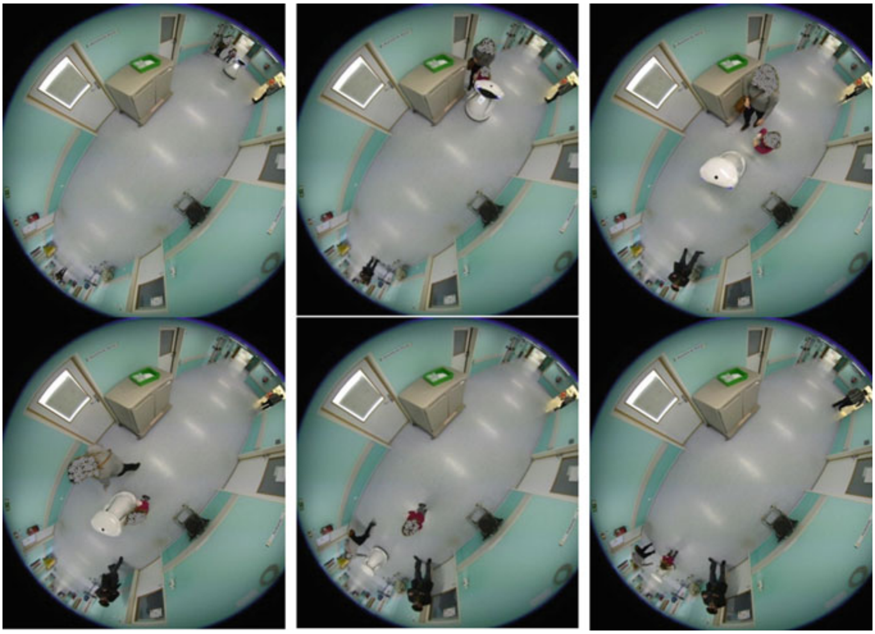


Fig. 2.10 Child playing catch-and-touch with the robot

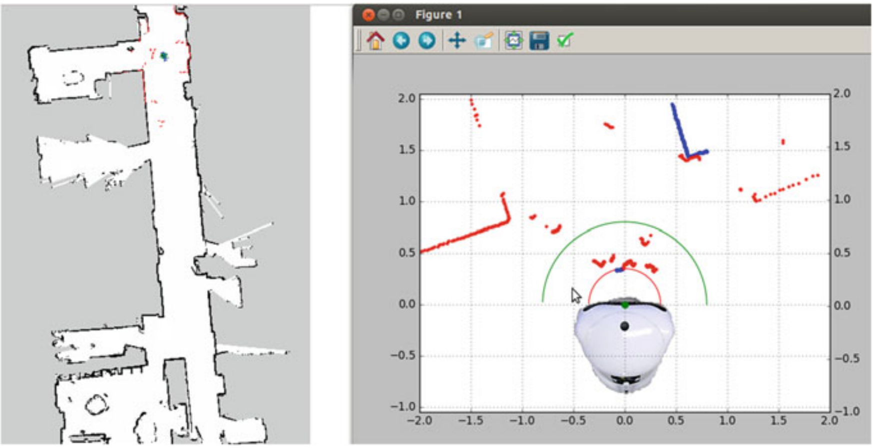


Fig. 2.11 A sample of laser range finder around the robot (the red dots stand for the laser range finder measurements)

standing in front of the robot (the legs of these people are visible as pairs of small sets of red points).

Primary interaction occurs through the facial expressions made through the eyes, mouth, and touch sensors. The legal restrictions on the use of video imaging discourage the use of the RGB cameras. Only the depth information is being used to detect people in the surroundings. Therefore, the robot does recognize or record RGB-D images but with no connection to databases maintaining inpatient health records.

The robot can operate either fully autonomously or using a Wizard-of-Oz strategy with various degrees of autonomy (see Fig. 2.12). Under full autonomy, the robot behavior is supervised by a finite-state machine that can be easily adapted to environmental changes (see Fig. 2.13).

Switching between the high-level behaviors is triggered through specific RFID tags detected by the reader inside the head of the robot. By default, the robot operates in the wander mode, moving around the main corridor without entering the inpatient rooms. The tags controlling the supervision state machine are only used by duly authorized staff members.

To account for emergency situations, the robot has a stop button (placed in a visible area at the back) that if activated stops all activity and allows anyone to push it out of the way.

People recognition is also made through the RFID technology. People wanting to be recognized must carry a small tag. This tag contains only information voluntarily waived by the user of the tag, e.g., a name, which does not need to have any relation with the person's real name.

The reader's antenna has a distinctive detection pattern (see Fig. 2.14) that is also used to provide a rough estimate of the angular position of a tag around the robot's head (Sequeira and Gameiro 2017).

Fig. 2.12 Wizard-of-Oz interaction using a smartphone

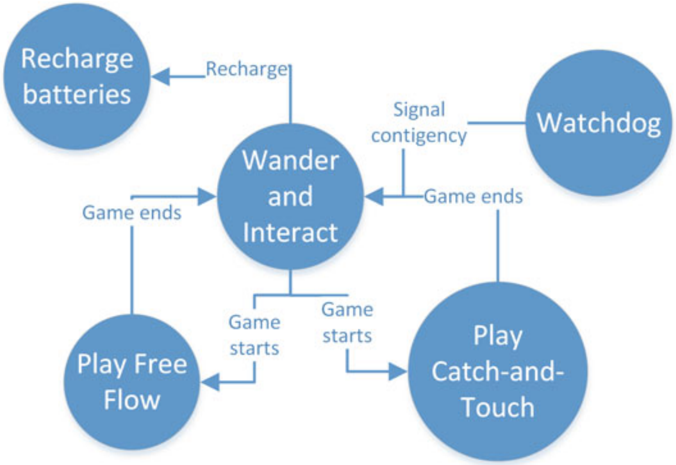
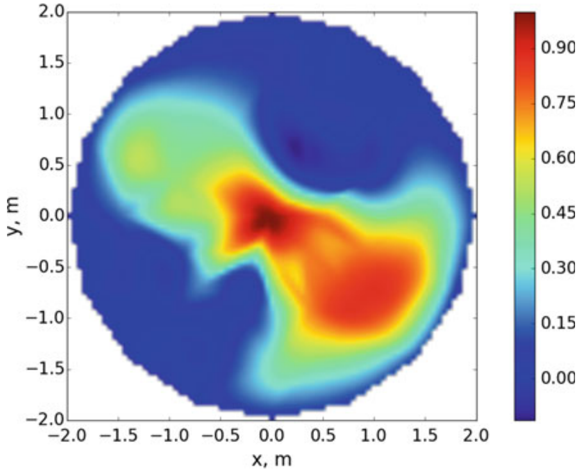


Fig. 2.13 An overview diagram of the high-level behavioral supervision state machine

Fig. 2.14 RFID antenna detection pattern (interpolated probability surface)



This rough estimate creates the interesting perception that the robot knows where a person carrying a RFID tag is, much like a normal person, i.e., often correct but failing sometimes.

2.6 Assessment

Developing metrics for social robotics' experiments have been a central topic in the field. The diversity of conditions makes the conclusions of one experiment not immediately applicable to another, even if seemingly equivalent.

The literature on the topic is extensive. For example, randomness has been recognized as helpful in some HRI scenarios (Holthaus et al. 2011), meaning that to properly compare different environments, uncertainty must be adequately estimated in them.

Moreover, assessing in-lab experiments may yield consistently different results than apparently equivalent out-lab ones (Weiss et al. 2011). In fact, standard techniques such as Likert questionnaires may easily introduce bias in out-lab experiments, e.g., by creating expectations about what is expected from people answering the questionnaire.

Annotation techniques, e.g., either directly or indirectly through video recordings, seem more appropriate for experiments in generic out-lab environments. With MOnarCH, annotated video recordings were used. Table 2.4 shows a list of micro-behaviors used in some of the experiments. These were selected to (i) be reasonably simple to identify, and thus minimize a priori misclassification of micro-behaviors and (ii) provide indicators that can be easily identified with the desired performance indicators, e.g., acceptance/rejection.

In MOnarCH, multiple indicators of micro-behavior relevance were used, namely, (i) direct counting of occurrences, (ii) activation rates, and (iii) functions of the time between occurrences (see Sequeira 2017 for details).

The activation rate, i.e., the number of micro-behavior occurrences per unit of time, indicates the micro-behavior relevance within a given time interval.

Counting the number of occurrences in an experiment allows for micro-behavior ranking and, hence, it is an indicator of their relative relevance.

The time between occurrences is intrinsic to the environment dynamics for which probabilistic models can be estimated.

In a sense, if the set of micro-behaviors to be annotated is rich enough, it will capture the environment dynamics, defined in terms of the timing of the micro-

Table 2.4 Sample of annotated micro-behaviors in a MOnarCH experiment

	Micro-behavior
1	Looking toward the robot, without direct interaction
2	Looking toward the robot and moving (around, ahead, and/or at the back of the robot)
3	Touching the robot
4	Aggressive movement toward the robot
5	Ignoring the robot
6	Following the robot
7	Compliant behavior toward the robot

behavior occurrence (the relevant events). Performance can then be assessed by looking at models of the environment and at any deviations from normal conditions.

As an example, experiments in MOnarCH yield aggregate countings, such as those in Table 2.5, found in two separate experiments. These occurred on different days with a 6-day interval in between, and with different children.

A ranking of micro-behaviors formed with these values, after normalization, suggests that (i) the robot does not significantly change the environment, as the micro-behaviors related to indifference are top rank and (ii) the robot is well accepted, as those related to acceptance are ranked next, while those related to non-acceptance are ranked bottom (see Sequeira 2017).

An example of the activation rates obtained in MOnarCH experiments is shown in Table 2.6. In this case, the set of micro-behaviors in Table 2.4 was used to annotate two different experiments on the liveliness exhibited by the robot.

A direct comparison between the two lines in Table 2.6 suggests that increased liveliness diminishes the relevance of micro-behavior 5, i.e., ignoring the robot. Furthermore, the values in the rightmost, micro-behavior 7, column suggest that people tend to be more compliant if the robot seems alive. People also appear to be less interested in following the robot if it shows improved liveliness. The differences between values relative to micro-behaviors 1–4 do not seem to be significant when drawing conclusions.

A major issue when assessing social interaction experiments in out-lab environments is the planning of experiments. To avoid introducing bias, experiments often cannot be scheduled in advance. Instead, they must occur at the environment's natural pace. The examples are the trials reported in Table 2.5. They had 6 days between them, as the team had to wait for the right environmental conditions.

Table 2.5 Aggregate counting for each of the micro-behaviors in Table 2.4, for two experiments

	1	2	3	4	5	6	7
Count 1	49	40	9	1	77	16	40
Count 2	50	18	1	0	97	0	65

Table 2.6 Activation rates ($\times 10^{-2}$) in two experiments (the micro-behavior list in Table 2.4 is used)

	1	2	3	4	5	6	7
Activation rate (low liveliness)	1	0.64	0.16	0.03	1.9	3.2	0.61
Activation rate (high liveliness)	0.86	0.78	0.16	0	1.1	0.23	0.82

2.7 Current and Future Challenges

In the near future, the widespread deployment of robots in different domains of human life will be one of the major technological and social challenges. There will, consequently, be a need for harmonious and sustainable coexistence between humans and embodied intelligent machines in shared physical, social, and cultural environments. So far, most of these new robotic applications have been conceived and tested in the lab, with their design process and evaluation being mainly guided by concerns with the functional correctness of their performance, e.g., when navigating, perceiving the surrounding environment, or grabbing things. There has been less concern about the need to produce autonomous artificial entities that are not only functionally efficient but also appealing and adequate for differentiated end user groups. If it is true that the process of incorporating a new artifact in society always involves the adaptation of human beings to it, it is also true that technology has to be user-friendly, so that it is easily accepted, understood, and smoothly incorporated in people's typical routines and environments. A user-centered approach, therefore, becomes essential throughout the design and production process. The identification of the potential end users and their corresponding characteristics, as well as the identification of the circumstances and contexts of use calls for the definition of what we designate the User's Referential Framework—URF.

The added value brought by a social robot, such as MOnarCH, must be assessed through long-term experiments. MOnarCH is simply a playmate for a physically and emotionally fragile population, a new experience that does not replace healthcare professionals. The empirical evidence collected suggested that the vast majority of children surveyed had the correct perception that the robot was not alive. Nevertheless, children acknowledged the robot's presence in the Pediatrics ward and the liveliness features implemented positively.

Ethical issues are currently gaining momentum, profiting from a media frenzy. MOnarCH followed the legal recommendations, namely (i) those from the National Data Protection Authority (CNPD), which severely restricts the usage of sensors, such as video cameras; (ii) the use of Informed Consents (EC 2017a) and (iii) the use of a code of conduct for the team members (Delvaux 2016; EC 2017b).

A Pediatrics ward is, by nature, a sensitive environment and requires extreme care in terms of the robot's behavior. From a physical point of view, people's safety in the Pediatrics ward was never an issue, with the current technology ensuring a collision-free operation. For approximately 18 months, the robot operated on a daily basis in two 1-h periods, one during the morning and the other in the afternoon. During these periods, several developmental stages were tested, always minimizing team member presence in the ward.

To continue improving inpatient QoL, it is paramount to innovate in perception techniques, namely avoiding ethics related issues. The real-time estimation of social environment models and the adjustment of robot behaviors to comply with any local social norms, especially related to multimodal communication to improve interaction with humans, are also topics of interest.

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