Care-O-bot® 3 – Vision of a Robot Butler

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Abstract. This chapter promotes the idea of a robot butler and investigates the advantages and disadvantages of embodiment for the proposed scenario „Tina and her butler". In order to make the discussion more tangible, Care-O-bot® 3 is introduced, which is the newest version of the Care-O-bot® series developed by the Fraunhofer Institute for Manufacturing Engineering and Automation IPA in Stuttgart, Germany. Remarkably, the prominent role of this robot was chosen to be a butler's. A brief overview is given of current human-robot interaction research, focusing on how users react to the idea of a robot companion. The results of different user studies provided inspiration during the design phase of Care-O-bot® 3, in particular with respect to the robot's appearance and the user interaction concept. The technological aspects are covered shortly before user interaction scenarios embedded in research projects related with Care-O-bot® 3 are presented. Results from real life trials conducted in an elderly care facility are given afterwards. Against the background of these scenarios, the benefits and drawbacks of embodiment for the virtual butler scenario are discussed using the example of Care-O-bot® 3.

1 Introduction

The scenario "Tina and her butler" presented in the preface of this book proposes a future vision of an artificial companion helping elderly people to better master their lives. In the scenario, the active elderly woman Tina is supported by a virtual butler, whose capabilities intensively rely on communication and information acquisition services. The butler is highly networked with home appliances, the internet and butlers of other persons, enabling it to e.g. quickly setup a communication channel to Tina's niece, to get the departure time of the next bus or to have the living room cleaned by autonomous vacuum cleaners.

Another important property of the butler is its ability to adapt to persons' individual preferences, learning about their special needs, their music taste and their social network. It is even able to be empathic about the current emotional state of the user, taking it into account for its planned actions.

Considering all these abilities, there seems to be no stringent need for an embodiment of the butler as a robot at first sight. However, the scenario is rather

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unspecific about how exactly the communication between user and butler takes place. How does the user address the butler? When does the butler know that it is addressed? How does the user know, when the butler is ready for communication? These are typical problems for which an embodiment could provide an easy solution. The benefits of a robot embodiment will be discussed in more detail in this article.

The chapter is organized in the following way: At first, current user studies concerning the expectations of users from an artificial assistant will be presented. How the results of these studies were considered in the design concepts of the newest development of the Care-O-bot® series, Care-O-bot® 3 [19], will be pointed out subsequently. In particular, the user interaction concept of Care-O-bot® 3 is introduced. Thereafter, scenarios guiding through the development process of the robot as well as scenarios from related research projects are presented. Finally, the potential contribution of Care-O-bot® 3 for the "Tina and her butler" scenario will be discussed, concluding with a short outlook to the next development goals of Care-O-bot® 3.

2 User Studies: The Role of an Artificial Butler from a User's Perspective

The research field of human-computer interaction (HCI) is well established and has existed for many decades, while human-robot interaction (HRI) is a fairly new research field that is related to, but also distinctly different from HCI and has gained a lot of attention recently. Concerning a mobile service robot, additional aspects with respect to the users' acceptance and their expectations have to be considered. So, what are people's views on the role of an intelligent service robot in their home?

Several studies have been conducted to investigate people's attitudes towards domestic robots. Syrdal [23] carried out a survey in order to examine adults' attitudes towards an intelligent service robot. Participants were 21-60 years old, while most of them were in the age of 21-30. Results show that most participants were positive towards the idea of an intelligent service robot and view it as a domestic machine or a smart intelligent equipment that can be 'controlled', but is intelligent enough to perform typical household tasks. Participants also prefer a robot to be neutral towards gender and age.

Scopelliti [24] investigated people's representation of domestic robots across three different generations and found that while young people tend to have positive feelings towards domestic robots, elderly people were more frightened of the prospect of a robot in the home.

Studies within the European research project COGNIRON assessed people's attitudes towards robots via questionnaires following live human-robot interaction trials [6]. Responses from 28 adults (the majority in the age range 26-45) indicated that a large proportion of participants were in favour of a robot companion, but would prefer it to have a role of an assistant (79%), machine/appliance (71%) or servant (46%). Few wanted a robot companion to be a 'friend'. The majority of the participants wanted the robot to be able to do household tasks. Also, participants preferred a robot that is predictable, controllable, considerate and polite. Human-like communication was desired for a robot companion, however, human-like behaviour and appearance were less important.

These three studies, conducted in different European countries, agreed with respect to the desired role of a service robot in the home: an assistant able to carry out useful tasks, and not necessarily a 'friend' with human-like appearance.

From the latter fact arises the following question: why do people possibly not want the artificial companion to be a friend? This question also impacts the virtual butler scenario in the sense that users might not want the butler to behave like a friend, knowing their personality, their interests, their preferences and even their current mood. These considerations led to the definition of a robot companion which must be a) able to perform a range of useful tasks or functions, and b) must carry out these tasks or functions in a manner that is socially acceptable and comfortable for people it shares the environment with and/or it interacts with [23].

This creates the following challenge for the development of such a robot: we have to bridge the gap between functionality, which goes along with hard technological properties of e.g. an industrial robot, and social acceptance, which goes along with the comfortable design of e.g. an electronic pet.

3 Care-O-bot® 3: Convergence of Design and Technology

Motivated by the user studies which brought the insight that artificial companions need not be necessarily humanoid to be well accepted, further considerations were made about the robot's appearance.

3.1 Considerations on Embodiment Appearance

Humans sometimes talk not only to persons, but also to inanimate objects like their cars, computers, alarm clocks or other devices, identify them by gender and give them sometimes even names [1], [10]. This phenomenon, that humans attribute human-like characteristics to inanimate objects is called anthropomorphism [10].

Anthropomorphism is a constant pattern in human cognition [2], [7], [14], [25], and the interaction of a human with a robot (or any kind of machine) cannot completely elude it. This becomes apparent also in the scenario, as Tina's neighbour, Dorry, gives her butler a name, 'Djinn', which does not perfectly fit to a human, but much less to a technical device.

According to Mori [11], the so-called uncanny valley would suggest to either stay in the domain of very non-human, toy-like robots, or to create a robot that appears to be almost perfectly human-like, because a robot that has many human-like features, but is still recognizable as non-human may elicit rather fearful responses. Unfortunately, at present the uncanny valley is not a good starting point for robot engineering and lacks a solid empirical foundation [12].

Furthermore, there is disagreement. The matching hypothesis [8] predicts the most successful human-robot interaction if the robot's appearance matches its role in the interaction. In highly interactive social or playful tasks participants in a study preferred the human-like robot. In serious, less emotional tasks, however, they did prefer the machine-like robot [8]. Similarly, a highly human-like robot may not be the best choice for a medical task that may involve people feeling embarrassed [28].

We must be aware of the fact that the appearance of the robot communicates its strengths, weaknesses and competences to the user, as well as psychological aspects such as perceived personality. User personality and the perceived personality of a robot impacts how people perceive robots and their behaviour [29]. It remains unclear of whether people would prefer their own personality and the robot's to match [30] or not [33] but, as discussed above, any such differences are also likely to be influenced by the task and context of the interaction as well as the robot's appearance and functions. A systematic study into people's perceptions of robot appearance and behaviour as well as robot and user personality attributions in a robot home companion scenario exemplified different factors [31]. It was shown that while the majority of people prefer robots with human-like appearance and attributes, introverted participants and those with lower scores for emotional stability tended to prefer the mechanoid (mechanically looking) appearance to a larger degree than other participants. From the perspective of robot designers who may wish to satisfy the preferences of as many potential users as possible, this suggests that less human-like robots may represent the 'best comprise' and find greater acceptance of a large target user group. It has been suggested that a variety of non-human cues may be used successfully in human-robot interaction [32] and indeed, this has been confirmed by a recent HRI study [34]. Note, finding a 'best compromise' is a design heuristic that can be important in situations where users may either not have the choice to choose from a variety of different designs, or if one system is being used by many users (e.g. in a care facility).

Human-like appearance is likely to trigger expectations that go beyond the capabilities of a machine. But being humanoid in appearance does hardly suffice to meet the expectancy of human-like reactions. To achieve this, the robot needs to interpret situations correctly to adapt its behaviour. This requires elaborate models of cognition and emotion. Even though research makes progress in these matters, e.g. within the COGNIRON [4] or LIREC [35] projects, the technology is not yet readily available. Instead findings suggest, that if a machine triggers high expectations concerning its capabilities, the user adapts accordingly and tends to overchallenge the machine [17] while getting frustrated himself.

Furthermore, the relation between human and robot gets even more complicated if we expand the focus from the capabilities of the robot to the characteristics of the interaction. Patterns of social behaviour become more important [15], [16] in this context. Thus, the robot designer also needs to be familiar with issues regarding social interaction aspects. At present, however, findings are still too preliminary to serve as design guidelines for a socially acceptable *humanoid* service robot.

3.2 Key Features of Care-O-bot® 3 Design

Based on these arguments, a non human-like appearance for Care-O-bot® 3 was decided and measures to avoid anthropomorphic attributions were investigated to support technomorphic perceptions. The most important of these measures include the avoidance of any parts that resemble a face or produce gender specific expressions or interpretations. Furthermore, the robot behaviour was modeled under considerations described above; the robot should never refer to itself by "I", or express its needs in a human way like "I am hungry" if the battery is low, for example.

The basic concept developed is based on a two sided design. One side is called the 'working side' and is located at the back of the robot, away from the user. This is where all technical devices like manipulators and sensors which can not be hidden and need direct access to the environment are mounted. The other side is called the 'serving side' and is intended to reduce the users' possible fears of mechanical parts by having smooth surfaces and a likable appearance. This is the side where all physical human-robot interaction takes place. One of the first design sketches can be seen in Fig. 1 (left).

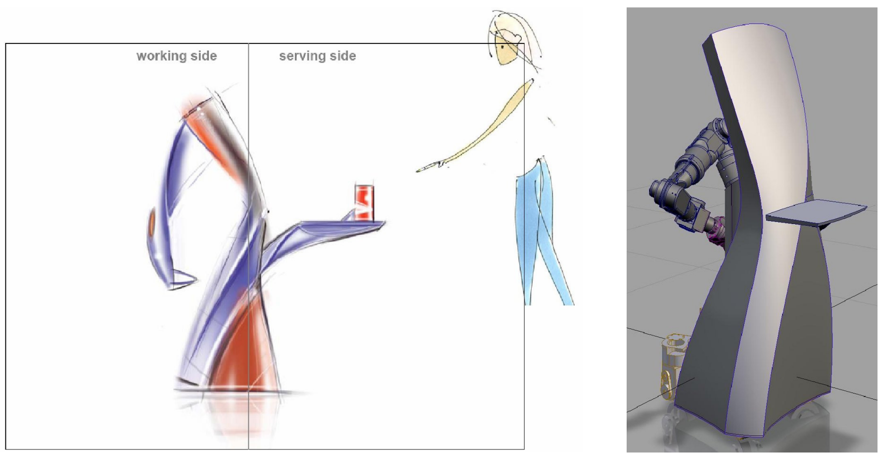

Fig. 1. Left: First design sketch, Right: first technical rendering

After several steps of design-technology convergence a simplified rendering was created (see Fig. 1, right hand side). Based on these images the underlying technology was integrated into this shape.

3.3 Technological Properties

Care-O-bot® 3 can be divided into the following components: mobile base, torso, manipulator, tray and sensor carrier with sensors.

The mobile base consists of four wheels, for each of which orientation and rotational speed can be set individually. This allows the robot an omnidirectional drive enabling advanced movements and simplifying complete kinematic chain (mobile base - manipulator - gripper) control. The wheeled drive was preferred to leg drive because of safety (no risk of falling) and stability during manipulation. The base also includes the battery pack for the robot, laser scanners and one PC for navigation tasks. The size of the base is mainly determined by the required battery space. Nevertheless, the maximal footprint of the robot is approx. 600 mm and the height of the base is approx. 340 mm.

The torso sits on the base and supports the sensor carrier, manipulator and tray. It contains most of the electronics and PCs necessary for robot control. The base and torso together have a height of 770 mm.

The manipulator is based on the SCHUNK LWA3, a 7-degrees-of-freedom (DOF) light-weight arm. It has been extended by 120 mm to increase the work area so that the gripper can reach the floor, but also a kitchen cupboard. It has a 6-DOF force-torque sensor and a slim quick-change system between the manipulator and the 7-DOF SCHUNK Dexterous-Hand SDH. The force-torque sensor is used for force controlled movements like opening draws and doors, but also for teaching the robot new tasks by physical interaction with the human.

The robot hand has tactile sensors in its fingers making advanced gripping possible. Special attention was paid to the mounting of the arm on the robot torso. The result is based on simulations for finding the ideal work space covering the robot's tray, the floor and area directly behind the robot following the ‘two sides’ concept developed.

The robot has a sensor carrier carrying high-resolution stereo-vision cameras and 3-D-time-of-flight-cameras, enabling the robot to identify, to locate and to track objects and people in 3-D. These sensors are mounted on a 5-DOF positioning unit allowing the robot to direct his sensors to any area of interest. It is very important in this concept not to create a face with these sensors which is quite difficult to avoid (see section 3.1).

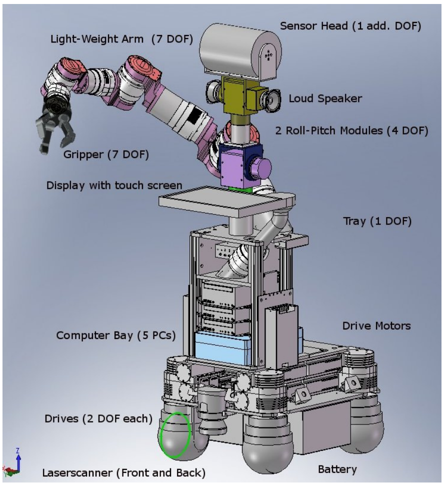

Fig. 2. Left: Hardware set-up of Care-O-bot® 3, Right: Care-O-bot® 3 with flexible casing

Fig. 2 shows the complete hardware set-up of the robot. The convergence of the original design idea and the underlying technology can be seen in on the right hand side, showing the robots final appearance.

4 User Interaction Scenarios

Development in robotics is mostly scenario driven. For Care-O-bot® 3, user interaction played an important role, such that a couple of user interaction scenarios were worked out during the development of the robot.

Variations of the "Tina and her butler" scenario get more and more the focus of research projects on national and European level. The research scenarios in contrast however mostly include handicapped or elderly people that suffer from mobility constraints, sensory and perceptual impairments or mental degeneration that complicate simple every day tasks and often prevents them from being able to stay in their homes, independently any more. But mobile robots cannot only assist people in their homes but also in elderly care-facilities. In the following, scenarios from current research projects with Care-O-bot® 3 as a project platform are presented. The section starts presenting guiding scenarios in the Care-O-bot® 3 development phase.

4.1 Guiding Scenarios during the Development of Care-O-bot® 3

The Care-O-bot® 3 project [3] particularly aims at the area of household helper robots and developed different user interaction scenarios, of which in the following those will be presented that are relevant to the "Tina and her butler" scenario. The fetch-and-carry service represents the robot's core functionality and is to some extent contained in all following scenarios. The scenario based design method [21] is applied to produce interface concepts. Each of the following scenarios is based on a single persona [18].

The personae developed in the Care-O-bot® design phase ranged from millionaires with the need for an electronic butler, retired engineers with the wish to have a technical companion to diabetic programmers with the need to have a dependable nurse.

Because of the diversity of the personae, different hardware solutions were considered, ranging from small form PDAs to full size Tablet PCs. As diverse as the hardware were the results for the actual user interfaces (UIs). The UI represents the traditional gateway to the Care-O-bot® 3 hardware. Its abilities can be accessed through all designed UI variants. As an example three personae will be described along with respective UI designs. A forth UI design is presented that was developed independent from a certain persona, as it simply comprises the core functionality of Care-O-bot® 3: the fetch-and-carry service.

The first UI version is based on a persona called 'Hartmut von Geiss'. He is a young manager of an IT business. He uses the robot at his home to support his daily housework. Casually his robot helps him in multitasking situations: Video phone call from his boss, during his diner while a parcel service is ringing. Fig. 3 (top left) shows the first design of an UI for this scenario. It is a very straightforward design using a small tablet PC with a decent segmentation of the available screen.

The second design is based on a PDA and uses the guidelines that are appropriate for stylus passed input devices. The story behind the design contains a persona called ‘Fabian Krasse’. He is a diabetic programmer who wants a reliable nurse that fits his technophile life-style. The interface of this scenario (see Fig. 3, top right) is based on a PDA that fits Fabians way of life and working.

The last concept presented is based on a persona called ‘Patricia van der Dellen’ and represents the group of so called ‘soccer moms’ - meaning they have the technical equipment, but not necessarily the knowledge of the underlying technology, a characteristic which could also apply to elder persons that are not afraid of using technology. This is a more challenging group of users and leads to an interesting UI concept. The hardware consists of a tablet PC with finger touch capabilities. The interaction concept is based on various ‘genies’ that represent the different characteristics and services that Care-O-bot® 3 can offer (see Fig. 3, bottom).

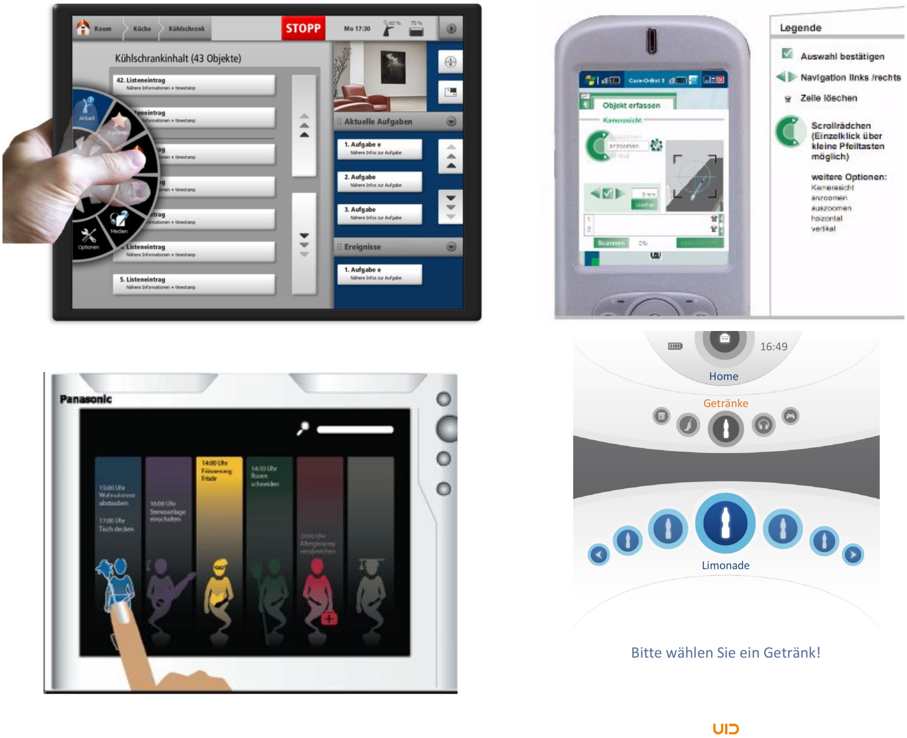

Fig. 3. User Interfaces for the different scenarios: Top left: User Interface for technical assistance at home (IT professional); Top right: User Interface for young technophiles; Bottom left: ‘Soccer Mom’ User Interface. Bottom right: Serving Drink User Interface [20]

The different genies cover the following areas: Household, entertainment, medical, education, cooking and personal secretary. Remarkably, the genie metaphor is also used in the „Tina and her butler“ scenario – it seems to fit well for the high-tech butlers: the user does not know how the work is done, but can be absolutely sure that it is done.

The forth UI is more general and focuses on the classical fetch-and-carry service in form of a serving drink scenario. The UI is not designed for a dedicated persona and can be implemented on the touchscreen of Care-O-bot® 3. The user may choose from an assortment of drinks Care-O-bot® is able to deliver and order the desired drink through the UI. Furthermore, the UI reflects the current state and operation the robot is performing, e.g. navigating, moving the arm or using its cameras.

All described scenarios were developed during the development of Care-O-bot® 3 to target the applicability of Care-O-bot® 3 for different user groups. In the following, scenarios from current research projects are presented that focus on supporting especially elderly people in their daily lives.

4.2 Home Assistant Scenario

The main idea behind the recently started European research project SRS (Multi-Role Shadow Robot for Independent Living) [13] is to allow elderly persons to live longer in their own homes instead of moving into an elderly care facility and therefore enable a more independent life. The prominent aspect of the project is to use a tele-operated robot to assist elderly persons at fulfilling household tasks. The robot acts in a semi-autonomous manner which means that it tries to accomplish a task autonomously until something unexpected happens. If the robot is not able to solve this problem, a remote operator is asked for help. The robot is also able to learn new actions by observing the actions of the human operator.

To identify appropriate scenarios for a tele-operated home assistant, a survey among three potential user groups was conducted. The three user groups for the SRS system are

- elderly persons as local users and beneficiary,
- private caregivers, e.g. relatives of the elderly person as remote operators
- employees of 24-hour teleassistance centers as professional remote operators.

The scenarios obtained from this survey were ordered with respect to both the feasibility and the benefits of a potential realization with a tele-operated robot.
The two top-ranked scenarios are defined as follows:

1) Fetch-and-carry service

The fetch-and-carry service constitutes the base scenario for SRS. The robot gets a request by the local user to an object to a certain location. For example, if the elderly person is sick and has to stay in bed, the request could be to bring a glass of water to the bed (see Fig. 4, lower left) or if the elderly person wants to read a book, the robot can be requested to retrieve this difficult to reach object (see Fig. 4, upper right). After receiving the request, the robot navigates to the location where the object should reside, detects it using its sensors, grasps the object and drives back to the location of the local user where it delivers the object. If, for example, the object is not located at its usual place and the robot cannot find it, it can request the remote operator for help. The remote operator then scans the room by moving the robot manually and observing the camera image in order to find the missing object and tell the robot where to find it.

Preparing food is a slight variation of the fetch-and-carry scenario (see Fig. 4, upper left). Additionally, it includes opening and closing furniture objects like a fridge or a microwave.

2) Emergency assistance

The second SRS scenario is emergency assistance (see Fig. 4, lower right). If an elderly person falls at night, the robot might help by giving support at standing up or by starting a video call with the tele-operator. The remote operator can then use the robot to observe the elderly person and decide to set up an emergency call. This scenario is based on the assumption that the local user is equipped with a fall sensor as the robot is not able to detect this with its sensors at every place in the elderly person's home.

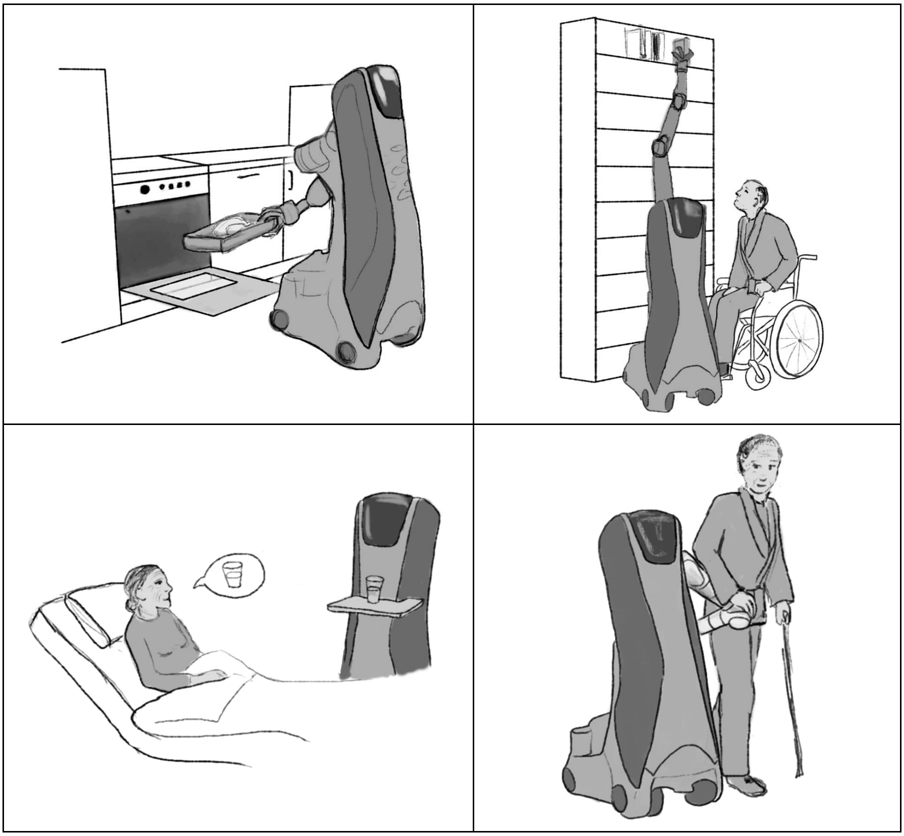

Fig. 4. Envisaged SRS Scenarios

4.3 Scenarios to Support Service Personal in Elderly Care Facilities

In contrast to the SRS project, the project WiMi-Care [26] is focused on the application of a robot butler in elderly care facilities. Here, tasks are mainly focused on supporting care workers in their daily work, taking over routine tasks such as transporting goods and journalizing their work to leave them more time for work in direct contact with the inhabitants. Regarding the background that a shortage of care workers is foreseeable in the future, taking over tedious, walk-intensive tasks can help to ensure adequate care for the increasing number of elderly people in the next decades. In the WiMi-Care project, two scenarios for Care-O-bot® 3 were identified following the method of scenario based design. To determine where support work in elderly care facilities is really needed and appreciated, a requirement analysis was conducted in an elderly care facility based on visits of the facility and interviews with care workers.

In the scenario "potation supply" (Fig. 5, left) Care-O-bot® 3 offers water which was drawn autonomously from a water cooler to the inhabitants. As elderly people generally tend to drink too little, the work of offering drinks to inhabitants is usually very time-consuming for care workers. In addition, journalizing the amount of consumed potation is usually error-prone as care workers often have to do several tasks at once and have to react to sudden alarms.

The potation supply scenario begins with Care-O-bot® 3 moving to the water cooler which is set up in a kitchen area on the ward. The cup of water is then placed on the robot's tray and is carried to a sitting area where Care-O-bot® 3 identifies the inhabitants sitting at the tables. The robot then chooses a person which according to the potation supply journal has not drunk enough water and offers the drink. Here special attention is paid to motivate the elderly people to drink, for example by addressing the people individually via speech output. If the drink is taken Care-O-bot® 3 thanks the inhabitant and moves back to the kitchen area where the next cycle can be started. Apart from the credible interaction with inhabitants, the development of Care-O-bot® 3 during the project aims on a safe and reliable task execution among people on corridors and in sitting areas.

The idea of the "entertainment" scenario (Fig. 5, right) is to offer individual entertainment functions and activities to inhabitants such as to read out texts, to play music or to play games like chess or memory. This allows the care facility to extend the program of activities for the inhabitants. Furthermore, memory training applications can complement occupational therapy. To start an entertainment function, a care worker selects an appropriate activity on the touchscreen of Care-O-bot® 3 or operates the robot with a smartphone. The robot then moves to the inhabitant and offers to start the selected entertainment program.

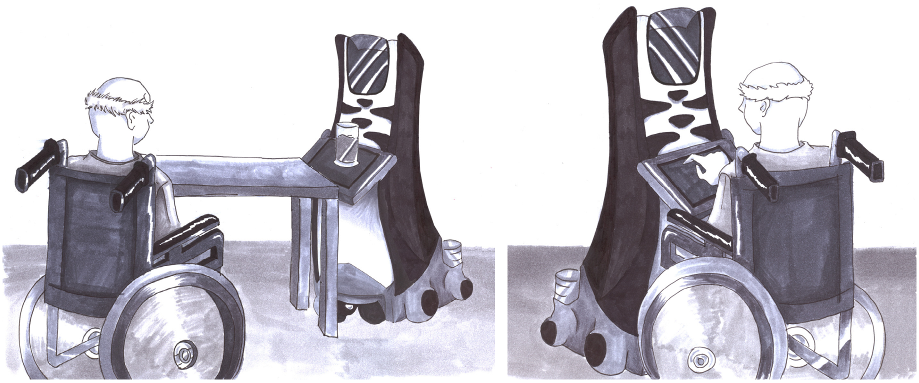

Fig. 5. Care-O-bot® 3 supporting care workers in an elderly care facility: Potation supply (left) and entertainment functions (right)

5 Experimental Results

In this section a short evaluation is given for the implementation of two scenarios presented in section 4: the fetch-and-carry service, which was shown at an international exhibition, and the “potation supply” scenario from the WiMi-Care project.

5.1 Implementation of the Fetch-and-Carry Service

Though many different scenarios guided the development process, the fourth and simplest of the scenarios described in section 4.1, the fetch-and-carry service, was implemented. This scenario contains the core functionality of Care-O-bot® 3, the fetch-and-carry service, in form of drink delivery. As described in section 4.1, the user may choose a drink from the user interface, which the robot then fetches autonomously and serves it to the user by putting it on the tray. Despite the low complexity of the scenario, the implementation was very challenging due to the high requirements on the robot’s autonomy.

The serving drink scenario was exhibited on international fairs, e.g. Automatica 2008 or IREX 2009, where the robustness and reliability of the service could be demonstrated.

5.2 Evaluation of Care-O-bot® 3 in an Elderly Care Facility

In May 2010 the potation supply scenario which was developed in the WiMi-Care project was tested in an elderly care facility in Stuttgart in a first practical test of one week. One goal of this test was to prove the feasibility of the potation supply scenario and to evaluate the acceptance of a robot performing support tasks in an elderly care facility. Another goal was to identify the need for further development of Care-O-bot® 3 during the project in order to ensure a reliable performance of the robot in the

Fig. 6. Implementation of the serving drink scenario at the IREX fair in Tokyo, November 2009

second and final practical evaluation which will take place in June 2011. For the first practical test, it was decided to implement the potation supply scenario in a simple, but robust version, leaving out for example the detection and grasping of cups in the kitchen, as well as the journalizing of the served fluid. The full potation supply scenario as well as the entertainment scenario will be implemented and evaluated at the second test phase.

The task of Care-O-bot® 3 in the first practical evaluation consisted of three steps (Fig. 7). At first, the robot drove to a kitchen and drew water from a water cooler. The second step was to transport the cup on a long corridor which was frequented by inhabitants and staff members to the sitting area. Here great requirements with respect to collision avoidance and path planning had to be met, especially when the corridor was crowded by inhabitants with wheelchairs and walking aids or when the way was temporarily blocked by carts carrying laundry or food. In the third step, the robot offered the drink to people sitting at a table. Here the challenges were to carefully approach chairs so that the water could be reached and to persuade inhabitants to take and drink the water.

All three steps were performed successfully [27]. Water was offered and handed over to inhabitants more than 20 times in a regular supply service that was installed after setup and basic tests were completed. The acceptance of Care-O-bot® 3 was very high. The test phase had been prepared with several information evenings so that care workers and inhabitants understood the idea of a robot supporting the staff without replacing them and showed no fear to interact with the machine. However, in many cases the elderly people did not drink the water, but just placed it in front of them. A reason for this might be that the inhabitants during testing were already offered beverages by the care workers. The inhabitants also were aware that the robot was tested and might have taken the drink to support the work of the scientists which of cause also was a distraction from their daily routine. It will be closely monitored in the second test phase, if this behaviour changed and if the robot will be able to convince the inhabitants to drink.

Generally the expectations towards the robot seemed to match its abilities, which surely can be accounted to the functional design of Care-O-bot® 3. Nevertheless, some inhabitants tended to treat the robot like a life form and for example thanked Care-O-bot® 3 and even tried to caress it when it brought them a drink.

Fig. 7. Course of the potation supply scenario: Drawing water from a water cooler (upper left), transporting it to a sitting area (upper right) and offering it to the inhabitants (bottom)

6 Considerations on Physical Embodiment

In the last sections, it was pointed out that the guiding visions during the development process of Care-O-bot® 3 and the scenarios defined within the research projects had many ideas in common with the virtual butler scenario. The question is now, to what extent the embodied robot could serve this vision of supporting elderly people to live an independent and social active life, and in which regard it is maybe hindering.

On the one hand, an embodiment brings many additional challenges, from the mechanical and electrical engineering point of view, from the software and integration complexity point of view, and from the users' safety point of view. Besides engineers, many experts in other fields are necessary to create a robust, reliable and functional system, with an appealing design on top of that. We have seen in sections above that the robot design has to be chosen very carefully in order to not provoke overdrawn expectations by the users and disappointing them with respect to the actually available functionality. Furthermore, the embodied butler is less mobile than a virtual one and most probably bound to the home.

On the other hand, most capabilities of the virtual butler described in the "Tina and her butler" – if available – could be easily made available on the embodied butler, too. Most functions would probably be implemented in pure software, and even if some special hardware device should be required, it surely can be integrated into the hardware set-up. Care-O-bot® 3 offers already a touch display, for example. So the question is not "virtual or embodied butler?" but rather "What additional benefits do we gain from a robot butler?"

Embodiment bears much potential. User interaction can be designed much more natural, as humans are used to communicate with some kind of counterpart. Besides human-machine communication via some kind of input device or speech, also visual cues like gestures or mimics can be used more easily and more intuitively. Care-O-bot® 3 is also able to give feedback via simple gestures like nodding, shaking the „head" or bowing. It can thus signal the user that he has understood the assigned task, in fact in the manner of a discreet butler. There is also a technical aspect: to be able to communicate with the user independently of his location and focus of attention, there's a need for extensive installation of fix sensors. A mobile robot relieves this challenge a lot by carrying sensors on board. Most commonly, the user will be directed to the robot if he intends to give it any commands or requests.

Finally, and importantly, the embodied butler is able to support the user physically – by doing housework like clearing the dish washer, bringing objects or even helping handicapped people to get up and walk (see scenarios in section 4 and [8]).

Concerning the user's perception of the robot butler, several previous studies found differences in terms of how people react to a physical robot, as opposed to a virtual, animated, projected or even 'disembodied' robot. Lee et al. [43] have shown positive effects of physical embodiment on the quality of interaction between robots and people. Participants preferred interaction with physical robots, compared to virtual robots. More specifically, they found that the physical embodiment enhanced the agent's social presence [43]. Likewise, Bartneck [44] suggested that physical embodiment facilitated social interaction with an emotional robot (eMuu), whereby participants gained a higher score in a negotiation experiment with the robot than with a computer screen character.

Tapus and Mataric [46] identified differences in how patients with cognitive impairment reacted towards a physical robot or a computer animation playing recorded songs. The studies in [41, 45] further support the importance of physical embodiment on performance and people's perception of social interactions. Here, participants perceived a physical robot as more appealing, helpful, watchful and enjoyable than a non-embodied robot. Note, while some studies [42] did not find strong differences between a physical robot and a projected robot in terms of people's perception and experience of the interaction, significant evidence is supporting the existence of such differences. Pereira et al. [40] found in studies with children that physical embodiment, compared to a virtually embodied agent, had a positive effect on children's enjoyment of a game. Kose-Bagci et al. [39] carried out a systematic study where 66 children played a drumming game either with an embodied child-sized, humanoid robot, a 'hidden robot' (only the sound could be perceived), or a real-time projected image of the same robot. Statistical analysis of the results of questionnaires and behavioural performance showed that the presence of the physical, embodied robot led to more interaction, better drumming and turn-taking performance, as well as more enjoyment of the interaction. Thus, concerning the user's perspective, there is support in favour of a robotic home companion, rather than a virtual butler. However, we need to consider that the task and function, efficiency and utility of the system also influence the acceptance of new technology. One area that is often contrasted to the vision of an autonomous robot butler is ambient assisted living (AAL). Indeed, many functions for elderly care may be performed by a virtual butler or non-robotic physical systems used in the domain of AAL where we find specific solutions e.g. for fall detection using radio tags [36], health and human activity monitoring using biometric sensors [37], or other sensors that can be integrated in a smart home [38]. However, for scenarios where several functions need to be combined into a single system, where physical tasks need to be performed by the system, and where the physical presence of a single robot as a focus of attention and interaction will enhance the user's experience and acceptance of the services provided by the system – in such situations an embodied robot companion, as described in this chapter, seems to be a very promising solution with many advantages over alternative, non-robotic systems.

7 Conclusion and Outlook

In this chapter, the robot butler Care-O-bot® 3 was presented, including design, technology and user scenarios. An important insight was the fact, that the appearance of a device provokes users' expectations with respect to its functionality. Embodiment consequently bears the risk of unsatisfying anticipations, e.g. that the robot is able to manipulate if it is equipped arms. It was shown that the robot's appearance was therefore designed carefully to express not more and not less than the discreet service of a butler.

How far are we then from the realisation of the "Tina and her butler" scenario? There is probably still a long way to go to make a robot butler robust, reliable and functional enough in dynamic environments like households, especially in connection with elder users. There exist many examples of robots performing very well in complex, but well defined and specific scenarios. Often this performance degrades rapidly when the scenario changes – mostly the loss of performance is disproportionate to the degree of change. This means in the worst case that the robot fails completely if the scenario differs in any respect (e.g. type and position of objects, obstacles or persons in the environment, etc.).

In other words, major challenges in robotics are about handling unstructured and unknown environments, user safety and particularly human-robot interaction. Integration effort increases steadily with the increase in complexity of the single components of a robot, such that in the first place specialists like autonomous vacuum cleaners or lawn mowers will propagate on the market rather than the all-rounding generalist. A fully autonomous household assistant might even not be necessary: the robot's deficiencies and unreliability could e.g. be diminished by the support of remote operators as proposed in the research project SRS.

At the moment, artificial intelligence and robotics research are conducted rather concurrently with only few contact points in some research projects like COGNIRON [4], LIREC [35] or competitions like RoboCup [22]. One community would possibly end-up with a virtual butler, the other with a physical one. As indicated in the section above, however, both approaches could be combined quite easily in the long run. Almost all functions of an intelligent virtual butler can be implemented on a robot, while the benefits of the robot can help in scenarios with more physical interaction of butler and person.

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