

Realization and User Evaluation of a Companion Robot for People with Mild Cognitive Impairments

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Abstract—This paper presents results of user evaluations with a socially assistive robot companion for older people suffering from mild cognitive impairment (MCI) and living (alone) at home. Within the European FP7 project “CompanionAble” (2008-2012) [1], we developed assistive technologies combining a mobile robot and smart environment with the aim to support these people and assist them living in their familiar home environment. For a final evaluation, user experience studies were conducted with volunteer users who were invited to a test home where they lived and freely used the robot and integrated system over a period of two days. Services provided by the companion robot include reminders of appointments (pre-defined or added by the users themselves or their informal carer) as well as frequent recommendations to specific activities, which were listed e.g. by their family carers. Furthermore, video contact with relatives and friends, a cognitive stimulation game designed especially to counter the progress of cognitive impairments, and the possibility to store personal items with the robot are offered. Recognition of the user entering or leaving the home is triggering situation specific reminders like agenda items due during the (expected) absence, missed calls or items not to be forgotten. Continuing our previous work published in [2], this paper presents detailed description of the implemented assistive functions and results of user studies conducted during April and May 2012 in the smart house of the Dutch project partner Smart Homes in Eindhoven, The Netherlands.

I. INTRODUCTION AND RELATED WORK

Socially assistive robotics for domestic use is a field of research that has seen considerably increasing attention in recent years. In contrast to other assistive devices like automatic cleaners, lawn mowers or pure surveillance robots, these social robots are designed to provide services to their human users through direct interaction, like displaying information, supporting communication with other people or simply entertaining the users.

“CompanionAble” was an Integrated Collaborative Research Project within the European Union’s 7th Framework Programme, running from 2008 to 2012 and focused on R&D

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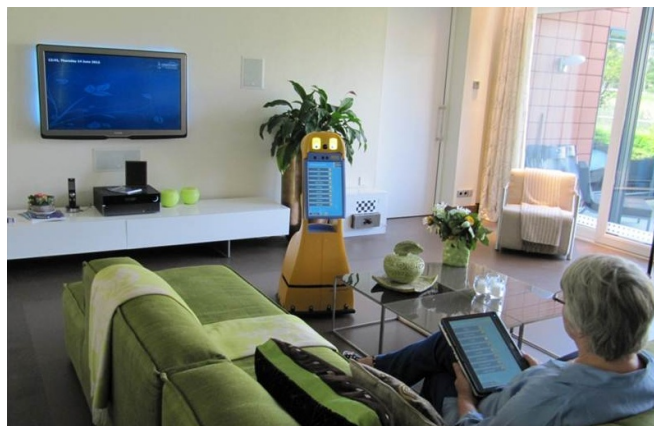


Fig. 1. The CompanionAble robot and the tablet PC in use during the user trials.

to support Ambient Assisted Living (AAL), in particular integrating assistive robotics within smart home environments, and focusing on people with Mild Cognitive Impairments (MCI) as primary users. Core development objectives of the project were:

- The design and realization of a new robot hardware platform, considering the requirements of the domestic application domain for key properties like size and weight, sensor equipment, power supply and self-preservation but also production cost, and software implementing the required navigation capabilities to autonomously move in the home environment
- Implementation of assistive service functions like agenda management, video phone calling, cognitive stimulation programs, storage and reminding of personal items, and centralized access to control of home devices (lights, curtains etc.)
- Development/improvement of enabling technologies for user perception and interaction like multi-sensor user tracking, sound and speech recognition, detection of falls as well as acquisition of selected vital signals using a body-worn device.
- Prototypical integration of an assistive environment comprising of a mobile robot, static smart home devices and connection to a central care center.
- Continuous supervision, control and evaluation of development by user requirements engineering and user feedback, in particular frequent user trial phases at different stages of the project.

Considering the main and most urgent needs of the target users, the focus was on social and cognitive support rather than physical manipulation. People with memory impairments tend to benefit more from cognitive reminders and social encouragement than from physical support.

Some other research projects rely on developing and using the best possible hardware and range of features, to a large extent disregarding, for the time being, any serious financial constraints. While this is a valid approach, in particular when focusing on developing new and sophisticated demonstrable assistive functions, it leads to mere prototype applications with no real perspective to an end user market. Typical examples here are the well-known service robot Care-O-Bot [3] or the very advanced PR2 by Willow Garage [4].

On the other hand, a number of domestic assistive robots are available to the market already or aiming to be in the very close future, however, many of those include only very limited autonomous and/or assistive functions. Quite the contrary, recently there has been a notable increase in “light-weight” robot platforms providing mainly telepresence functionality requiring manual control by a remote user, in some cases offering an open robot software framework relying on third-party developers to add relevant applications. Typical examples for the first group are Giraff [5] and the related ExCITE project [6], [7], VGo [8], QB [9], Gostai Jazz [10], Texai [11] or Double [12]. In the second group appear such robots as Luna [13], [14] and AVA [15].

In between those two poles, there exist many mainly research-oriented projects trying to develop socially assistive robot companions similar to CompanionAble, most of them basically with just slightly varying focus. Among these are ALIAS [16], HealthBot [17], Mobiserv [18], FLORENCE [19], KSERA [20], DOME0 [21], EmotiRob [22] and Robo M.D. [23].

In contrast to many similar related works, the aim of CompanionAble in its final stage, presented in this paper, was to analyze the added value of a mobile robot companion in a smart home environment - in the quest to support people with memory impairments - and to evaluate their user experience, proving that a robot developed with the commercial perspective in mind can act autonomously to provide useful and enjoyable services.

II. OVERVIEW OF THE COMPANIONABLE FUNCTIONALITY

A. Mobile robot platform

The CompanionAble robot is a Scitos G3 platform by MetraLabs, as seen in Fig. 2. This robot model is a dedicated development of the CompanionAble project, specifically taking into account the requirements for a domestic companion robot. Remarkable hardware features include

- a small footprint of approx. 50 cm radius and relatively low height of 120 cm
- differential drive using two driven wheels and one castor, enabling the robot to traverse thresholds up to about 1.5 cm



Fig. 2. Left: Scitos G3 platform developed as a companion robot for CompanionAble. Right: Robot charging and close-up of the charging station.

- a LiFePO4 battery providing enough capacity for ten hours of operation
- two storage trays for small personal items, able to recognize up to five tagged items using RFID antennas
- a tiltable touch screen that can be dynamically adjusted to the suitable interaction angle of a sitting or standing user
- dynamical eye displays for lively and “emotional” expression

For collision avoidance, user perception and environment monitoring, the robot is equipped with multiple sensors, namely a laser range finder, a ring of ultrasonic range sensors, a Kinect depth camera as well as a high-resolution, 180° field-of-view camera, and a CMT microphone [24].

For charging the battery during extended autonomous operation, the robot is complemented by a charging station, which provides a direct 220 Volt connection through a secure plug as used for electric appliances like water boilers. In comparison to other power connectors used for automatic docking of mobile devices, this system uses no exposed connections and therefore can securely provide high voltage, resulting in shorter charging times. With the corresponding adapter built into its back, the robot can dock to the charging station without the use of an articulated arm or other active mechanical components. The required precise positioning is facilitated by visual markers on the docking station (Fig. 2) and a rear camera that tracks the relative position during the docking maneuver.

The robot’s basic functionalities for user tracking, navigation and interaction are implemented using MIRA [25], a middle-ware developed for robotic applications, providing a framework suited to the requirements of distributed real-time software. For an introduction of MIRA and comparison to the popular robotics software framework ROS [26], see [27].

For more detailed descriptions of the hardware base and the methods used by the robot for perception, navigation and interaction, please refer to previous publications [28], [29].

B. Static smart home installation

The robot is integrated with a smart home which provides functionalities not available on the mobile device, e.g. network infrastructure, additional sensors, static interaction devices and remote control capabilities for lights and curtains.

Infrared presence sensors are used to track the user's position in the home. These sensors do not match the resolution of the robot's internal person tracking capabilities, but they are able to observe most of the area and therefore can be used as a hint where to look for the user when s/he is not in the robot's perception range [30].

A presence sensor in the hallway gives notice when the user is preparing to leave home, and an entry door sensor recognizes him/her coming home again.

Apart from the sensors and networked control, the smart home also provides its own interaction devices, which can be used in parallel to the mobile robot. A fixed touch screen in the kitchen and a tablet PC provide access to a subset of the services offered by CompanionAble. A unified Graphical User Interface supports the experience of a common CompanionAble system. Details about which services are accessible for the user on which devices are described in the following subsection.

C. Assistive service functionalities

On top of the hardware platform, various assistive services are offered. These services are presented to the user by means of a multi-modal dialog system: the robot can be operated by Graphical User Interface (GUI) on the touch display, but it can also process speech input and uses speech output to express itself. In order to enable ergonomic usage in sitting and in standing position, the tiltable display screen automatically adapts to the height of the user's head (based on face and upper body recognition). Manual adjustment of the display angle is possible at any time through persistent GUI elements.

To enable multi-modal interaction, the frame-based dialog manager defines abstract semantic inputs and reactions based on them, as well as abstract output expressions. GUI button clicks, recognized speech phrases and even system events like "user detected" or "battery level low" are then mapped to the defined input semantics, separating the definition of interaction sequences from the concrete input/output module.

Each frame in the dialog manager describes a self-consistent set of interactions, defining a service provided by the robot. The main services are explained in detail below.

In addition to the robot, some of these services were also available on the other computers/displays described in the previous subsection. However, these only offered conventional GUI interaction. Previous research shows that "speaking walls" can be quite confusing, especially for people with memory impairment. The robot - with its embodiment and affordances for natural interaction - was the part of the environment that was proactive and was in charge of the multi-modal interaction, following the expressed preferences of test users during previous user trials with shorter and more restricted interaction scenarios, in which the static home

environment could actively express itself, too [31], [18]. Still, people could use the different functionalities on multiple devices in order to be able to answer the question whether a mobile robot provides added value over - or in - a smart home environment.

Agenda: An agenda system stores and manages appointments, events and to-do lists for the user. The agenda entries can be displayed and edited using the GUI on the robot, and also on the other display devices in the house. In order to keep the set of recognized phrases small (increasing robustness), the respective dialog frame only allows to open/close the agenda and to change the view (between a calendar view, a list of open to-do items, or an overview of the current day), but editing is done using the GUI only. Since the agenda database is stored in a networked server, it can also be seen and edited by authorized personnel e.g. at a care center or the informal caregiver, e.g. the partner.

Distinguishing the robot from a passive calendar, the dialog manager actively delivers reminders: when a reminder or an appointment is due, the robot starts searching for the user and notifies him/her when found. Meanwhile, the reminded agenda item will stay active until it is confirmed by the user, i.e. the robot will repeat reminding it until the user has taken notice.

Suggestions: Similar to reminders for appointments, the robot can deliver suggestions for activities (like "This would be a good time to get a glass of water", "Have you read the newspaper?"). These suggestions can also be entered in the agenda database as separate items, e.g. by the trial conductors, but also by a care giver.

Video Call: A video phone application is integrated, using the SIP protocol and enabling communication with relatives or the care center. In the user trials, contacts were pre-configured for each participant. The user can initiate a call with one of the known contacts by either selecting him from a list in the GUI, or by vocal command. During the call, the robot follows the user, so s/he is able to change position or even to show the remote person around in the apartment.

In the complementary case of an incoming call, the robot starts searching for the user, while announcing the caller vocally and with a ring tone. The user can then either accept or decline the call. After establishing the connection, the robot again follows the user around during the call. If the user cannot be found or the caller hangs up before a successful connection, the missed call is memorized together with the caller's ID, to be notified later.

Cognitive Training: For supporting and stimulating the cognitive abilities of the elderly care recipients, a Cognitive Training application is integrated, which presents a variety of cognitive exercises, selected by professional therapists according to the health status of the individual user. Results of the exercise sessions are transmitted to the therapist's database and can be used to track the cognitive health over time and to adjust the therapy where needed and possible. This application is available both on the robot and on the tablet PC.

Item Storage: As described before, the robot recognizes when an RFID tag is placed in one of its storage baskets, located below and behind the display. By attaching tags to personal items like keys, wallet, glasses or cell phone, the robot can take care of these items. The robot acknowledges depositing an item to the basket or taking it away, and can even be queried which items it has in custody.

Home Control: Integration with previously installed smart home technology allows to control these features using an interface integrated within the CompanionAble GUI. This graphical interface is available on the robot as well as on the static displays.

Robot Control: The robot control menu allows to control the robot's position, by sending it to pre-defined locations, or telling it to dock to the charger. In order to lead the robot to any desired position, it can also be told to just follow the user. Robot control is also available on the static displays, e.g. the user can call the robot to the kitchen from the kitchen screen or by using a vocal command.

Coming Home: Upon coming home, the robot approaches the user in the hall to greet him/her, and announces missed and upcoming agenda items as well as calls that were incoming during the user's absence (offering the option to call back). It also encourages the user to deposit personal items that are not needed while at home.

Leaving: When the robot notices the user is about to leave home, it will go to the door and ask when s/he expects to be back. Based on that information, it presents the agenda items that are due in the meantime. Furthermore, it reminds the user to take along any personal items that are still in the robot's storage basket. Before saying goodbye it offers to switch off the lights and close the curtains after the user has left.

Whenever the robot is not searching for or interacting with a user, it automatically returns and docks to its charging station after a short while of idling, in order to save power. Whenever an event occurs that requires a user interaction (e.g. a reminder is due or a call is incoming), it will start searching for the user again.

During the night or at other times when the user does not wish to be disturbed, it can set the robot in a "silent mode", where it will just passively wait at its charging station and suppress any reminders, incoming calls etc., until silent mode is left again.

An extended overview of the CompanionAble robot and the services it can provide can be seen in a video which is available online at <http://youtu.be/yQFFQ2FvjUY>.

III. USER TRIAL DESIGN

User trials were conducted in April and May 2012, in smart home environments in Eindhoven, The Netherlands, and in Gits, Belgium. Overall, six trial sessions were conducted. In total 11 people (5 couples, 1 single person) agreed to live in the test homes (with the CompanionAble robot installed) for two consecutive days each. In all of the couples, one of the persons had been diagnosed with a form of

dementia of varying severity and the other trial participant was the informal caregiver (4 wives, 1 daughter, see Table I). Although CompanionAble originally was developed with mainly people living alone in mind, nearly all of the trial users were living at their home with a partner, who was also the primary informal carer. In the course of the project and the user research that has been conducted, it appeared that not only the person with memory impairments benefits from support of the CompanionAble robot, but that their caregivers (partners) are also supported significantly and that some of their burden can be relieved. That is why couples were recruited for these final trials. Moreover, the partners/informal carers are a valuable information source about their partners for personalizing and about whether and how an environment like CompanionAble can add value to their daily lives.

TABLE I
OVERVIEW OF USER TRIAL PARTICIPANTS.

FTD = Frontotemporal Dementia, MCI = Mild Cognitive Impairment

Trial	Sex	Age	Category	Memory impairment
1	M	77	User	Alzheimer's
	F	80	Partner	-
2	M	57	User	Alzheimer's
	F	55	Partner	-
3	M	74	User	Pick's/FTD
	F	71	Partner	-
4	M	63	User	Alzheimer's
5	M	80	User	MCI
	F	75	Partner	-
6	F	77	User	MCI
	F	49	Daughter	-

Even this relatively small user sample proved to deliver meaningful results on many levels. From a technical, as well as psychological and social perspective, these trials were meaningful. Of the six couples participating, two had experience with the CompanionAble project from earlier project stages, while the other four were completely new and only knew from verbal explanations what to expect. Most participants were quite proficient in using technology and had an open mind towards it. Also their attitude towards using technology to support people in daily life was very positive. It is not uncommon that all of them regularly used a TV (100%) and most also mobile phones (80%), but all of them were also of relatively high computer literacy, mostly being familiar with internet web browsing (90%), most using an own PC (80%) and E-mail (80%) regularly, and some even Skype (20%) and home automation (20%).

It was crucial that the trial participants had an open mind and were able to express their attitudes, feelings and wishes freely. Only in this way we were able to receive high quality and in depth reflections of their reactions to such a new and innovative solution like CompanionAble. Only expressing that they like or dislike it would not help us in our understanding of how to support them in their daily lives.

In preparation of the trials, users were asked about their

typical daily life, which appointments, tasks or activities they would like to be reminded of during the trial days, which items they liked to be stored by the robot, and what suggestions or reminders would make sense to support them in their daily living etc. The goal of our trials was to assess whether support given by CompanionAble was indeed of value for the participants and/or their carers. Therefore it was crucial that the trials were as closely matching their “normal” daily life as possible. That is why participants were encouraged not to deviate from their normal routine nor to change any existing or recurring appointments, and to bring objects or activities they would normally occupy themselves with, like reading, puzzles, or handicraft. Even though all the essential accessories were provided in the “home”, they were free to go out for shopping or for appointments or meet with friends. We encouraged them to live in the smart home as much as possible like they would live at home.

The evaluation methods used and procedure followed during the user trials are shown in Fig. 3. The selection of the methods was based on experiences from previous trials and adopting the User-Intimate Requirements Hierarchy Resolution Framework (UI-REF) methodology [32]. A combination of semi-structured interviews, a diary approach, observation sheets and supportive questionnaires were applied for both the primary and secondary users, in order to elicit usability, user experience, acceptance and societal impact results at different points of experience (prior, during and after using the robot). Most of these methods were focused on collecting qualitative user feedback. Qualitative measures provide valuable data about the appreciation, experience with and nature of the CompanionAble environment. Supporting people with memory impairments by means of a robot companion in a smart home environment is so new that a lot of deep insights can be gathered by doing qualitative research.

In the morning of the first day, a participating couple arrived for a demonstration and training of the CompanionAble functions and abilities. They were instructed to freely use the robot and further devices as they wish, and were provided with a semi-structured diary (for the primary user) and observation sheets (for the secondary user) to be filled out directly after each interaction, to capture the immediate impressions of usability and user experience. During the day, the trial conductors were available to be contacted by the video phone service, and at least one call was pre-arranged each day at a certain time, for some intermediate feedback. In the evenings, the observation sheets and the diaries were evaluated together in an interview session between primary and secondary users and the trial conductor, discussing what people had filled out, what happened and what they thought of it.

Due to security and comfort considerations, it had been decided not to let the trial participants sleep in the smart homes over night during the trials. Instead, they were taken home on the first evening and arrived again early the next morning for a second day of testing, similar to day one.

At the end of the complete trial session, at the second evening, both participants’ experiences were captured

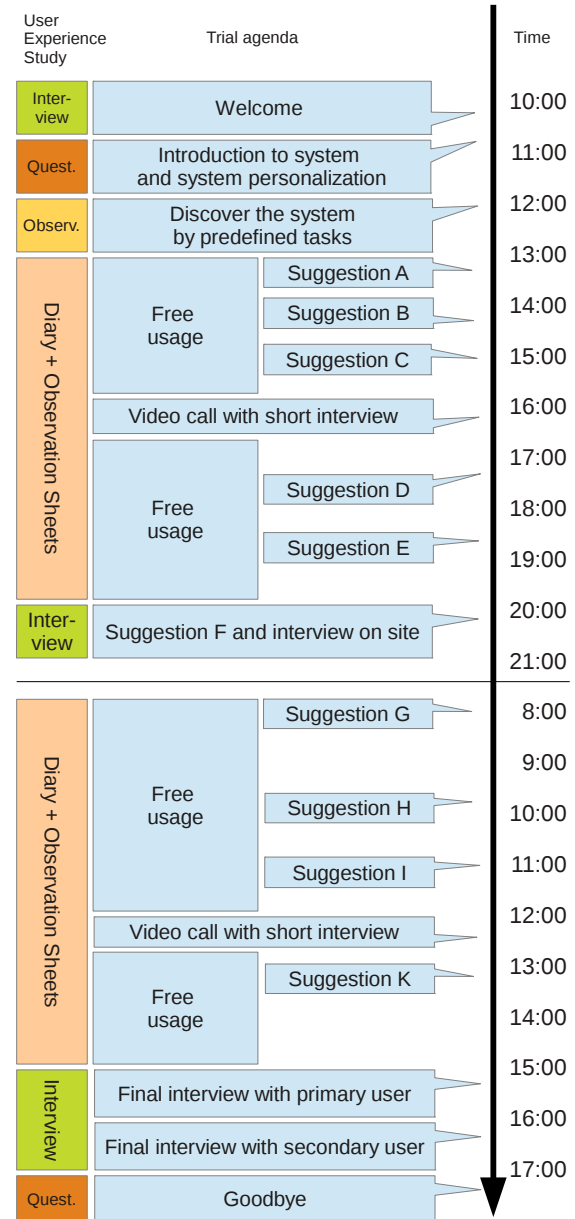


Fig. 3. Schedule of a two days trial session (for each trial participant)

through a final qualitative semi-structured interview and an adapted UX (user experience) questionnaire.

IV. EVALUATION RESULTS

At the beginning of several trial sessions, participants were a bit skeptic about the robot. They had stereotypical ideas about robots and expectations that were not in line with what CompanionAble actually offers. When introduced to the CompanionAble robot, all of them expressed their interest and appreciation and actually started to think along on how it could even better match their needs (“I was rather skeptic about a robot for older people, but now I see this, I am wondering if it would be possible to use it for even more support, more reminders, more active triggers”). Eventually, all users described the trials as an enjoyable experience, and

some even asked if they could start earlier the second day to have more time for trying out the robot. Some quotes of primary users that reflect the overall feelings: “The more initiative the robot takes, the more enjoyable it is.” “I think this could really work for me, it will become our house buddy, that functions perfectly, and is available 24/7. What more do you want? He takes away discomforts and I feel good because of that.” And some quotes of secondary users: “What surprised me, is that I myself started talking to the robot several times.” “Oh yeah, he believes in it and thinks it is great” (referring to her husband).

Both primary and secondary users gave many valuable suggestions for improvements of the overall system and for individual functionalities. The cases in which the robot did not function flawlessly were extremely rich in learning about people’s reactions. It seems that trial participants were rather forgiving about glitches they observed, attributing many issues to the robot’s “mood” or “personality”: “He is not in the mood, is he?”, “That’s not really nice, is it?”. Clearly, people tend to attribute human characteristics to the robot’s behavior, e.g. when arriving on the second day: “Ooooh, we should also greet Hector!” (name given to the robot). This is in line with the media equation [33], showing that the robot is perceived more as e.g. a pet (with personality) than as a passive device like a PC or TV.

From the quantitative data gathered, primary users rated enjoyment quite high, while their partners rated the usefulness of the robot very high. Detailed analysis of the statements in the various interviews can explain this fact: partners usually act as informal carers that carry the main burden of their partner’s cognitive disease. They go to great lengths to remind of daily tasks and have to deal with all the increasing limitations and disabilities, often heavily suffering themselves from reduction of own freedom and time for individual activities. Therefore, they hope that a technical system taking over reminding and suggestion functions, ideally even reliably recognizing task execution, can significantly unburden them, making both the care receiver’s as well as their partner’s life easier.

A number of findings can be presented for several of the sub-components. *Speech Recognition* turned out to be not robust enough for intuitive use. Participants had been instructed how they could use speech commands, however, they did not succeed in doing so very often, even when speaking the correct commands. When explicitly asked by the trial conductors to repeat commands, the robot reacted correctly after a few tries. When using the robot freely, user often gave up before that. On the other hand, speech recognition sometimes reacted to something that was spoken between the users or the trial conductors, often the reaction was completely unrelated to what was spoken. For all trials, speech recognition was switched off on the second day.

The *GUI* needs significant enhancement to be intuitively usable for this specific target group. Users often overlooked graphical elements at the lower part of the screen. Some elements like the virtual keyboard were found to be too simple by some users very familiar with computer use, but

hard to use by others who even had difficulty finding some keys. This is just one of many places where personalization is required, which in fact will be one key aspect of a successful solution.

Person detection and tracking was not 100% reliable, which sometimes disturbed interaction. In some other occurrences, the robot would ignore users when searching for them, and just pass along, due to limitations of the currently used tracking system. Sometimes also the opposite case happened where the robot erroneously believed to have found a person and stayed at some seemingly random position, leaving users wondering why it stopped moving. We hope to improve the person tracking performance by making use of the integrated Kinect sensor for people detection in further development.

General system stability needs improvement. Making numerous heterogeneous software modules by various developers, most of them in a more or less experimental state, work robustly in an integrated system is not a trivial task. As a safeguard, a script was employed which frequently checked if all modules were running normally and in case of failures would restart the entire application. This way, we could prevent full failure of the robot. However, not all modules were absolutely stable and indeed the application had to be restarted several times, in some cases disturbing interaction.

Despite these detail glitches, we could demonstrate the suitability of the robot companion for everyday-like use during 6 two-day field trials with 11 end users. Eventually, we can refer to 120 h trials and robot operating time without supervision by roboticists on location.

V. CONCLUSIONS

A major contribution we presented here is one of the first and most extensive “long-term” user studies with a robot companion working autonomously under non-lab conditions with cognitively impaired elderly people. Having conducted overall 12 days of user trials, we can report that the CompanionAble environment can indeed provide useful service and enjoyable experience to older people with cognitive impairments, as well as their partners. Though in several cases skeptic at first, trial participants got convinced and eventually appreciated the CompanionAble idea of support by a combination of a smart home with an embodied social robot.

In general, CompanionAble very much offers what the target people need, which is structure, initiatives and reminders. It was explicitly stated by nearly all trial participants that they see a clear added value for the pro-active and mobile robot. The robot was valued for its embodied interaction possibilities, the fact it comes to you physically, talks to you, shows initiative, and has a certain personality. However, some users also found that particular functionalities are preferred on the tablet PC over the robot. These included e.g. applications requiring text input by virtual or even real keyboard (like the Agenda system), and the Cognitive Training application, which comprises long GUI interaction.

Main lessons learned that go beyond shortcomings of single sub-modules are:

The initiative of the robot is the single most valued aspect of CompanionAble. The ability to actively give reminders and suggestions is found to be exactly what care receivers with cognitive impairments need, and what they do not see in comparable quality realized by any other solution like a static PC or even a device worn on the body.

The role of the informal caregiver (often the partner) has been insufficiently explored and supported in early phases of the project. The robot can be a very valuable tool to these partners, if they are provided with the right interfaces for customizing and setting up the system according to their individual wishes. As one partner stated "It is me that has to set it up, because no one knows him (her husband) better than I do."

More and longer field trials are required to evaluate behavioral impacts and longer term effects on well-being, and the influence of different backgrounds and abilities of the users. We found that not everything needs to work perfectly in order to conduct user trials, but a robust and stable system is required that can ensure uninterrupted interaction. By planning user trials with partial systems early in the development cycle, more emphasis can be put on robustness while gaining significant insight about acceptance, usability and usefulness early on. Moreover, conducting comparative trials in people's natural living environment - with a control group - will be highly interesting.

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