in: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics (IEEE-SMC 2012), Seoul, South Korea, pp. 637-644, IEEE 2012

Further Progress towards a Home Robot Companion for People with Mild Cognitive Impairment

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***Abstract*—This paper presents results of the development of a socially assistive home robot companion for older people suffering from mild cognitive impairment (MCI) and living (alone) at home. This work was part of the European FP7 project "CompanionAble" (2008-2012) [1] which aimed at developing assistive technologies that can support these elderly and help them to remain in their familiar living environment for as long as possible. To overcome current market entry barriers, from the start we consistently adopted a user- and application-centered development process of the companion robot and focused on three main aspects: (i) the realization of a set of mandatory functionalities to support care recipients and caregivers, (ii) a strict design and usability driven realization to increase the acceptance of the robot by the different end-user groups (the elderly, their relatives, and caregivers), and (iii) the development and component selection considering production and operational costs. In continuation of the work presented in [2], this paper describes the final implementation of the companion robot and presents latest results of functional tests and early findings of user studies recently conducted in the smart house of the Dutch project partner Smart Homes in Eindhoven, The Netherlands.**

***Index Terms*—Socially assistive Robotics, Human-Robot-Interaction, User studies, Companion Robots, Smart Homes**

Fig. 1. Two usability evaluators interacting with the mobile home robot companion developed within the CompanionAble project [1].

I. Introduction

Continuing the work presented in [2], this paper reports on further progress in developing a low-cost home robot companion which aims at assisting older people suffering from mild cognitive impairment (MCI) in living independently at home in their daily life (see Fig. 1). The robot has been developed as part of the European FP7 project CompanionAble [1] which was running from 2008 to 2012. In [2] results of the requirements specification of such a robot companion were outlined as well as the preliminary version of the robot platform, its control architecture, several technologies for user-centered navigation, and first results of functional tests. Based on this work, this paper provides an overview of related work in the research field, discusses the applied approach to a user- and application-centered development process, describes the final version of the robot platform, and presents latest results of recent functional tests and early findings of user studies that were conducted in the smart house of our Dutch project partner Smart Homes in Eindhoven, The Netherlands.

Socially assistive robotics for domestic use has been a rapidly increasing field of research in recent years. As the characteristic of socially assistive robotics is that it is focused on helping human users through social rather than physical interaction [3], mobile robots with elaborated manipulation skills, as for example the robotic home assistant Care-O-Bot 3 [4] or Willow Garage's PR2 [5], [6], have not been included in this brief overview.

An important step on the way to introduce social robotics technologies in real homes has been done with the commercially available or announced mobile telepresence systems *Giraff* [7], *VGo* [8], *QB* [9], *Jazz Connect* [10] or *Texai* [6]. All these systems can be remotely controlled by authorized relatives or caregivers to interact with the elderly in their own home. An example for a more autonomously operating home robot is *Kompai* developed by Robosoft [11]. This robot is intended to support the elderly in scheduling their tasks, reminding to take their medicine, or doing a videotelephony call. It can be controlled remotely or drive autonomously to given positions within the environment. Another example of a service robot for home environments is *Luna*, a personal robot

This work has received funding from the European Community's 7th Framework Program (FP7/2007-2013) under grant agreement no. 216487.

recently presented by RoboDynamics [12]. RoboDynamics aspires to widely distribute this robot to home applications based on two main aspects: an adequate price and an open software architecture.

Having true autonomy and real-world suitability in mind, however, none of these systems can already be considered as home robot companion which i) is suitable for autonomous operation and everyday use in real home environments, ii) is suitable for interaction with the target group of elderly people, and iii) can deliver an adequate support of the elderly at acceptable purchase and running costs. Most of them still show limited functionality regarding really autonomous navigation and user-robot interaction behavior, which in our previous user studies proved to be a *must* for a home robot companion that can be accepted by the elderly. Others still require the presence of experts during their operation to guarantee safety and handle unexpected situations. To overcome these acceptance and market entry barriers, since the start of the CompanionAble project a user- and application-centered development process was consistently applied focussing on three main aspects: (i) the realization of a set of mandatory robot functionalities to support both care recipients and caregivers, (ii) a strict design and usability driven realization to increase the acceptance of the robot by the different end-user groups (the elderly, their relatives, and caregivers), and (iii) the development and component selection considering production and operational costs.

The requirements specification for the robot companion is based on a set of surveys and studies that were carried out in the first two years of the CompanionAble project [13] [14]. In different surveys, more than 250 end-users (care recipients (CR), their relatives, caregivers, and care professionals) in Austria, Belgium, UK, France, The Netherlands, and Spain have been observed and interviewed about their individual needs and priorities in assistive smart home technologies and services that could be provided by home robot companions. As a result of these end-user studies, five categories of system requirements (communication, safety, services and assistive functions, therapy, and smart situation awareness) were identified (see [2] for more details). To fulfill these requirements, a broad spectrum of functionalities and capabilities had to be implemented for navigation, HRI, and the assistive services. For autonomous *navigation* this includes: a) to build a detailed map of the apartment while the robot is manually driven around by an expert during the installation phase of the robot, b) to robustly self-localize within the apartment, c) to drive to any given target position in the home, d) to reliably avoid collisions with known and unknown obstacles, e) to efficiently pass through narrow doors or gaps between furniture, f) to autonomously drive and dock to a charging station, and g) to pass over thresholds and carpets.

For *HRI*, the following requirements were defined as mandatory and have been implemented by the different project partners: h) to reliably detect and keep track of a moving/static person, i) to orient towards a user or drive in a position facing the user, j) to follow a user through the apartment, k) to autonomously search for a user in the apartment, l) to express simple emotions by using its facial capabilities, m) to notice when personal items of the user are placed in the robot's tray, n) to understand a defined set of command words/phrases, and o) to recognize a defined set of critical sounds, e.g. glass shattering.

Regarding the *overall services*, in the user studies the following use cases were specified: p) initiating a video telephone call to relatives or a care service, q) reminding the user to do a cognitive stimulation exercise, r) reminding of a forgotten event (e.g. taking medication), s) welcoming the user when returning home including t) storing personal items in the robot's storage tray, and u) saying goodbye when the user leaves the home including a notifying of upcoming appointments, items to take along, and weather forecast.

For the realization of these functionalities, the technology of the robot platform requires high performance computational units for the execution of the interaction, navigation and service algorithms running in parallel, intuitive interfaces adequate for elderly people, and multiple sensor systems to analyze to robot's environment. Moreover, the system design had to consider that the robot typically needs to move in narrow domestic environments. As a consequence, numerous requirements to the design, the technical realization, and the sensor equipment of the robot platform were derived which have directly influenced the final design and the functionality of the robot companion. In addition to the functionalities and a pleasant design, we have considered later production and operating costs and the longevity of system components during the development process. This led to the technical implementation described subsequently.

II. Implementation of the Robot Companion

Platform design and drive system: Fig. 2 depicts the final version of the robot companion. With a height of 120 cm, the robot companion is comparable to the size of an eight years old child. Its size is optimized for a friendly appearance and an ergonomic operability by a standing or sitting user. The design of the robot should suggest a cartoon-like appearance (e.g. by a certain resemblance to the cartoon bird Tweety) instead of a human-like look to make clear that the robot does not have a similar intelligence as a human. As usual for socially assistive robots [3], our companion does not have any manipulators. The drive system of the robot consists of two driven wheels combined with one castor wheel on the rear side. The two driven wheels are placed outside the centreline of the robot which increases the stability and reduces the complexity and costs of the platform. The roundish form of the robot's rear side still allows for a good manoeuvrability. The robot has a footprint of about 50 x 50 cm and a weight of 42 kg.

User interface: The *tiltable touch-screen* is the main unit for graphical communication between a user and the robot. We decided to use a vertically mounted 15.4 inch wide touch screen display for presentation of information to the user and touch-based input of user commands. To ensure the best

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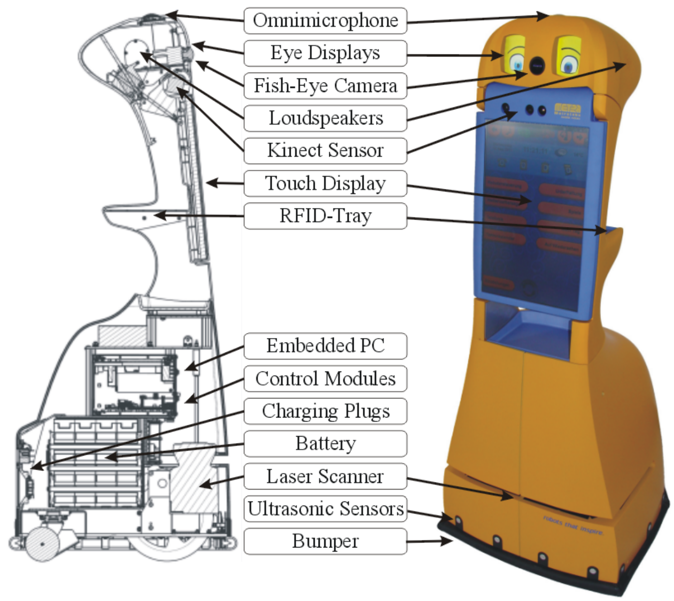

Fig. 2. Robot companion developed in the CompanionAble project [1] with its main equipment for environment perception, navigation, and HRI. The left picture shows a schematic of the placement of internal modules, the right picture shows the final design.

usability and to allow for an optimal interaction in standing and sitting position, the display unit can be tilted - either automatically based on the head position of a standing or sitting user, or manually by the user via the touch-screen. To avoid trapping of fingers between the display and the robot casing, for safety reasons a force sensor is integrated.

Robot head and face: To give the robot a friendly appearance, we integrated two OLED displays as robot eyes. The displays have a size of seven inches and a resolution of 800 x 480 pixels and can be used for expressing the robot's internal states or emotions (e.g. sleeping, listening, being surprised or bored) or following a user with the eyes. These features are helpful for intuitive HRI and for getting and staying in contact with the user.

Storage tray for personal items: As requested by all end-user target groups, the robot companion is equipped with a storage tray, where the user can deposit items important for daily usage but often mislaid, like glasses, wallet, keys, mobile phone, etc. It is located at the same height as the touch display for a good accessibility when sitting and standing. The tray uses RFID technology to detect and automatically register all personal items equipped with RFID tags. Using the knowledge about the items put down in its tray, the robot is able to remind the user to move something in or out, if needed.

Loudspeaker: The robot head contains two loud-speakers used for speech output or playing music.

Sensor equipment: For HRI and navigation, the robot is equipped with diverse sensor systems (see Fig. 2).

Laser range finder: For obstacle detection, map building, localization, and person tracking, the robot is equipped with a SICK S300 2D-laser range finder with a scanning range of $270°$. The laser is located at the front side, facing in the driving direction of the robot. Because of the integration inside the robot casing, the field of view is limited to $180°$, which is still sufficient for the described applications. The S300 scanner conforms to the SIL2 security level and is integrated into the safety concept of the robot.

Sonar sensors: 14 sonar sensors have been integrated as redundant sensor system for the laser range finder. Located close to the ground they can detect smaller objects on the floor that are invisible for the laser.

Bumper: A closed rubber-based security collision sensor mounted around the robot's base plate is used to detect collisions of the robot with obstacles that are invisible for the other sensor systems or moving faster than the reaction time of the robot. The usage of a soft rubber-based collision sensor reduces the impact of a collision.

Cameras: For human-robot interaction, the robot is equipped with a high resolution color camera (1600 x 1200 pixels, 25 fps) in combination with a $180°$ fish-eye lens. This camera is located in the robot's face and indicates the nose of the robot. It is mainly used for user search and tracking, but also for visual obstacle avoidance. A second camera with a resolution of 1,3 megapixels is located at the rear side of the robot and used for detection of the charging station (see below).

Kinect depth camera: In addition to the laser scanner and the camera systems, a Kinect depth camera is integrated within the tiltable touch display. This sensor delivers 3D information of the environment in front of the robot platform. The angular field of view of this camera is $57°$ horizontal and $43°$ vertical. The detection range is from 1.2 m to about 3.5 m. The camera is connected to the embedded PC and is used for obstacle detection and user tracking. The RGB camera of the Kinect is used for videotelephony.

Microphones: The robot is equipped with an omnidirectional microphone array using the coincidence microphone technology (CMT) developed by project partner AKG in Austria [15]. The CMT array is utilized for localizing a talking person and sound signal enhancement based on beam-forming, which is helpful for videotelephony and speech-based user tracking. For an optimal acoustic performance, this microphone array is placed at the top of the robot's head.

Power supply and charging: To be able to operate the robot for more than ten hours, the battery capacity and the overall power consumption were optimized. For the storage of the required energy, the robot platform was equipped with a lithium battery with about 1000 Wh. For the charging of the battery, two solutions are available: a standard power plug and an autonomous charging plug. The standard power plug can be used to charge the robot at any place with line voltage and a standard power cable within four hours, but requires manual plug-in. For autonomously connecting the robot to the charging power, a new docking concept had to be developed and integrated. One of the main challenges was to find a technological solution that allowed for a direct connection of

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Fig. 3. (Left) Charging station with a line voltage connector inspired by the connector concept known from water boilers and synthetic markers utilized for the autonomous docking process. (Right) Robot successfully docked to the charging station.

the robot to the line voltage of the home, because it should be possible to connect and disconnect the charging connector by the robot platform itself without expensive actuators or the assistance by a human. Inspired by the connector concept known from water boilers used in millions of households, a safe version of an autonomous line voltage connector has been developed. We have integrated the socket at the robot platform and designed a spring loaded plug at the charging station. A small camera located at the rear side of the robot above the socket is used to detect synthetic markers utilized for the autonomous docking process (Fig. 3). Based on this concept, we realized a reliable (see Sec. IV), safe and cost-effective docking system, which is an important prerequisite for autonomous re-charging and long-term applicability of the robot companion.

The integration of all system components was carried out under the consideration of a later production of the platform. All components were combined to functional groups that can be pre-assembled independently from each other. Moreover, the casing was optimized for a low-cost production process. Considering all costs and production aspects, a later sales prize of this robot system of less than 10,000 Euro is aspired, which will be unique for a fully autonomous robot platform with such characteristics.

III. Control Architecture and Used Technologies

Because the robot control architecture has already been introduced in [2], here only a brief summary is given to recapitulate the main ideas and arguments. Our control architecture is characterized by a clear separation of the robot-specific methods and skills from the application itself resulting in a flexible layered system architecture (Fig. 4). In this architecture, the bottommost layer, the *Hardware Layer*, encloses the robot hardware (sensors and actuators), the operating system, and the low-level interfaces to the hardware. The low-level sensor information is processed in the next higher level, the *Skill Layer*, which provides a set of necessary, robotic-specific basic skills that are executed in the Hardware Layer. The *Skill Layer* covers the whole spectrum of navigation skills including

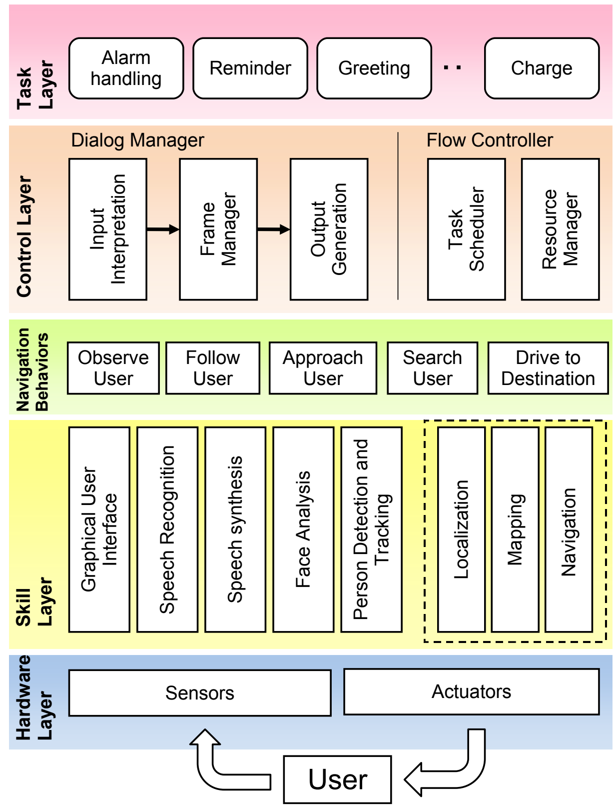

Fig. 4. Main components of the robot's layered control architecture. The GUI and Speech Recognition at the Skin Layer have been developed by other project partners involved in the CompanionAble project [1].

occupancy map building, Adaptive MCL for self-localization [16] and motion control based on the Dynamic Window Approach [17]. Furthermore, specific perception skills, like person detection and tracking (integrating multiple visual and laser-range-based detection cues in a Kalman filter framework [18], plus explicitly verifying the person's presence at typical resting places [19]) are implemented in that layer. The interface to the speech synthesis module (using Loquendo TTS [20]) is also placed in the skill layer, providing its service to the higher application levels.

Above the independent skills there are diverse modules representing the application control which make use of the basic features provided by the skills. The simplest controllers using the navigation and people detection skills are the *Navigation Behaviors*. These are exclusive units each representing an individual control loop for accomplishing the different task-oriented navigation behaviors of the robot. Here, for example, a "Search user" behavior is realized, other behaviors are "Approach user" and "Follow user" which are necessary for direct interaction as well as passive user observation, which is active most of the time when no direct interaction takes place.

The exclusive navigation behaviors as well as the input and output skills are utilized by the modules of the *Control layer*, which form the "Dialog Manager" and the "Global flow control". The "Dialog Manager" consisting of an input

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interpreter, a frame manager, and an output generation module is responsible for organizing the direct interaction with the user. Here, the infrastructure for multi-modal input fusion, coordination of the dialog progress, and generation of multi-modal outputs using speech, display, and facial expressions is provided. The "Dialog Manager" follows a frame-based approach, where the content of the dialog is defined in a set of scripts residing in the highest layer, the *Task Layer* where the content of the application is defined. Since the "Dialog Manager" is more a reactive subsystem handling interaction with humans once the dialog has been initiated, the proactive part consists of a "Task Scheduler" and a "Resource Manager", which are responsible for coordination of the partially competing task controllers implemented in the *Task layer*.

Currently, the modules of the Hardware and Skill layers are implemented using our new C++ middleware MIRA [21], [22], while higher layers consist of scripts running on top of the MIRA framework. In order to further harmonize the individual application parts, we are going to implement all components of the application (including the GUI) as MIRA modules in a next development step.

The robot's internal functions are supported by external perception modules provided by project partners and typically running on separate hardware (communicating via network interfaces), most notably for speech recognition [23] and coarse person tracking based on stationary presence sensors in the home [24]. Furthermore, the GUI frontend operated by touch screen is also running as a separate process, exchanging notifications through a generic network interface.

IV. Functionality Testings

As described in Section I, numerous navigation, HRI and service capabilities of the robot companion are required which had to be evaluated in functional tests before usability studies with the end users could take place.

A quantitative analysis of the robot's navigation capabilities regarding localization and positioning errors, velocity profile and smoothness of the movement trajectories, distances to obstacles, and unexpected stops or collisions with static or dynamic obstacles was executed as long-term test during the "European Robotics Week" at the end of 2011. In this test, the robot was running continuously on four consecutive days (operation time 36 hours), driving successively to predefined, but randomly selected targets in our living lab used as test environment (Fig. 5). The navigation behavior was observed by a webcam (for qualitative evaluation and live streaming to the robotics community) and an external laser scanner network for position referencing [25] which was installed temporarily for this experiment. Simultaneously, the odometry data of the robot, the pose estimations of the on-board self-localization, all observed events (targets, failures, collisions, etc.) were logged for subsequent evaluation of the navigation performance. During this 36 hours test, in 2,480 individual target approach runs the robot drove about 17 kilometers within this area of approximately 12 x 10 meters (consisting of 3 separate rooms). From the 2,480 runs, 93,5% were successful

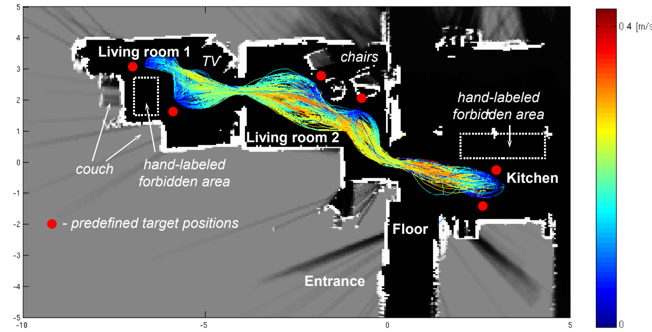

Fig. 5. Motion trajectories of the robot during a long-term (36 hours) functional tests of the navigation system within our living lab (shown as occupancy grid map learned in advance). The colors indicate the current velocity of the robot.

(2,320). Only eight collisions occurred, mainly as only laser was used for obstacle avoidance in this experiment, or persons kicked at the bumper. In the remaining unsuccessful runs (6,5%), the targets could not be reached as the paths were blocked by people or other robots, or other rather "uncritical" failures occurred (such as the robot believing to stand within an obstacle due to slight delocalization or perception limits, which was resolved automatically by resetting the map and restarting with a new target after a short time period).

Figure 5 shows the learned occupancy grid map of the living lab, the motion trajectories driven by the robot between the randomly selected targets (marked as red dots), and the velocity profile along the motion trajectories. It can be seen that the velocity profile is very smooth with an average speed of 0.3 m/s and maximum of 0.4 m/s (which we specified as the maximum motion speed for this home robot). In front of the target points, the velocity was smoothly reduced to zero to allow for an interaction with a potential user sitting on the couch or chair or standing in the kitchen, before the next test run was started. The dashed rectangles mark forbidden regions which had to be placed in the map by hand as the objects standing at these places (e.g. tables) were not detectable by the 2D laser scanner used in this experiment. We have also analyzed the localization accuracy of the navigation system comparing the logged results of the self-localization and the external position reference of the laser scanner network. This shows an average deviation of less than 20 cm, and a maximum of not more than 40 cm. In further experiments that are scheduled for the next iteration cycle after the user trials, we plan to tighten the experimental conditions (broader spectrum of static and dynamic obstacles, diverse floor covers, usage of carpets, etc.). To this end, a 3D obstacle perception using the on-board Kinect sensor (see Fig. 2) is to be integrated in the near future.

In comparison to the state presented in [2], meanwhile also for the test case *Autonomous driving and docking to the charging station*, a robust and repeatable technical solution has been developed (see Fig. 3). In this test case, we performed about 100 docking tests from different starting positions in front of the docking station (average distance 2 meters), from which 85% were already successful at the first trial. The remaining 15% required only a second attempt for docking. As far as we know, this is the first time that a robot of this size and inertia is able to dock autonomously using a single vision sensor only - without the help of manipulator arms (as for the PR2) or an active charging station that moves itself to fit into the robots plug. This robust autonomous recharging capability was an important prerequisite for all long-term functional tests and the user studies.

Most of the defined requirements on *Human-Robot Interaction (HRI)* have been tested and evaluated as well. Of particular importance for the robot's service functionality is the "search user behavior", because the robot should robustly find its current user as quickly as possible if s/he has been lost from view and reminders and incoming video calls have to be delivered. As already reported in [18] and [19], for the quantitative study of this behavior we played more than 100 hide-and-seek "games" and determined the average search time and success rate for finding the user who hid somewhere in the apartment on one of a set of learned resting places, sometimes only stood somewhere in the apartment, or even left the apartment before the game. When the user was lounging at one of the predefined places, the success rate was rather high with 74%. The average search time over all successful and unsuccessful games was 28 seconds with a minimum of 5 and a maximum of 122 seconds. In the test runs when the user was standing somewhere in the apartment, the success rate increased to 87%. This is because the range- and vision-based person detection modules, which are particularly dedicated to detecting standing people, achieved better detection results. Note, that in a real application the robot will not consider the person as found until an actual interaction is initiated, e.g. the user pressing a button on the GUI or answering vocally. Based on this set of successful functional tests, we could start to tackle the final user studies and field trials.

V. User Studies and Field Trials

A. Aims, Scope and Setup

The main aims of the final user studies and field trials have been: (i) to evaluate the added value of the functionalities of the robot companion, (ii) to evaluate the usability, user-satisfaction, and acceptance of the system, (iii) to evaluate the added value of the robot companion, (iv) to obtain insight in the preferred types of interaction, and (v) to obtain user's feedback on the system in order to generate improvement guidelines for the robot companion.

The field trials with the robot companion were conducted at two trial sites, in The Netherlands, in the test facility of the Dutch project partner Smart Homes in Eindhoven, and in Belgium. In these field trials, the person suffering from MCI, called the primary user, and her/his partner, the secondary user, have lived together for two full days in the fully equipped smart home environment. The primary user was the main person who interacted with the robot companion and used a set of functionalities, services, and free interactions with the system whenever s/he wanted. The secondary user accompanied the primary user as they would do in their own dwelling as well. To allow for a flexible and not predefined interaction regime between primary user and robot, a set of functionalities was specified and implemented on the robot and personalized for that specific trial couple. These will be presented in the section below.

B. Functionalities for the User Trials

Three different kinds of interaction were envisaged to be used during the user trials: (i) robot-initiated interaction to activate and stimulate the user, (ii) user-initiated interaction, and (iii) externally initiated interaction triggered by others, such as family or carers. The most important examples for each kind of interaction are given subsequently.

Robot-initiated interactions:

- *Locating the user:* All of the following interactions require an autonomous locating and moving of the robot to the user.
- *Welcome home:* When the system detects the arrival of the user, the robot approaches the user and welcomes her or him. It asks if it should store some items for the user in its storage tray and reminds the user about upcoming appointments and open tasks.
- *Active daytime management:* The robot gives appropriate reminders for upcoming appointments, for medicine intake, and for open tasks in the to-do list.
- *Suggestions, stimulation, encouragements to stay active:* The robot gives appropriate suggestions for doing an activity like going for a walk, preparing food, having breakfast, lunch, dinner, making a video call to family and friends, going for a visit, reading the news, etc.
- *Encouragements to do cognitive training:* The robot tries to initiate cognitive training at certain moments.
- *Leaving home:* When the system detects that the user is leaving the home, the robot approaches him/her and asks when the user will be back. Based on this, the robot reminds the user about upcoming appointments and open tasks. Then it asks the user whether s/he needs items that the robot has stored, and reminds about other items s/he might want to take along.
- *Automatic screen adjustment:* The robot recognizes whether the user is standing or sitting in front of it, and adjusts its screen accordingly.
- *Fall detection and response:* When the user is wearing the fall detection device, and a fall is detected, the robot comes to the user to ask about his/her situation. If the user says s/he needs help, or does not respond at all, the robot makes an emergency call. During this call, the other side can have a look at the situation by remote-controlling the movements of the robot.

User-initiated interactions:

- *Consulting the today screen:* to get an overview of the day, showing the current time/date, the weather forecast, upcoming appointments, or items on the to-do list.

- *Asking the robot to come to the user:* Using speech or the external tablet, the user can ask the robot to locate and come to the user.
- *Asking the robot to follow:* By speech or touch, the user can ask the robot to follow him/her. The robot will follow the user until a stop signal is given by the user.
- *Sending the robot to a specific location:* By speech or touch on the robot, the user can navigate the robot to predefined locations in the home.
- *Seeing, adding, removing items from the to-do list:* to add new tasks and remove old ones from the list.
- *Doing cognitive training:* On the screen of the robot, the user can do cognitive training, adjusted to his/her cognitive level.
- *Making a video call:* By speech or touch, the user can make a video call using the robot.
- *Storing items on the robot:* By putting items in its tray, the robot knows which items it keeps safe for the user.
- *Switching to silent mode and back:* The whole system can be put in 'silent' mode, in which it will only respond to critical situations, but will not give any other reminders, encouragements, or messages.

Externally initiated interactions:

- *Receiving incoming video calls:* When there is an incoming call, the robot verbally informs the user about who is calling, and searches the user so s/he can accept the call. After accepting the call, the robot follows the user, so s/he can find a comfortable chair to have a chat.
- *Adding and removing items from the agenda:* From a remote location, a secondary user can add, change, or delete appointments from the agenda.

Because of its automatic recharging capability, the robot autonomously docks to the charging station (see Section IV) whenever it is idle, or when it is explicitly told to do so.

C. Used Approach for the Field Trials

In accordance with the lessons learnt from previous user studies executed in Eindhoven in 2011, where the test users stayed in the smart house for a few hours and performed specified test cases with the robot, the focus for the field trial evaluation was on a more qualitative approach. This allowed to focus on collecting qualitative user feedback since the previous trials have shown that quantitative measures such as questionnaires and scales were not suitable for this kind of primary users (persons suffering from MCI), especially for those who were not familiar with modern technologies and showing a higher cognitive impairment. Qualitative measures, however, can provide valuable data about the appreciation, experience, and nature of the robot companion functionalities. Based on these findings, an observational approach was applied in order to elicit usability and experience sensitive results supported by a combination of semi-structured interviews and a semi-structured diary instead of applying questionnaires and scales.

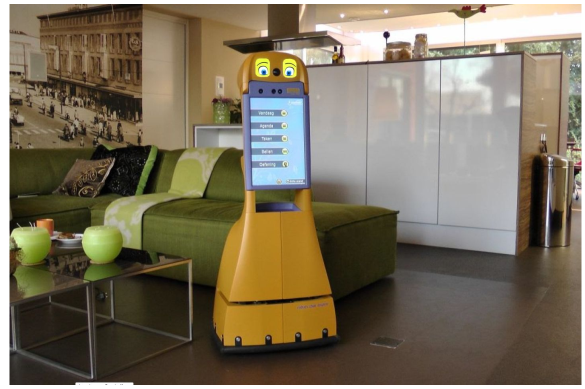

Fig. 6. Test environment at the project partner SmartHomes in Eindhoven, Netherlands (www.smart-homes.nl).

D. Preparation and Execution of the User Trials

In the months before the start of the user trials in April 2012, the final CompanionAble system was set-up, adjusted, and fine-tuned at Smart Homes in Eindhoven. Because the final user trials were scheduled for trial sites in Belgium and The Netherlands, the complete interaction system, including all screens, speech input, and speech output, has been implemented in Dutch.

As planned, 4 couples spend two full days in the test house of the project partner Smart Homes (Fig. 6). These couples included the person suffering from early dementia/MCI and his/her partner. They lived in the smart home as if it were their own home, while being supported by the CompanionAble system consisting of a smart home environment and the robot companion. In the morning of day 1, they were welcomed by the trial conductors and got a thorough introduction of the smart home and the CompanionAble system. After that, they were left alone. In the evening, after dinner, the trial conductors returned for an interview. This concluded day 1, and the participants went home. They did not stay overnight, although some of them mentioned they would have liked that. In the early morning of day 2, the participants returned to the smart home, where they were welcomed again, and left alone. Around noon, a video call was made to check how they were doing, and around in the late afternoon, the trial conductors returned for the final interview with both participants.

E. Early Findings of the User Trials in Eindhoven

All 8 participants were very positive about their experience in these two days. Given this, a very interesting observation was that there were quite some participants, especially partners, who were not enthusiastic or even a bit negative at the start. Some partners stated that they thought it was scary, and that they were only here because their partner (the MCI sufferer) wanted to. It was very nice to see that their attitude changed completely, already after one day, and that they really started to see the various benefits of a mobile robot companion. The participants indicated that certain functions, like the cognitive training (that was highly appreciated) or entering text, were more comfortable on the tablet which was used as additional input device. However, they appreciated the robot, which came to them physically and talked to them, very much for taking initiatives and actively stimulating, encouraging and reminding them of many things (eating, drinking, going out, calling someone, taking medicines, to do list, agenda, etc.). All participants saw this as the main and big added value of a social robot companion in comparison to a tablet solution.

After one day, the participants already indicated that they got used to *"such a thing in your home that drives around"*, and that they unconsciously started talking to the robot almost like to a human or pet. The trial conductors observed that people attributed human characteristics to the robot very quickly, even when things went wrong: *"He is not having his day", "He is not in the mood"*, or *"That is not really friendly, is it ..."*. From these final quotes, we can learn two things; a) we have to improve many (often little) things, and b) people accept it and like this technology!

Also the accompanying partners recognized the many possibilities of a robot companion after one or two days, and they saw a big role for them in this. Like one participant said: *"It is me that has to set it up, because no one knows him (her husband) better than I do."* To make the system really work, it will have to be flexible and highly personalized (much more than what was possible till now), and this is the role of the partner or social carer. He or she knows the preferences, hobbies and little things of the care recipient like no one else does. All partners really saw the added value of a robot companion, despite their age, background, or initial scepticism. They saw that it can be a very valuable addition to the care for their partner. It will never replace other care, but it will be an addition to the existing care chain of the partner, home care, day care, etc.

VI. Summary and Outlook

We have presented further progress in developing a mobile, socially assistive home robot companion for elderly people suffering from mild cognitive impairment (MCI) and living alone at home. The focus of this paper was on the hardware and software implementation of the novel robot platform, the results of further functionality tests regarding navigation and HRI, and early findings of the final user studies with the robot companion that were conducted in the test house of the Dutch project partner Smart Homes in Eindhoven in April and May 2012. An important insight of these studies is that a robot companion and its accompanying services could really become the right hand of the partner or social carer, and that in this regard, the social carer would become a primary user of the robot just as well as (or even more than) the actual care recipient that is to be supported.

In our future work, particular attention has to be paid to quantifying the long-term effectiveness of socially assistive robot companions on health and well-being of the care recipients. As suggested by [26], this could be done by measuring (i) the level of stress (e.g. by stress hormones in urine), (ii) the positive mood (evaluating the facial expressions and using questionnaires), or (iii) the communication activity between the elderly and their family (measurable by the frequency of contact between them). However, for these investigations it is necessary to expand the length of the studies from days to several weeks or even months. This will require really autonomous robot companions suitable for long-term use in real homes. The presented work is an important step towards this objective.

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