Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 85 (2014) 328 – 338

Procedia Engineering

www.elsevier.com/locate/procedia

Creative Construction Conference 2014, CC2014

Co-adaptation of robot systems, processes and in-house environments for professional care assistance in an ageing society

T. Linner[a,*], W. Pan[a], C. Georgoulas[a], B. Georgescu[a], J. Güttler[a], T. Bock[a]

[a]Technische Universität München, Arcisstrasse 21, 80333 Munich, Germany

Abstract

The recruitment of new workforce for the field of care taking is difficult in highly industrialized countries and the gap between demand and availability of care takers will further increase with the expected increase in aged populations in the future. In particular, service robot systems are able to enhance the capabilities of assisted environments significantly as they add critical capabilities and thus allow environments to actively support care givers and care takers with the full bandwidth of necessary processes, tasks and services. Service robot systems add to assisted environments besides the aspect of hard physical assistance capabilities with flexibility, increased intelligence and situational awareness and provide new ways of intuitive man-machine-interaction. However, the integration of service robot systems into real world assisted environments has been difficult due to the usually separate development of environment and stand-alone robot systems. In this paper, the authors present a conceptual approach for a robotic care environment in which care environment (including room layouts, furniture and distributed sensors), service robot systems and care processes are fully synchronized and co-adapted.
© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the Diamond Congress Kft.

Keywords: Robotics; Care; Robot Oriented Design; Structured Environments; Ambient Intelligence

1. Background

In highly industrialized countries, aging society [1] [2] [3], shrinking work force [4], demand for increased productivity in working and private life [5] as well as the development towards a society in which scientists predict an increased emergence of Centenarians and Super-centenarians (and the enlarging of the average life span by another 20 years, see [6] and [7]) over the next decades, necessitate novel technological approaches, in-home

* Corresponding author. Tel.: +49-89-289-22176 ; fax: +49-89-289-22102
E-mail address: thomas.linner@br2.ar.tum.de

1877-7058 © 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the Diamond Congress Kft.
doi:10.1016/j.proeng.2014.10.558

services and support for ambient assisted living that are fully and invisibly integrated into our daily activities (see, for example, [8]).

Already today the recruitment of new workforce for the field of caretaking is difficult in highly industrialized countries and the gap between demand and availability of caretakers will further increase with the expected increase in aged populations in the future. This is true for both the field of caretaking in institutions as care homes and supervised accommodation as well as in the field of home care. Reasons for the ongoing image damage and unpopularity of the caretaking profession are, amongst others, low salaries, tough work schedules, high physical burdens, the execution of hygiene critical tasks (washing and cleaning of elderly, etc.), repetitive and monotonous tasks and the increase of documentary administrative work. The often-honored personal contact of the caretakers to the caregivers (which is often used as an argument against the extensive use of technology in the care field) in current caretaking reality is already missed out on due to the aforementioned aspects and burdens on the caretakers. The situation can be expected to become more severe with the increase in the gap between demand and availability of caretaking workforce.

With our research in co-adaptation of robot systems and in-house environments for professional care assistance in an ageing society presented in this paper, we aim to dramatically change the image and performance of the professional and non-professional caretaking field and, at the same time, improving the life situation of the caretakers in care homes, supervised accommodation and home care. We are not aiming at the substitution of the caretaking workforce by capital investment in technology but at the substitution and redistribution of individual tasks making caretaking a creative, technology-oriented, high-level profession that is attractive for skilled and motivated people. Assisted living environments in which a multitude of assistive subsystems and service robots operate seamlessly allow a complete redesign of the processes and task structures leading to the fact that the caretakers become more self-dependent (which enhances life quality and decreases the burden on caretakers). On the other hand, such environments allow that the caretakers can be relieved, to a large extent, from the aforementioned challenging mental and physical burdens and instead concentrate on increasing the quality of service, personal care and mental and physical treatment and training of the elderly, which definitely demands intensive personal contact.

In particular, service robot systems are able to enhance the capabilities of assisted environments significantly as they add critical capabilities and thus allow environments to actively support caregivers and caretakers with the full bandwidth of necessary processes, tasks and services. Service robot systems add to assisted environments, besides the aspect of hard physical assistance, capabilities such as flexibility, increased intelligence and situational awareness and provide new ways of intuitive man-machine-interaction. However, the integration of service robot systems into real world assisted environments has been difficult due to the usually separate development of environment and stand-alone robot systems, high cost of highly dexterous service robot systems and lack of seamless integration and user acceptance. Therefore, with our research in this field, we aim at creating the scientific basis for the integration of service robot systems into assisted environments, considering the ultimate goal of creating care and home-care environments that allow a radical restructuring of processes and tasks for dramatically changing the image and performance of future technology-oriented caretaking.

2. Research question and research method

Our research focuses on the redesign and structuring of care environments (at home as well as in care facilities) and the processes taking place within them for the creation of modular and mass-customizable robot-compatible assisted living and service environments as well as the redesign and adaptation of existing service robot systems. In an interdisciplinary approach, we will develop optimized care environments in which service robot systems seamlessly interact with the physical environment, embedded medicals sensors and systems, various sets of standardized and non-standardized processes and human beings (caretakers as well as caregivers) to provide multidimensional assistance and a broad set of modular and customizable services. The basic premise consists of a distributed layered architecture enabling omnipresent communication, and an advanced human–machine communication protocol. The Ambient Intelligence (AmI) paradigm sets the principles to design a pervasive and transparent infrastructure capable of observing people without interfering with their lives, adapting to the needs of the user. It must be noted though that populating a home environment with robotic elements must be performed following a space-efficient utilization scheme. Elderly people, and especially those using assistive devices such as wheelchairs and rollators, require increased barrier-free space for mobility purposes.

A particular focus in our research is the co-adaptation and creation of compatibility (in a physical and informational sense) of assistive environments and service robot systems. In contrast to usual service robot development (see, for example, *Care-O-Bot* [9], *Patient Transfer Assist* [10], *RI-MAN* [11]), the complexity of functions (hardware, software, tasks, etc.) will not be concentrated solely in the robot system but distributed strategically between the robot system and the environment. Previous research by the authors showed that such an approach has the potential for significantly reducing the complexity and cost of the service robot system, enhancing their reliability/robustness and above all, creating completely new service and assistance capabilities [12].

In this paper, the authors present a conceptual approach for a robotic care environment in which furniture and robot systems are fully synchronized and co-adapted. The conceptual approach borrows further ideas and methods developed in a series of large research projects (*GEWOS* [13], *LISA* [14], *PASSAge* [15], *USA²* [16], *LISA-habitech* [17]) in the field of Ambient Assisted Living (*AAL* [18]) by the authors. Furthermore, within these research projects, the authors were already able to test individual sub-systems of the now suggested, more comprehensive approach. Primarily in experimental, user oriented approaches, and in these research projects, sub-system prototypes of robot-compatible interiors and building "infill" compatible service robots were developed, and their interaction was demonstrated, evaluated and developed further in several development cycles within relevant use cases. The ultimate goal of the authors is to systematically investigate the tradeoffs related to the distribution of complexity between environment and service robot system and identify optimized effective and cost efficient solutions that will boost implementation and commercialization of service robot systems.

The remainder of the paper is structured as follows. First, the authors outline the background, need and general direction of the research. Following this, the authors define and outline influencing factors and building blocks for robot adapted care environments. Third, the authors present an analysis of processes taking place in professional car environments, build process categories and relate those to the possible task for robot systems that could potentially be used to support or carry out those tasks. Fourth, the authors present their comprehensive approach for a robotic care environment in which a variety of co-adapted robot systems (mobile robots, manipulators, etc.) interact with human beings and the co-adapted the physical environment. The authors then present – as a proof of concept – exemplarily two individual sub-systems, which they could develop, test and optimize within ongoing research projects. Finally, the authors show the impact their research can have on strategies and business models in the caretaking field.

3. Robot Oriented Design for care environments: definition of influencing factors and building blocks for co-adaptation of service robots, processes and environments

Following the methodology developed by the authors in Robot Oriented Design [19] and Robotic Micro-Rooms [20] functions can be arranged in a three-dimensional architectural space so that a smooth and optimum operation of processes and activities is possible: a highly structured care environment can be realized that enables the automation of assistive functions and the efficient integration of robotic subsystems. In this space:

1. Processes and activities widely known and partially standardized are possible.
2. The geometric and functional configuration of the environment is known.
3. Distributed sensor systems are able to recognize and locate robots, objects, persons, vital signs, etc. in a robust way.

This creates, similar to a factory environment for industrial robots, a comparatively structured space for care environments. In this sense, factors that influence the co-adaptation of robots and environments are the environment category, the type of service robot, the type and amount of the embedded system distributed in the environment, the service robot complexity reduction function and, last but not least, the type and composition of the process in which the service robot is embedded.

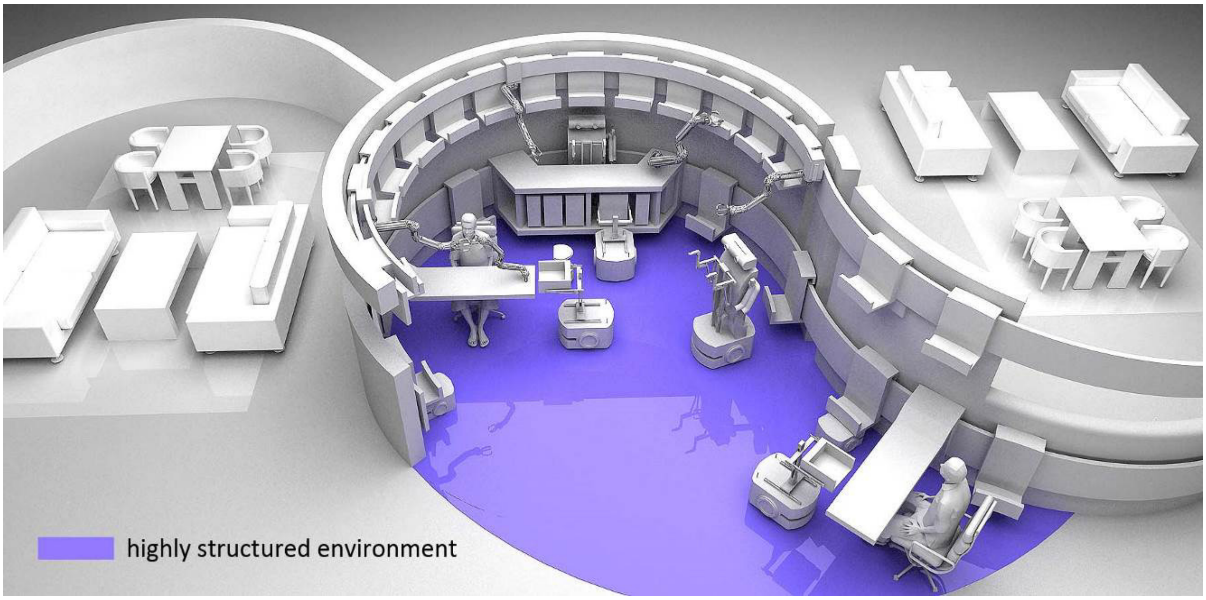


Fig. 1. Implementation and optimization of robot compatible environment and co-adapted service robots.

3.1. Categories of environments:

Different types of environments with different levels of suitability or difficulty for the introduction of service robot systems can be identified. Similar to the example in manufacturing industry and in factories, the degree of process standardization can vary in care environments. A low degree of process standardization results in an unstructured environment, which often makes it more difficult for the robot to navigate and/or to perform tasks. A low degree of process standardization results in a structured environment, which often makes it easier for the robot to navigate and/or to perform tasks. In structured environments, the complexity and cost of the robot system can be reduced.

- Low process complexity (= high degree of process standardization): care homes
- Medium process complexity (= high degree of process standardization): supervised accommodation
- High process complexity (= low degree of process standardization): home care

3.2. Categories of service robots suitable for care

The commercialization activity in the field of service robotic is continuously increasing. Service robots with qualities that can be utilized in the professional caretaking can be categories as follows:

- Category 1: various mobile platforms with specific payloads
- Category 2: telepresence/edutainment robots

- Category 3: simple humanoid robot (for example Baxter or UBR-1)
- Category 4: various lightweight robot arms (for example Kinova/Ergosurg JACO)
- Category 5: aerial systems – for example quadrocopters
- Category 6: robot moving on wall/ceiling

3.3. Categories of embedded Systems (Sensors, Interfaces, assistive devices, medical devices, etc.):

In order to allow coadaptation and an intelligent structuring of the care environment in which the robot operates, embedded systems (sensors, interfaces, assistive devices, medical devices, etc.) can be heavily distributed in the environment:

- medical devices inconspicuously integrated in the home environment (for example ECG)
- non-medical devices to validate health and disease progress (for example Kinect sensor for gait, fatigue measurements and analysis)
- Lightweight robotic manipulators
- Lightweight linear/angular actuators, manipulators
- Gesture driven 3D scanning devices for intuitive robotic actuator manipulation
- RFID scanners/tags for sensing and monitoring people and items
- Projectors/monitors, to facilitate all Graphical User Interfaces (GUIs)

3.4. Service-robot complexity reduction functions

Through the co-adaptation of the environment, in relation to the robot system following possibilities for complexity and cost reduction can be identified.

- Reduction of navigation complexity
- Reduction of kinematic complexity
- Reduction of complexity caused by necessitated dexterity
- Reduction of end-effector complexity
- Reduction of informational complexity
- Reduction of human-machine communication and manipulation complexity by proposing and developing more intuitive and less complex human-machine interfaces

4. Processes, tasks and robots

In previous research, the authors have developed methods for the systemic development of assistive home environments that support elderly people to live independent based on an analysis of processes that result from activities of daily living (see, for example, [21] and [22]). Care processes, both in ambulant and stationary settings, are different as the focus, on one hand, is on people that demand a higher level of care but on the other hand, include in some way professional and non-professional care personnel. In particular, in stationary care processes, room layouts and furniture are highly standardized and thus, present a solid opportunity for automation and robotisation. Based on analysis of care processes and discussions with professional caretakers and care managers, the authors of this paper have identified the major process categories, related tasks with a high potential for automation and robotisation and robot system suitable for those tasks.

Table 1. Identification of major process categories, related tasks with high potential for automation and robotisation and related robot systems suitable assisting within those tasks.

Process Category	Scenario/Tasks	Suitable robot system categories
Supply (especially food logistics) and meal supply	Supply of meals and drinks from kitchen/supply area in ground floor or basement to dining rooms or individual rooms	mobile platforms
	Feeding	lightweight robot arms, robot moving on wall/ceiling
Functional transfers (bed-to-wheelchair, wheelchair-to-bathroom, etc)/ In-house mobility	Activation (getting up from bed, bed-to-wheelchair, wheelchair-to-bathroom/toilet)	simple humanoid robot, robot moving on wall/ceiling
	Mobility (move from A to B) –assisted by caretaker	mobile platforms, simple humanoid robot
	Mobility (move from A to B) – not assisted by caretaker	mobile platforms
Hygiene and medical treatment	Medical scanning of the body	telepresence/edutainment robots
	Assistance with Washing of Body	simple humanoid robot, lightweight robot arms, robot moving on wall/ceiling
	Assistance with tooth brushing etc.	telepresence/edutainment robots, lightweight robot arms
Communication, reminding, etc	Giving timely framework for ADLs (e.g. through reminders for waking up, watching, TV, etc.) to elderly (for example with dementia)	telepresence/edutainment robots, home automation system
	Avoiding dehydration: Provision of water and drinks (and control as well)	simple humanoid robot, telepresence/edutainment robots
Emergency detection, false call recognition	Detection of critical situations	aerial systems, telepresence/edutainment robots
	Verification of alarms	aerial systems, robot moving on wall/ceiling
	Automated adjustment of parameters relevant for well being (CO2, light, temperature, humidity)	Home automation system
	Detection of Falls	aerial systems, telepresence/edutainment robots
Automated documentation	Automated documentation of detailed care activities conducted by care personnel	telepresence/edutainment robots
	Assistance in detection and documentation of medical issues and patient’s health	simple humanoid robot
House-economical activities, house/ room-keeping	Logistics of devices, waste, etc.	mobile platforms
	Logistics of laundry, cleaning	mobile platforms
	Logistics of medication	mobile platforms
	Placing of laundry and clothes in shelves etc.	simple humanoid robot
	Cleaning of rooms, furniture, windows, etc.	simple humanoid robot, robot moving on wall/ceiling

5. Conceptual approach

Our concept aims at the co-adaptation of service robots, environment (including floor layouts, furniture, and distributed sensors) and processes to a total system for professional (stationary and ambulant) care environments. Our concept considers, in particular, a seamless relationship and ubiquitous interaction between the user, robotic systems and smart furniture. Every aspect of the caregivers’ and caretakers’ activities can be influenced and enhanced by implementation of the robotic care environment. Each robotic system will work either individually or as a group in order to provide necessary assistance for the user. The smart furniture is equipped with various sensors, which can communicate with the surrounding environment. For instance, the mobile robot platform will provide efficient logistic service within the living environment, such as delivering shopping from the doorway to the kitchen, or delivering food from the kitchen to the bedside table. The telepresence robot could provide a network interface between the health care provider and the user. It can also be utilized as primary mobile communication platform or social network media. The floor and window-cleaning robot will operate in an autonomous manner to carry out cleaning duty only when it is necessary. The lightweight robot arm will assist caregivers and caretakers with essential tasks such as preparation of food, feeding and personal hygiene operations. The above scenarios provide an excellent opportunity to evaluate and validate the overall concept of an embedded robotic care environment. *Figure 2* gives an overview over a fully robot assisted care environment that might be deployed either in a care home (stationary care) in a home to assist ambulant caretaking (ambulant care). *Figure 3* explains the co-adaptation of robots systems, environment and processes for each sub system in detail.

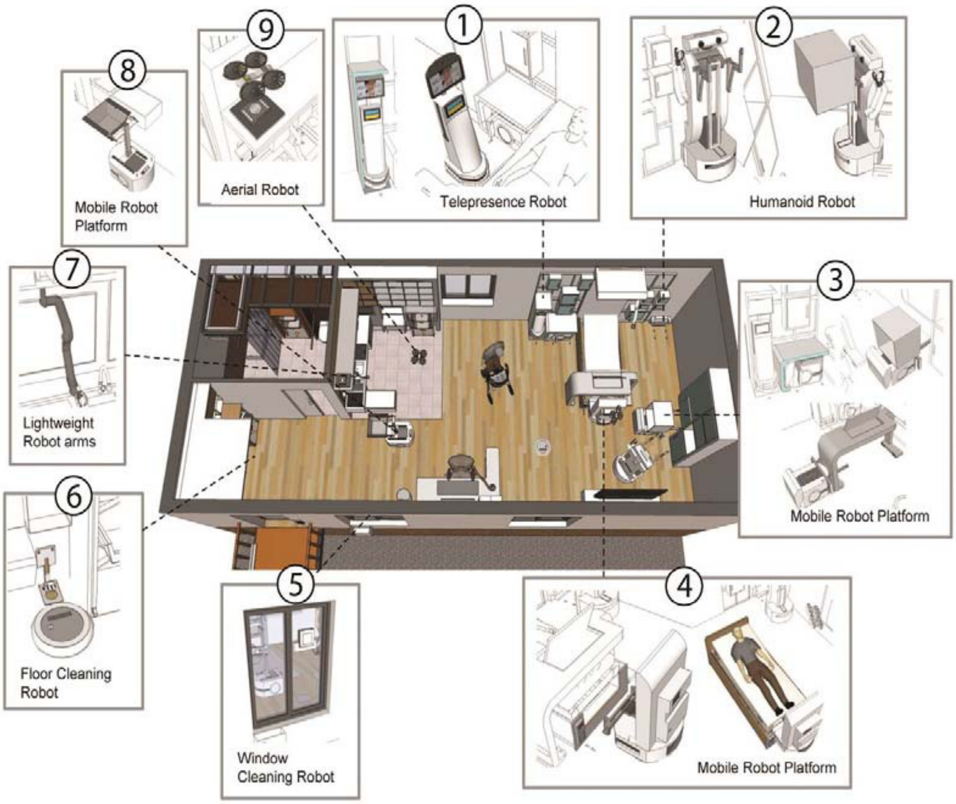
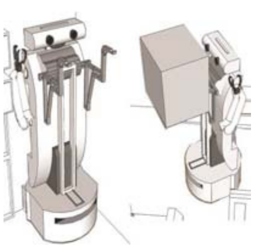
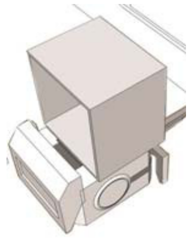


Fig. 2. Overview over a fully robot assisted care environment that might be deployed either in a care home (stationary care) in a home to assist ambulant caretaking (ambulant care).

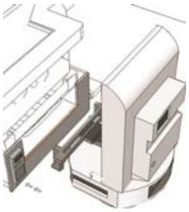
Subsystem 1: Telepresence Robot will operate in the flat and offer a mobile interactive interface by using a Graphical User Interface between the health care provider and the user. The robot will also assist the user with daily administration tasks. Further, it will monitor the user's movement with the living environment and detecting any hazards as well as signalling for first aid.



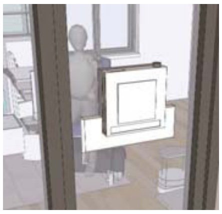
Subsystem 2: Humanoid Robot offers assistance when carry out lifting tasks and also support in house mobility of the user. It also equipped with numerous sensors and simultaneous localization and mapping devices to guide the robots manoeuvre within the living environment. When it is not in operation, the robot will automatically travel back to its charging station.



Subsystem 3: Mobile Robot Platform will carry out various logistic transportation jobs, which depending on the system payloads. For this module, it will offer services like delivering laundry, placing shelves, etc. It is equipped with RFID scanners, obstacle avoidance sensors and can be operated fully automatically. When it is not in operation, the robot will automatically travel back to its charging station.



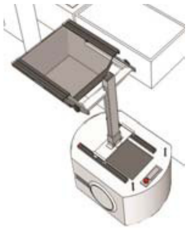
Subsystem 4: This Mobile Robot Platform will act as a heavy-duty logistic platform. Thanks to its greater payloads, it is capable of moving heavier loads, for example, moving the user along with the bed from the one location to another. The end-effector of the robot system is designed to be compatible with the smart furniture and enhance in house mobility of the user.



Subsystem 5: Window Cleaning Robot is used for cleaning, inspection and maintenance of the glazed window. The on board sensors will allow the robot to detect and analysis the condition of the window. The robot will be dispatched when required. When it is not in operation, the robot will automatically travel back to its charging station, which is located near the window sill.

Subsystem 6: Floor Cleaning Robot is used of cleaning of floor automatically. It has similar features as the Window Cleaning Robot described above. It will navigate its way around a room and carry out necessary cleaning duty.

Subsystem 7: Lightweight Robot Arm is modular, compact and efficient. It can be used for may application for assistive user with their daily activates such as cooking, washing, administration and personal hygiene.



Subsystem 8: This lightweight Mobile Robot Platform will transport smaller objects from a docking station to the rollator or other location without the user's intervention. It is also equipped with RFID scanners, obstacle avoidance sensors and can be operated fully automatically.

Subsystem 9: Aerial Robot is used to assist the user and operating as a surveillance drone in the flat. It is equipped with motion sensor, which can detect and release alarm in case of emergence. The robot can interact and exchange information with the user and other system when required.

Fig. 3. Detailed explanation of co-adaptation of robots systems, environment and processes for each sub system.

6. Proof of concept by implementation and experimentation

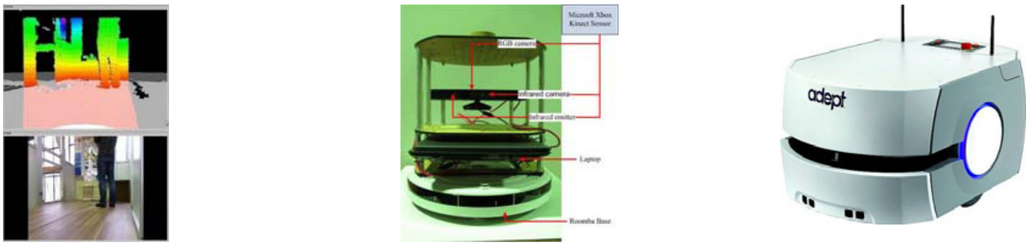
The possibility of co-adaptation, the dimensional space layout and furniture systems was tested and validated by the authors in different use cases and by using variety of robot systems in the AAL projects GEWOS, LISA, PASSAge, USA², and LISA habitech. All of these projects were initialized and conducted in the laboratory run by the authors and involved both commercial and industrial partners. The following two examples demonstrate exemplarily how the authors tackled the co-adaptation process.

The research project LISA investigated the possibilities to embed assistive functions and services into wall "terminal" components and, therefore, to enable an autonomous and independent living upon performing activities of daily living by (partially structured environments) robotic micro-rooms (RmRs). The terminal generated a geometrical known and structured environment for the integrated robot systems (Kinova's *JACO* robot arm [23]; *TurtleBot* [24]) and provided them with additional information (for example, example about location of objects to be grasped) through the embedded systems (for example, RFID readers). Details on the LISA project, the developments, experiments and user test conducted within this project are presented in [25] and [20].

In the project USA², assisted workspaces for decentralized high-tech home production of customized goods were developed. The workspaces developed are embedded in larger Cloud Manufacturing systems and will allow companies to utilize a highly skilled workforce (including highly experienced elderly) worldwide. Within the project, the workspace (its functions and design), the embedded sensors distributed in the environments, novel interfaces (for example, leap motion sensors; for further details, see also [26]) and the related work processed were fully co-adapted. Details on the *USA²* project, the developments, experiments and user test conducted within this project are presented in [16].

Fig. 4. Development and testing of robot-environment-process co-adaptation strategies within ongoing research projects LISA (a) and USA² (b).

Both in LISA and USA², the TurtleBot mobile rover platform was used to act as the human-machine communication interface. Furthermore, TurtleBot was used to acquire additional visual information (for example, example recognizing dynamic obstacles as human beings) using the Microsoft Kinect Sensor [27]. The depth sensor consists of an infrared laser projector combined with a CMOS sensor, which captures 3-D real-time data. The sensing range of the depth sensor is adjustable, and the Kinect embedded software is capable of automatically calibrating the sensor based on the user's physical environment arrangement, accommodating for the presence of furniture or other obstacles. Due to the fact that the Kinect sensor uses an infrared sensor, it can also provide night-vision abilities. Thus, in the proposed architecture, elderly people can be assisted by TurtleBot, in low lighting conditions and even if lights are switched off, i.e. during the night. The TurtleBot tele-operation is based on ROS open-source software [28].



3-D point cloud generated by TurtleBot | TurtleBot Mobile Platform | Lynx (Adept) has a payload of 60 kg

Fig. 5. Experimentation related to the co adaptation of mobile platforms, environment and processes.

The experiments with TurtleBot in LISA and USA² showed that the co-adaptation of environment and mobile platform allows for a multitude of assistive functions (for example, intuitive user interface, transports of goods, detection of emergencies, etc.). The capabilities and technical details of TurtleBot acting in a co-adapted structured environment are presented in detail by [12].

In the next step, the authors will use the generated knowledge and implement and co-adapt care environments and mobile platforms with higher payloads (for example, *Lynx* [29]), which will increase the range of possible application significantly. Figures 2 and 3 outline application scenarios for such mobile platforms in professional care settings.

7. Conclusion and future research

The authors have identified the need of and possible use cases for the implementation of service robot technology within professional stationary and ambulant care scenarios. The authors have tested strategies for the adaptation of service robots (for example, example TurtleBot and JACO) in a series of projects in the field of Ambient Assisted Living. In the next step, the authors will apply the knowledge gained so far to create professional care settings in which, in particular, the caretakers are heavily supported by a variety of robots. Similar as in the research projects conducted so far, the authors conclude that the co-adaptation of robot systems, physical environment and processes will reduce total system complexity and cost and thus boost implementation and commercialization of service robot systems for ambulant and stationary care.

References

[1] Robine, J.-M.; Cournil, A.; Gampe, J.; Vaupel, J. W. (2005) 'IDL, the International Database on Longevity', Living to 100 and beyond, Orlando: Society of Actuaries
[2] Doblhammer, G.; Scholz, R. D.; Maier, H. (2005) 'Month of birth and survival to age 105+: evidence from the age validation study of German semi-supercentenarians', Experimental Gerontology
[3] Staudinger, U.; Kessler, E.-M. (2007) 'Intergenerational potential: Effects of social interaction between older people and adolescents', Psychology and Aging, No. 22, pp. 690-704
[4] Brugiavini A., Croda E., Mariuzzo, F. (2005) 'Labour Force Participation of the Elderly: Unused Capacity? ' [research report] Survey of Health, Ageing and Retirement in Europe, Vol.5
[5] Börsch-Supan, A.; Mariuzzo, F. (2005) 'Our Sample: 50+ in Europe' [research report] Survey of Health, Ageing and Retirement in Europe, Vol.2
[6] Jeune, B.; Vaupel, J. W. (1995) 'Exceptional Longevity: From Prehistory to the Present'. Odense: Odense University Press
[7] Maier. H.; Gampe, J.; Vaupel, J. W.; Jeune, B. (2010) 'Supercentenarians'. Berlin/Heidelberg: Springer
[8] Wichert, R.; Eberhardt, B. (2011) 'Ambient Assisted Living', Berlin: Springer
[9] Care-O-Bot – mobile robot assistant developed by Fraunhofer Institute for Manufacturing Engineering and Automation [Robot System], website: <http://www.care-o-bot.de/en/care-o-bot-3.html> accessed 28 March 2014
[10] Patient Transfer Assist – Care robot developed by Toyota Motor Corporation [Robot System], website: <http://phys.org/news/2011-11-toyota-machines-sick-elderly.html> accessed 28 March 2014
[11] RI-MAN – Care robot by research center of RIKEN [website], <http://rtc.nagoya.riken.jp/RI-MAN/index_us.html> accessed 28 March 2014
[12] Georgoulas, C.; Linner, T.; Kasatkin, A.; Bock, T. (2012) 'An AmI Environment Implementation: Embedding TurtleBot into a novel Robotic Service Wall', Proceedings of 7th German Conference on Robotics. Munich, Germany: VDE Verlag
[13] GEWOS - Gesund Wohnen mit Stil. (German Ambient Assisted Living Program) [Research Project], BMBF funded Project dealing with Building Infill and Furniture equipped with sensor systems and augmented by digital services, project website: http://www.gewos.org/
[14] LISA - Living Independently in Südtirol/Alto Aldige [Research Project], Project funded by the city of bolzano, central R&D topic: Modular Mechatronic Walls, project website: http://www.br2.ar.tum.de/index.php/component/content/article?id=35
[15] PASSAge - Personalisierte Mobilität, Assistenz und Service Systeme in einer alternden Gesellschaft [Robot System], BMBF funded Project, Personalized Mobility, Assistance and Service Systems in an Ageing Society, project website: https://www.passage-projekt.de/projekt.html
[16] USA² - Ubiquitäres und Selbstbestimmtes Arbeiten im Alter [Research Project], BMBF funded Project, Workspaces for Cloud Manufacturing in an Ageing Society, project website: http://www.br2.ar.tum.de/index.php/component/content/article?id=98
[17] LISA habitec - Living independently in Südtirol Alto-Adige through an Integration of Habitat, Assistance, Bits and Technology by a value System based on local Resources. [Research Project], Project funded by the city of bolzano, Start: April 2014
[18] AAL – Ambient Assisted Livig [Research Initiative], website: http://www.aal-europe.eu/
[19] Bock, T. (1988) 'Robot Oriented Design' [Dr.-Ing. Dissertation], Faculty of Engineering, Chair of Building Production, The University of Tokyo
[20] Linner, T.; Güttler, J.; Bock, T.; Georgoulas, C. (2014) 'Assistive Robotic Micro-Rooms for Independent Living'. Submitted to Journal of Construction Automation (acceptance pending)
[21] Linner, T., Eibisch, N., Bock, T. (2011) 'Strategy for the development of assistive Environments based on geriatric Assessment'. In: Proceedings of 28th International Symposium on Automation and Robotics in Construction (ISARC), Seoul, Korea
[22] Bock, T.; Linner, T. (2012) 'Demografic Change Robotics: Mechatronic Assisted Living and Integrated Robot Technology'. In: Introduction to Modern Robotics II, Edited by N. McDowall (Eds.) Daisuke Chugo and Sho Yokota. Month 2012, ISBN 978-0980733075.
[23] JACO – robotic lightweight manipulator produced by Kinova [Robot System], website: http://kinovarobotics.com/
[24] TurtleBot – mobile robot platform produced by the company Willow Garage [Robot System], website: http://www.willowgarage.com/
[25] Güttler, J.; Georgoulas, C.; Linner, T.; Bock, T. (2014) 'Unabhängiges Wohnen durch modulare und mit Assistenzfunktionen individualisierbare Mikro-Roboterräume'. In: Proceedings of 7th German AAL-Kongress, Berlin, Deutschland
[26] Georgoulas, C.; Raza, A.; Güttler, J.; Linner, T.; Bock, T. (2014) 'Home Environment Interaction via Service Robots and theLeap Motion Controller'. In: Proceedings of 31st International Symposium on Automation and Robotics in Construction (ISARC), Sidney, Australia
[27] Biswas K.K., Basu S. (2011) 'Gesture Recognition using Microsoft Kinect'. In: Proceedings of the IEEE International Conference on Automation, Robotics and Applications (ICARA), Delhi, India
[28] Robot Operating System (ROS) [Wiki Online], website: http://www.ROS.org/wiki/, Accessed: 09/12/2013.
[29] Lynx – mobile robot platform produced by the company Adept [Robot System], website: https://www.adept.de/produkte/mobile-roboter/mobile-plattformen/lynx/allgemeines