Potential of Robotics for Ambient Assisted Living

Final Report

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Abschlussbericht der Studie

Potenzial und Grenzen von aktueller Robotik zur Nutzung im Themenfeld des Ambient Assisted Living

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Contents Overview

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List of Abbreviations

AAL	Ambient Assisted Living, Active Assisted Living
ADL	Activities of Daily Living
iADL	instrumented Activities of Daily Living
CEN	Comité Européen de Normalisation
CENELEC	European Committee for Electrotechnical Standardization
COPD	Chronic Obstructive Pulmonary Disease
EADL	Extended Activities of Daily Living
ELGA	Elektronische Gesundheitsakte (Electronic Health Record)
FP7	7^{th} Framework Programme (EU Research Programme)
H2020	Horizon 2020 (EU Research Programme)
HCI	Human Computer Interaction
HHR	Home Healthcare Robot
HRI	Human Robot Interaction
IEC	International Electrotechnical Commission
ISO	International Organisation for Standardisation
MCI	Mild Cognitive Impairment
PCP	Pre-Commercial Procurement
PPP	Public-Private Partnership
QALY	Quality Adjusted Life Years
SAR	Socially Assistive Robot
TAM	Technology Acceptance Model
TRL	Technology Readiness Level
UTAUT	Unified Theory of Acceptance and Use of Technology
WoZ	Wizard of Oz

Executive Summary

The last few years have witnessed an intensification of efforts in AAL Robotics within the AAL community but also in the HRI (Human-Robot-Interaction) and robotics research communities at large. The central aim of this study is the definition of the field of AAL robotics, the description of its state and challenges, and a realistic presentation of its potential both in terms of markets and to enable and prolong independent living especially of older persons. To this aim, work for the study proceeded in several thematic areas: a) an overview of the field, covering products, research projects, and key players, b) the comparison of needs of primary, secondary, and tertiary user needs with the needs and requirements focused on by current research, c) an analysis of key technical challenges and evaluation methods, and d) a scenario-based analysis of market potential.

a) Overview of AAL Robotics:

We define an AAL robot as a robot that assists the target group of older users including users with disabilities, supports the target group during daily life or work, and improves or maintains the independent living of the target group. The ten main application areas of AAL robots are: mobility support, manipulation support, personal care, household, social assistance (companions), telepresence, entertainment, emotional support, fetch & carry support, and rehabilitation. 60 examples of AAL-related robots were collected, categorized, described and made available as a catalogue.

b) User Needs and their coverage by R &D in AAL robotics:

Main primary user needs can be classified into needs regarding (by order of importance) health deficiencies, social factors, environmental factors, and financial factors. Robotics R & D deals sufficiently with health deficiencies and social factors. Environmental factors can only partly be solved by robotic solutions, whereas financial factors are largely neglected in user studies. AAL robotics have a high potential to support secondary user groups (formal and informal caregivers) through direct (lifting, carrying) and indirect (patients' mobility) physical support. Secondary positive effects on emotional well-being, stress reduction and quality of life of secondary users can be assumed, but evidence is still lacking. Needs of tertiary users, in particular cost efficiency, are rarely taken into account by R&D. Long-term studies to produce evidence of positive impacts are still rare.

c) Key technical challenges and technology readiness:

High demands on key robotic abilities, varying by robot categories, make the field of AAL robotics a challenging research topic. The particularly high demands on mobile socially assistive robots make them both an attractive research field and a field still far from developing marketable products. Household robots and emotional robots, as well as some robots for the institutional market (rehabilitation, mobility/lifting&carrying) have already been commercialised. Because of the complexity of AAL solutions (vulnerable target group, unstructured environment, complex user needs), the more a solution corresponds to what we understand to be relevant for AAL, the further away it is from the market.

d) Market potential of AAL robotics:

Robots, even at current prices, have the potential to compete with products and services on the home care and assistive technologies market, on condition that their functionality fits closely with a) the needs of consumers in specific situations of age-related change of lifestyle and/or care, and b) with the alternative products and services on the market. For product development, market segments have to be much more thoroughly defined and studied in order to design for the market.

The report ends with a short outlook on the field, and with recommendations for research funding, research, product development and marketing.

Zusammenfassung

In den letzten Jahren fand die AAL-Robotik innerhalb der AAL Community, aber auch in der Mensch-Roboter-Interaktion (HRI) und der Robotik allgemein zunehmend Beachtung. Ziel dieser Studie ist die Definition des Gebiets der AAL-Robotik, die Darstellung von Stand und Herausforderungen, und eine realistische Einschätzung ihres Potenzials für die älteren Menschen wie auch für die Wirtschaft. Zu diesem Zweck wurden mehrere Themen bearbeitet: a) ein Überblick über Produkte, Projekte und Organisationen, b) ein Vergleich zwischen den Bedürfnissen verschiedener Nutzergruppen mit den Bedürfnissen und Anforderungen, auf die sich die Forschung derzeit richtet, c) eine Analyse der technischen Herausforderungen und Evaluationsmethoden sowie d) eine szenario-basierte Einschätzung des Marktpotenzials.

a) Überblick über die AAL-Robotik

Ein AAL-Roboter wird hier definiert als ein Roboter, der die Zielgruppen der älteren Menschen und Menschen mit Behinderung im täglichen Leben oder Arbeiten unterstützt, und der ihnen ein unabhängiges Leben ermöglicht oder erleichtert. Die zehn Hauptanwendungsgebiete sind: Unterstützung der Mobilität, der Manipulation, der persönlichen Pflege und der Haushaltsführung; weiter soziale Assistenz (Companion-Roboter), Telepräsenz, Gesundheits- und Sicherheitsüberwachung, kognitiv/emotionale Unterstützung, Bringen & Tragen, sowie Rehabilitation. 60 Beispiele von AAL- oder AAL-nahen Robotern wurden gesammelt, kategorisiert, beschrieben und in einem Katalog online zugänglich gemacht.

b) Nutzerbedürfnisse und ihre Abdeckung in der AAL-Robotik-Forschung

Hauptbedürfnisse der primären Nutzer gliedern sich in Gesundheits-, soziale, Umwelt- und finanzielle Faktoren. Die Forschung beschäftigt sich ausreichend mit Gesundheitsdefiziten und sozialen Faktoren. Umweltfaktoren sind nur teilweise robotisch zu lösen, während finanzielle Faktoren weitgehend unberücksichtigt bleiben. AAL-Robotik hätte viel Potenzial zur Unterstützung der sekundären Nutzer (Pflegepersonen) durch physische Hilfe, von der auch positive Auswirkungen auf die Lebensqualität (emotional, Stressverringerung) der Pflegenden erwartet werden, wofür es jedoch noch an Evidenz fehlt. Die Bedürfnisse der tertiären Nutzer, vor allem Kosteneffizienz, werden noch kaum beachtet, Langzeitstudien über positive Wirkungen sind noch selten.

c) Technische Herausforderungen und Technologie-Reifegrad (TRL)

Hohe, je nach Kategorie variierende Fähigkeiten machen AAL-Robotik zu einer Herausforderung für die Forschung. Insbesondere die hohen Anforderungen an mobile sozial-assistive Roboter machen sie zu einem attraktiven und zugleich noch marktfernen Forschungsgebiet. Haushaltsroboter und emotional unterstützende Roboter sowie einige Roboter für die institutionellen Märkte (Mobilität, Heben/Tragen, Rehabilitation) sind bereits auf dem Markt. Bedingt durch die Komplexität von AAL-Lösungen (sensible Zielgruppen mit komplexen Bedürfnissen in unstrukturierter Umgebung) kann gesagt werden: je relevanter ein Roboter für den Kernbereich des AAL ist, desto weiter ist er noch vom Markt entfernt.

d) Marktpotenzial von AAL-Robotern

Roboter haben selbst zu heutigen Preisen, das Potenzial, mit Produkten und Dienstleistungen auf dem Markt der privaten Pflege und assistiven Technologien zu konkurrieren, wenn ihre Funktionalität gut auf a) die Nutzerbedürfnisse in spezifischen Situationen altersbedingter Veränderungen des Lebensstils und b) die alternativ verfügbaren Produkte und Dienstleistungen abgestimmt sind. Dies bedeutet für die Produktentwicklung, dass die einzelnen Marktsegmente genau definiert und untersucht werden müssen, um Design und Kosten zielgerichtet auf den Markt zuzuschneiden.

Die Studie endet mit einem kurzen Ausblick in die Zukunft sowie mit Empfehlungen bezüglich Forschungsförderung, Forschung, Produktentwicklung und Marketing.

1 Introduction

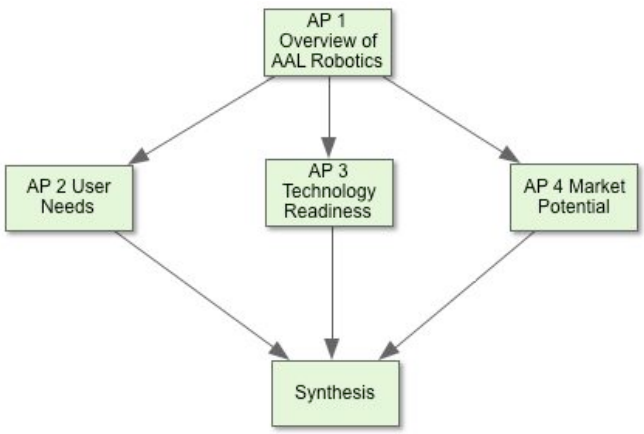
1.1 Goals of the potenziAAL study

Ambient Assisted Living (AAL, now more often called Active Assistive Living) has been introduced as a term for a field of technology research and development with the general aim to facilitate and extend independent living (aging in place) of older adults. Both robotics and AAL are interdisciplinary areas of research with numerous interfaces to other branches of R & D. The last few years have witnessed an intensification of efforts in AAL Robotics within the AAL community but also in the HRI (Human-Robot-Interaction) and robotics research communities at large, as is illustrated by numerous projects and prototypes and the first arrivals of assistive robots on the market. Still, the field of "AAL Robotics", combining both disciplines, has not yet been precisely defined and does not present accepted structures and concepts that would allow to communicate unequivocally its methods, projects and approaches. Consequently, a deficit persists with regard to studies that analyse the potential of assistive service robots from the perspectives of actual satisfaction of user needs, technical readiness, ethics, law and commercialization.

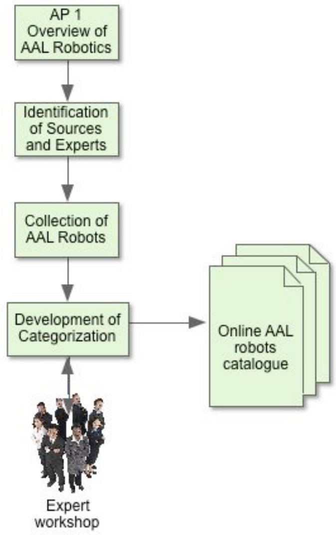
The central aim of this study is the realistic presentation of the potential of AAL Robotics, based on the analysis of parameters drawn from user needs, technical readiness and market studies. The results of the PotenziAAL study are intended to serve the AAL and Robotics Communities as an overview of current potential and limits, decision makers on programme level as a background for designing future funding and evaluation schemes and future proposal and project developers as an orientation on needs, concepts, and state of the art.

1.2 Approach

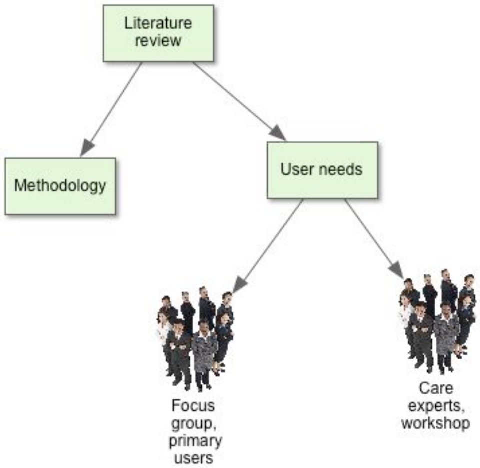
The following charts represent the structure of the project in a shortened overview of the workplan:



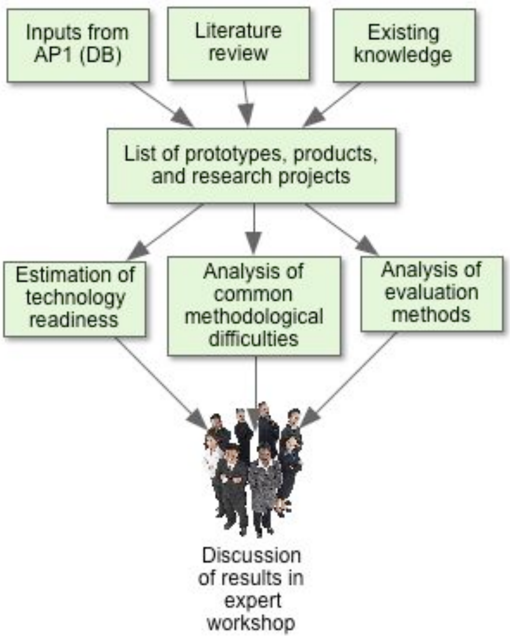
The project was structured in four thematic workpackages. Workpackages 2 to 4 represent the three pillars of the approach: humans – technology – market (and largely correspond to chapters 3 to 5 of this study)



Workpackage 1, “Overview of AAL Robotics”, established the knowledge base for the project. Sources of data and expertise were identified through competences of the partners, literature and web research, and input from external experts. A broad collection of examples of AAL robots and literature pertaining to them was undertaken. Collected data were the basis for several cycles of definition and categorization. The results – AAL robots and their characterizing features – were stored in a database. In an expert workshop, definition and categorization were discussed and validated.

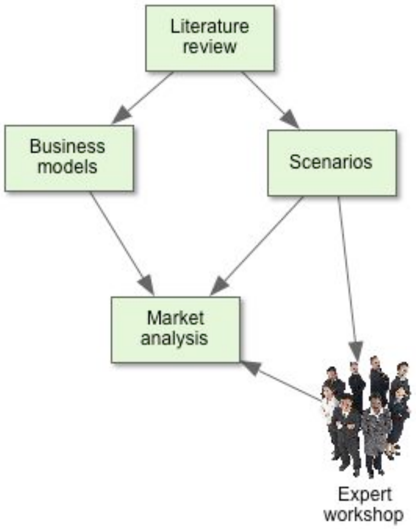


Workpackage 2 was based on an extensive literature review covering demography of older users, deficits and objective needs of primary, secondary, and other users, as well as factors of acceptance. One section is concerned with the methods used in robotics research to elicit user needs and acceptance. Findings were presented and discussed in two workshops, one with primary users and one with care experts.



The literature review undertaken in Workpackage 3 investigated relevant European research projects and analyzed their results for current technical and methodological difficulties. For already completed projects, papers and public deliverables were analyzed for methods used in evaluation, the technology readiness reached and common methodological difficulties reported.

Additionally, the technology readiness of prototypes and products found via web-searches and the literature survey was estimated based on an analysis of the used evaluation methods. The results of the workpackage were discussed in the final expert workshop.



Workpackage 4: Market-related studies of AAL technologies and service robotics were analysed in order to develop realistic assumptions about the market potential of AAL robotics. From consumption scenarios and examples of (near) commercial AAL robots, case studies on purchasing decisions were developed. In the final expert workshop, participants worked on these case studies and largely corroborated the project's findings.

1.3 Structure of the Report

Chapter 2 presents the definition and categorization of the field of AAL Robotics, and gives an overview of AAL-related robots at different technology readiness levels.

Chapter 3 deals with the needs of primary, secondary and tertiary users of AAL robots and the methods used to elicit these needs.

Chapter 4 discusses technology readiness levels of AAL robots and the key technological challenges.

Chapter 5 deals with the market potential of AAL robots as well as standardization, legal and ethical issues.

Chapter 6 gives an outlook on the future of AAL robotics and deduces recommendations for research and its funding, product development and marketing.

Annex A is the catalogue of AAL robots that has been collected for this study. The catalogue is also available online[1] and searchable.

[1] www.potenziaal.at

2 Overview of AAL Robotics

2.1 Methodological considerations

2.1.1 Naming and defining AAL robots

Describing robots that belong to the field of ambient assisted living (AAL) is a difficult task since there are no commonly agreed definitions for "robot", "assistive technologies" and "ambient assisted living". There is a long philosophical discussion in particular for the definition of a robot. In literature several researchers already named groups of robotic solutions that assist people and hence at least partly represent the group of AAL robots.

Incomplete list of currently used terms to describe robots that help older people and people with disabilities:

Assistive robotics (AR) for example is, according to [Feil-Seifer2005], largely used to refer to robots that assist people with physical disabilities through physical interaction. In addition Feil-Seifer and Matari formed the term *socially assistive robots* (SAR) to refer to robots that are meant to assist people in a non-physical way such as those that assist through non-contact interaction to support patients in a hospital or senior citizens in a nursing home. [Feil-Seifer2005]

Another more recent classification of robotic solutions was undertaken by the international organization for standardization within the standard ISO 13482:2014 for safety of *personal care robots*. A "personal care robot" is defined to "typically perform tasks to improve the quality of life of intended users, irrespective of age or capability." [ISO13482]. The standard further classifies these kinds of robots into three categories:

Mobile servant robot: "Personal care robot that is capable of travelling to perform serving tasks in interaction with humans, such as handling objects or exchanging information".

Physical assistant robot: "Personal care robot that physically assists a user to perform required tasks by providing supplementation or augmentation of personal capabilities".

Person carrier robot: "Personal care robot with the purpose of transporting humans to an intended destination".

Explicitly excluded are robots that travel faster than 20km/h, robot toys, water-borne robots and flying robots, industrial robots (covered in other ISO specification), robots as medical devices, military or public force application robots. [ISO13482]

Alaiad and Zhou describe a similar category of robots: *home healthcare robots* (HHRs*)* [Alaiad2014a]. Among *doctor healthcare robots*, *nurse healthcare robots,* they present a subcategory of ***healthcare robots***. *Home healthcare robots* provide health care services to people in their homes. They include other categories such as *remote presence robots* [Coradeschi2014], *social robots* [Kidd2006], and multi-purpose platforms such as Pearl [Pollack2002].

The international federation of robotics defined an often used term for our field – the ***service robot***. "A service robot is a robot which operates semi- or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations" [IFR]. This is a wide category that includes all application fields including military and space applications. To narrow the field down a sub-category was created – the *personal service robot* or *service robot for personal use*. "A *personal service robot* is a *service robot* used for a non-commercial task, usually by lay persons" [IFR]. Examples are domestic servant robot, automated wheelchair, personal mobility assist robot and pet exercising robot. Although this is still a wide definition, in literature this term is often used in parallel to the sub category "*domestic service robot*" specifically for home automation robots such as automatic lawn mowers or cleaning robots. [Fink2011]

Relation of current terms to the developed definition of AAL robots

AAL Robots do not fit exactly into the categories *assistive robots* or *socially assistive robots* since they cover both categories but restrict the target group to older people and people with disabilities in their living environments. Since assistive robotics refer to all kinds of target groups including children, care personnel [Mukai2010], and workers in their work environment, this term is too wide in scope. Socially assistive robots on the other side exclude robots giving physical support and is hence too narrow in scope.

Whilst the definition of *personal care robots* again includes all user groups, the sub-categories narrow down the field too strictly as they leave out potential applications that do not provide physical support such as physical and cognitive training, rehabilitation or safety and monitoring.

The definition of *home healthcare robots* alone suggests a use *at home*, which is not the case for all applications of AAL robots. What is more, the target group are primarily patients whereas the target group of *AAL robots* include healthy older users.

The definition of *personal service robots*, on the other hand, is not selective with regard to the target group, even training aids for pets are included [IFR]. Hence it is less restrictive in this regard than the category "assistive robot", and too broad for our purpose.

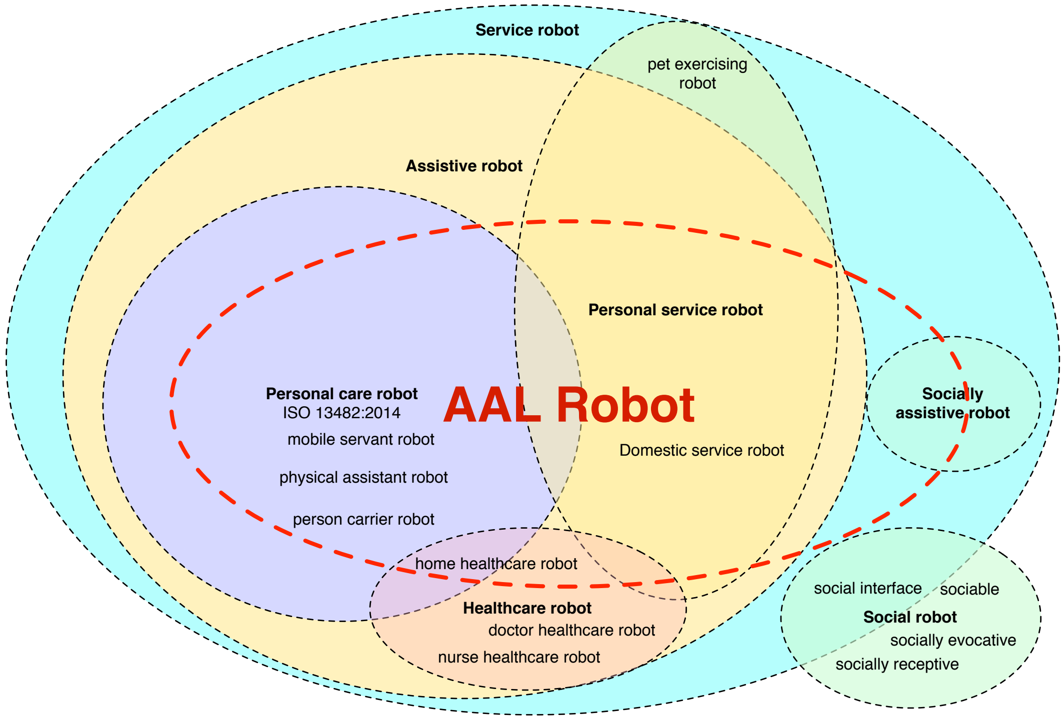


Fig. 1. *AAL robots in relation to other robot definitions*

Figure 1 shows the overlap of current categories of robots that are relevant for the field of *AAL robots*. Since *AAL robots* include the intended target group in the definition, they do not cover the other categories completely. Dotted lines were chosen to visually represent the fuzzy borders between the categories.

The core category of AAL robots

The main distinction between AAL robots and the previously named categories is the specificity to the target group which is congruent with the target group of ambient assisted living.

An AAL robot is a robot that:

1. assists the target group of older users including users with disabilities.
2. supports the target group during daily life or work.
3. improves or maintains the independent living of the target group.

ad 1: the term "assists" was preferred to the term "developed for" in order to include also solutions that were not developed with the intention to serve the AAL target group, but can support them.

Furthermore, it tells that the robotic solution also has to be applicable by the target group – potentially excluding solutions that were designed for the group but are not senior-friendly.

Similar to the variety of terms used for robots with assistive goals, the term "robot" itself has various definitions. For our goals of structuring the field of AAL robots we defined the term robot as follows:

> A robot is a *mechanism* that has *sensors and actuators*, makes *sensor- or knowledge-based decisions* in order to fulfill its aims and is capable of *visible motion* in *two or more axes*.

This definition is roughly in line with existing definitions that mostly also include the capability of (semi-)autonomous acting (sensor-based decisions) [Oxford] and the ability to move or actuate [IFR]. The term "visible motion" was chosen since studies suggest that visual motion changes the social presence of robots and represents a typical characteristic that people use to differentiate between robots and machines.

Decision on the term "AAL robot"

The term "AAL robot" was chosen over several alternatives, as the definition of AAL is already widely circulated and adopted by researchers and this naming will allow the AAL community to recognize the contribution to their research field. As robots are in general not "ambient", which the original term suggests (ambient assisted living), we more often refer to the newer international definition "*active* assisted living" by the European AAL Joint Programme.[2]. "Ambient Assisted Living" continues to be used in the context of the title of this study and the Austrian funding scheme (benefit).

2.2 Categories and Database of AAL Robots

To generate the database of AAL robots, a secondary analysis of literature was undertaken and the results were validated by means of an expert discussion.

The following questions drove the research:

1. How can the interdisciplinary field of robots in AAL be defined in a way suitable to allow simple identification of AAL robots and to enhance communication between stakeholders?
2. Which criteria can be used to structure existing and future robotic solutions and how can solutions be clustered into different categories?

Relevant primary and secondary literature was identified based on keywords suitable for the respective research question above. Literature was searched for in literature databases, Google scholar, by means of "hand-searching" of references, web-searches for "robot" and "robotics" in combination with keywords "service", "assistive", "healthcare", "care", "eldercare", "assisted living" and by contacting investigators – in particular researchers involved in projects that target assistive robotic solutions.

In a first step literature was searched for relevant definitions of the keywords "ambient/active assisted living" and "robots". Identified definitions were analysed for shared concepts, words and phrases. The most widely shared concepts defining "ambient/active assisted living" and "robot" were adopted and integrated into our definition of "AAL robots". This definition was presented to six experts from robotics and the field of ambient assisted living during an expert workshop where the most important characteristics for both definitions were discussed and slightly altered to the version finally adopted for this study.

By using the key aspects of our definitions we were able to identify robotic solutions that met the criteria of the new class of AAL robots. To get an overview of robotic solutions within this new class, a database of currently 60 robots was built including the following information for each robot: robot name, company or project developing the robot, country of origin, use cases the robot is intended to support, a general description, the year of construction of the robot, the estimated technology readiness level according to NASA's TRL score [Mankins1995], the price (if available), and an image of the robot. The goal was not a complete register of AAL-related robots, but a collection of sufficient examples for each category in order to give a representative overview of the field.

[2] http://www.aal-europe.eu/

2.2.1 Overview by field of application area

Table 1 summarizes the currently described and categorized types of AAL robots together with the activities that they (are intended to) support [Smarr2011]:

- ADL = Activities of daily living. They include the ability to toilet, feed, dress, groom, bathe, and ambulate.
- IADL = Instrumental ADL. They include the ability to successfully use the telephone, shop, prepare food, do the housekeeping and laundry, manage medications and finances, and use transportation
- EADL = Enhanced ADL include participation in social and enriching activities, such as learning new skills and engaging in hobbies.

Table 1. Types of AAL robots by application field and assisted activities

robot class	ADL supported	IADL supported	EADL supported	other needs supported
Robotic Mobility Aids (wheelchairs, lower limb exoskeletons, scooter robots, robotic walking aid)	all ADLs requiring mobility	cooking shopping cleaning	all	stability (by some)
Fetch & Carry Support (fetch&carry robots, robot trolleys)	----	carrying shopping	----	---
Robotic Manipulation Aids (robot arms, upper limb exoskeletons)	all ADLs involving manipulation	all	hobbies work	---
Personal Care Robots (mostly specialised robots)	eating, drinking bathing toileting	----	----	---
Household Robots (specialised cleaning, cooking etc. robots)	----	cleaning cooking	----	---
Companion Robots	---	management (health, administration) use of services use of transportation (tele)shopping	learning, cognitive training reading writing participation, social activities entertainment	safety physical training company
Emotional Robots	---	---	entertainment	company
Rehabilitation Robots	---	---	---	physical training fitness
Telepresence Robots	---	management (health, administration)	---	provide company
Entertainment Robots	---	---	entertainment cognitive training	provide company

It has to be noted that not all example robots described in what follows have been designed explicitly as AAL robots in our sense. Likewise, they vary in their degree of "robot-ness", e.g. with regard to autonomous decision-making: although included in our broad definition, these examples are, on one or more dimensions less typical AAL robots than others. The class of AAL robots is therefore best conceptualized as a radial category [Lakoff1987]: a radial category has no central representative, i.e. a single prototype for the whole category. Instead, there co-exist several features that equally contribute to membership in the category (see also chapter 2.2.2.2 for an example).

2.2.1.1 Robotic Mobility Aids

This class of robots shares the ability to directly support the mobility of the target group by supporting their movements or navigation between locations. In this way the class augments the mobility of the users. Typical subclasses include: robotic wheelchairs, lower limb exoskeletons, "scooter robots" and robotic walking frames.

One example is the assistive robot “Friend II - functional robot arm with user-friendly interface”[3] which was developed to assist older users and users with disabilities to navigate, move and support activities of daily living such as cooking and serving meals.

2.2.1.2 Fetch & Carry Support

This class of robots supports its users by alleviating their need for mobility; in this way supplementing the lacking mobility or strength of users. Typical subclasses of this group include robots fulfilling fetch&carry tasks such as robotic trolleys. Our example “Botlr” is a system designed to deliver goods to users inside a hotel or care residence. The system uses a wheeled base and a tray for goods to autonomously deliver objects to the entrance of users’ premises.

				
Robotic Mobility Aid **Friend II**	**Fetch & Carry Support** **Botlr**	**Robotic Manip. Aid** **Asibot**	**Rehabilitation Robot** **Auto Ambulator**	**Telepresence Robot** **Giraff**
				
Personal Care Robot **Bestic**	**Household Robot** **Scooba**	**Companion Robot** **Hector**	**Emotional Robot** **Paro**	**Entertainment Robot** **Ifbot**

Fig. 2. Examples of robots for each robot category

2.2.1.3 Robotic Manipulation Aids

This class includes robot arms and exoskeletons or “wearable robots” [Pons2008] for upper limbs. In the ideal case, they assist the user with all activities that require dexterity and/or strength of a hand or an arm and so are of more general use than those personal care robots that are or contain a robot arm with a pre-defined activity. “Asibot” is a manipulator robot with 1.3 m of reach and 2 kg of payload. The applications are oriented mainly to domestic assistive tasks for elderly and handicapped people. The robot has a gripper to manipulate different objects or tools. The applications that have been tested in real environments are: eating, drinking, shaving, make up, tooth cleaning, etc.

[3] Links and references for this and all following expamples of robots are given in the potenziAAL catalogue of AAL robots.

2.2.1.4 Personal Care Robots

This class of robots comprises systems that support personal care tasks such as bathing, toileting, brushing teeth, showering, eating and drinking. Typical subclasses are robotic toilets, robotic baths and robotic feeding support aids. The example shown in Figure 2 is the feeding support aid "Bestic". Bestic can be best described as a small, robotic arm with a spoon. By choosing a suitable control device, the user can independently control the movement of the spoon on the plate and choose what and when to eat. The system autonomously performs various movements to support food intake, which qualifies it as a robot.

2.2.1.5 Household Robots

This class of robots is distinguished by its support for housekeeping tasks such as cleaning and cooking. Typical subclasses include the various forms of commercial specialized cleaning robots such as robotic vacuum, window and floor cleaners, such as the "Scooba" by iRobot, which is depicted in Figure 2. This robot is capable of autonomously swiping the floors of users' homes by driving in a random pattern across the floors until it needs a recharge. Obstacles such as doorsills or furniture can either be navigated around or the user is asked to help. The current class of commercial household robots has, however, not been designed specifically for older adults or people with disabilities, given that their operation may involve bending and lifting tasks.

2.2.1.6 Companion Robots

The class of companion robots typically facilitates communication with the user and integration into a smart environment to accomplish a wide range of tasks to support the target group including but not limited to monitoring of health, security or safety, cognitive support or communication and social support such as provided by telepresence systems. Note that they are often combined with a) manipulation (robot arm) or b) passive mobility (fetch&carry) capacities; but some, especially the non-mobile ones, only rely on their communication with the user to give reminders or warnings.

A representative example of this group is the robot "Hector" which was used within the Companionable[4] project (EU-FP7). The platform is targeted for use at homes of older users with mild dementia where it can navigate autonomously on wheels and provide motivating suggestions, an agenda to structure the day, medicine reminders, video conferencing, memory training and entertainment. The system uses voice and a touchscreen for communication and is able to recharge itself.

2.2.1.7 Emotional Robots

Emotional robots are used either in care institutions or in home care settings and typically represent either pets (mostly cats and dogs) or caricatures. Their benefits are derived from pet therapy and result from a set of psychological impacts of animals and animalistic robots on humans. Certain benefits such as opening up in social communication could be shown in studies such as those of Wada and Shibata [Wada2007], [Shibata2010]. Although they are often referred to as prominent examples of robots for older adults, they are only marginally AAL robots according to our criteria. The probably best-known example is the robot seal "Paro". The robot is mainly used in care institutions and supports primarily the caregivers in their social work with the elderly people.. The robot represents a baby seal and is capable of reacting to pet strokes with movements of flippers and head as well as acoustic signals.

2.2.1.8 Rehabilitation Robots

This class of robots does not directly support the users in performing their ADLs but helps to recover from certain physical conditions that are related to typical age related diseases such as stroke. Rehabilitation Robots traditionally are expensive complex machines that are used in clinics specialized on physical rehabilitation such as the given example "Auto Ambulator" [Waldner2008]. More recently also mobile robots for consumers are being developed, aiming at supporting users with rehabilitation at home, such as the "Rufus Running Companion[5]", a robotic device developed to support runners.

[4] http://www.companionable.net

[5] http://www.blue-ocean-robotics.com/en/robots/healthcare/rufus-running-companion

In addition to the rehabilitation function this device also supports Alzheimer patients in guiding them on their way.

2.2.1.9 Telepresence Robots

Telepresence robots differ from companion robots as they do typically not offer any additional services but telepresence. Such systems may be used at home such as the research-prototype Giraff, but can also be used in institutional care like the RP-VITA[6], a remote presence robot that mainly supports care staff who can visit patients at the bedside virtually by remote control.

2.2.1.10 Entertainment Robots

Robots with the sole function to entertain older users at home or in an institutional setting are currently rather theoretical concepts as this ability is mostly incorporated with others into multi-functional companion robots. Still, the entertainment industry develops ever more new robots for the general public that might also be used by the target groups of AAL. Also for some robots that were developed to support older users, the entertainment functionality seems to be the most prominent such as in the shown example of "ifbot" which has been used in hospitals to entertain the elderly by conversation, puzzles and memory games.

2.2.2 Database

2.2.2.1 Distribution of AAL robot types

Figure 3 shows the distribution of different robot types in the database established within the potenziAAL study. This distribution makes no claim to represent the real distribution among projects and products, given that the database did not aim at completeness, but rather at the broadest possible snapshot of the field of AAL-related robots.

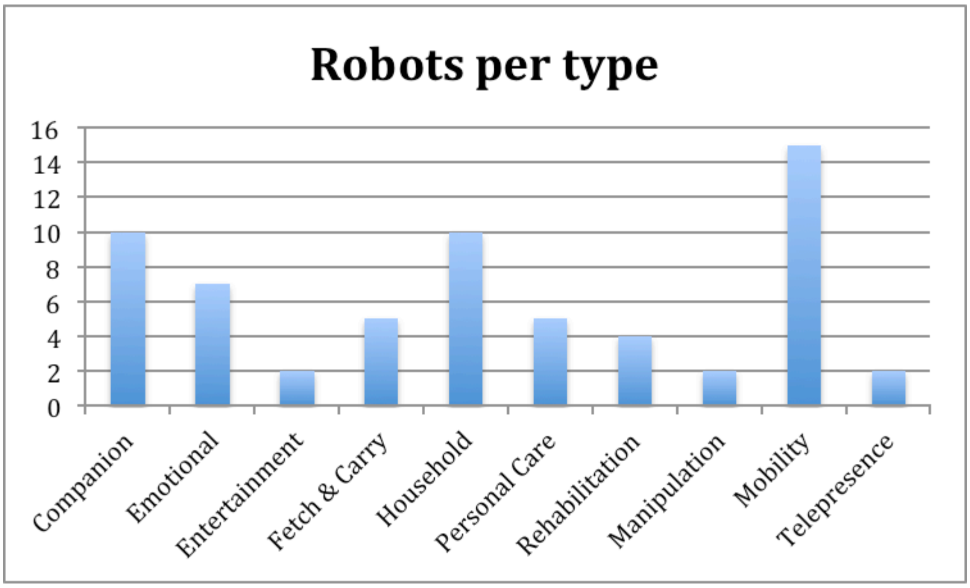


Fig. 3. Distribution of robot types in the database

2.2.2.2 Distribution by AAL relevance

The degree of "AAL-ness", i.e. relevance to and potential for AAL, was described in the database with the following attributes:

The device belongs to the group of **AAL Systems** if

a) The device assists during activities of daily living / working.
b) The device was specifically designed for older adults or seems to be usable by older adults
c) The device improves or maintains the independence of the target group.

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[6] http://www.irobot.com/For-Business/RP-VITA.aspx

The device belongs to the group of **robots** if
e) The device has sensors and actuators
f) The device is capable of sensor-based decisions
g) The device is capable of visible motions

The number of attributes that a robot collected determined its designation as an AAL robot. In the following diagram (Figure 4), the higher the score, the closer the robot is to the centre.

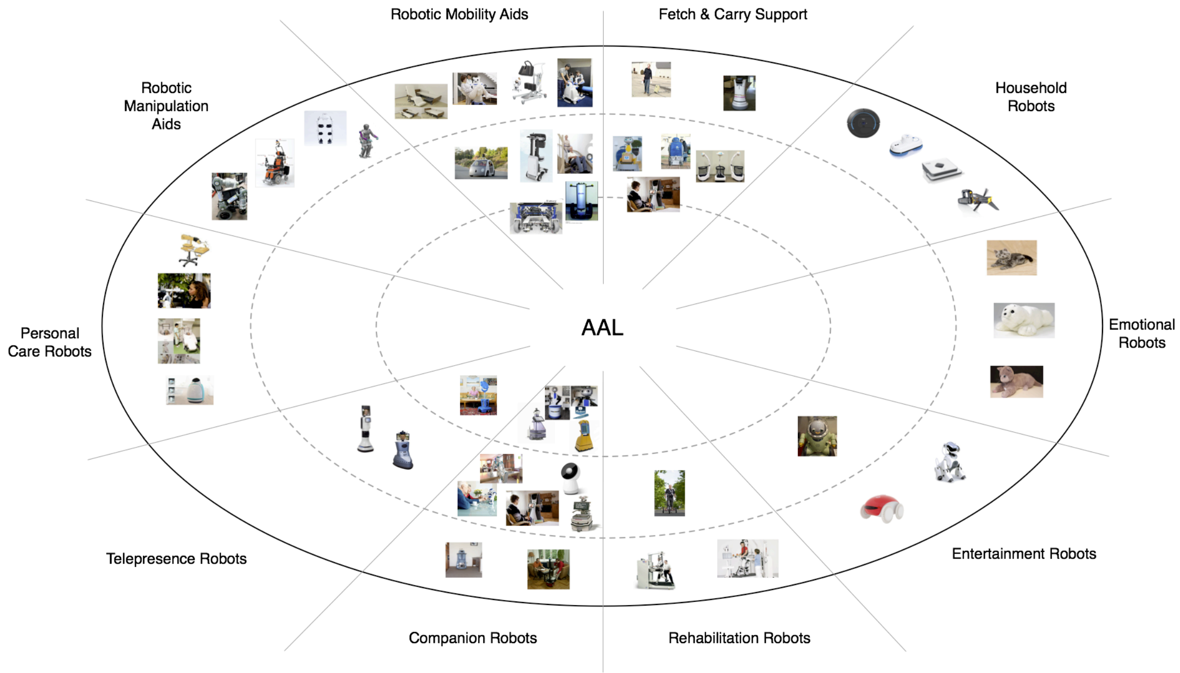

Fig. 4. Distribution of robot types in relation with their relevance for AAL (more central = more relevant)

2.2.2.3 Overview by TRL

For a discussion of our assignment of Technology Readiness Levels see chapter 4. The graphical overview shows clearly that we found more commercially available AAL-related robots than expected: over half of the robots in the database are already on the market or very close to it. This, however , does in no way represent the field: the bias can be simply explained with the fact that commercialized robots are almost by necessity present on the Internet, while R&D projects often don't use or don't have a name for their robot, and ongoing industrial R&D is not disclosed. Nevertheless, even the number of commercial AAL-related robots taken as an absolute number is higher than initially expected.

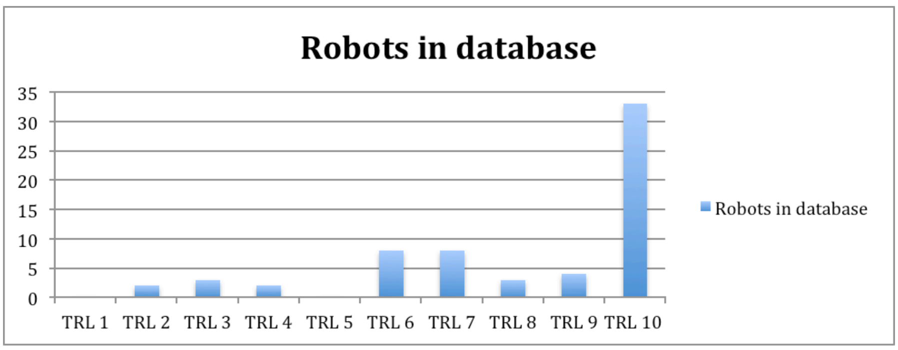

Fig. 5. Robots in the database by Technology Readiness Level (TRL)

2.3 Research and Development in AAL Robotics

2.3.1 Austria

Austrian key players within the field of AAL robotics were identified based on expert interviews, web search, contacting potential key players and analysis of project partners of research projects within the field. The short descriptions of the institutions partly were provided by the institutions themselves or are based on public information on the institutions web-pages.

The R&D activities in this research field in Austria are limited and mostly undertaken by research institutions or small research-focused private companies. Some end-user organizations have gained experience in the field by assisting in the design and evaluation of AAL robots with their staff and affiliated end-users.

The following Figure 6 gives an overview of identified key players by the three sectors research, industry and end-user expertise.

Fig. 6. Key-players of AAL robotics in Austria (research: upper left, industry: upper right, end-users: lower part)

2.3.1.1 Key-players Technology – Research[7]

<u>Technische Universität Wien, Centre for Applied Assistive Technologies (AAT)</u>[8]

AAT, the "Centre for Applied Assistive Technologies" is part of the Human Computer Interaction (HCI) Group of the Institute of Design & Assessment of Technology of the Vienna University of Technology. AAT is committed to user-driven research and stresses broad interaction with users during all phases of a project. The focus of AAT's activities is on applied research and development of innovative systems and services for disabled and/or old persons. The activities cover analyses of user needs, development of concepts and prototypes, evaluation of prototypes in laboratory and in real life settings.

Contribution to AAL Robotics:

The institute has a history of several international and nationally funded research projects targeting mostly the development of mobility aids and robotic companions

[7] for a description of the European research projects mentioned in this section, see section 2.3.2.2
8 http://www.aat.tuwien.ac.at/index_en.html

- Larah: The nationally funded project (Location-aware Assistant Robots At Home) aims at providing older persons with an assistive robot, to provide support and safety in their own homes.

- Personaal: Within this nationally funded project different options for personalities of robots and their influence on end-user acceptance are explored.

- Hobbit: In contrast to current approaches, “Hobbit, the mutual care robot”, is developed with the goal of practical and tangible benefits for the user with a price tag starting below 14.000 €.

- DOMEO: DOMEO was a research project in the area of “Ambient Assisted Living”, partly funded by the EU and by national funds. DOMEO aimed at the demonstration of the use of robots for providing support in the home of older people.

- KSERA: The main aim of the FP7 project KSERA was to develop a socially assistive robot that helps older people, especially those with Chronic Obstructive Pulmonary Disease (COPD), with their daily activities, care needs and self-management of their disease.

- MOVEMENT: MOVEMENT aimed at the development of a modular versatile mobility enhancement system. The core is an intelligent mobile (robotic) platform which can be attached to a user-definable selection of application modules (e.g. chair, manipulator, ICT Terminal).

Technische Universität Wien, Automation and Control Institute, Vision for Robotics Group (V4R)[9]

The Vision for Robotics group within the Automation and Control Institute of the Vienna University of Technology is focused on machine vision methods to perceive structures and objects that allow robots to act in and learn from everyday situations. The core expertise of the group within machine vision is on safe navigation, 2D and 3D attention, object modeling, object class detection, affordance-based grasping, and manipulation of objects in relation to object functions.

Contribution to AAL Robotics:

The group’s expertise is of particular relevance for the field of assistive robotics as visual analysis for complex unstructured environments is the current state-of-the-art in perception and a main research goal of AAL robotics. The following projects undertaken by this group are relevant:

- Squirrel: Clearing Clutter Bit by Bit (2014-2018)

- Strands: Spatio-Temporal Representations and Activities for Cognitive Control in Long-Term Scenarios (2013-2017)

- Hobbit: The Mutual Care Robot (2011-2014).

- MOVEMENT: Modular Versatile Mobility Enhancement Technology, a robotic wheelchair.

Raltec - researchgroup for assisted living technologies[10]

The non-profit “**r**esearch group for **a**ssisted **l**iving **tec**hnologies” – raltec conducts applied research and development on innovative ICT-based technologies and services in the areas of Ambient Assisted Living (AAL), eHealthcare and eHomecare for the target groups of older people and people with special needs.

Contribution to AAL Robotics:

Raltec’s goals within the field of robotics are “the design, development and evaluation of reliable, cost-effective assistive robotic solutions capable of enhancing the quality of life of older persons and their carers over the short- and long-term”. Raltec took part in the following national and international research projects with relevance for AAL robotics:

[9] http://www.acin.tuwien.ac.at/forschung/v4r/

[10] http://www.raltec.at/en/projects/assistive-robotics/

- PotenziAAL: The potenziAAL study undertook an analysis of robotics in the field of Ambient Assisted Living (AAL) with the aim of assessing the potential of robotic technologies for assisting older users and their carers. The present document is an outcome of this study.

- PhysicAAL: Evaluation of socially assistive robotics for physical training support in everyday life of older people.

- KSERA: Knowledgeable Service Robots for Ageing, an EU funded project (FP7) with the goal to develop a robot that supports COPD patients at home..

OFAI – Austrian Research Institute for Artificial Intelligence

For over 30 years, the OFAI has been involved in leading basic and applied research in several fields of Artificial Intelligence, including machine learning and data mining, music analysis and performance, natural language technologies, virtual agents and social robotics.

Contribution to AAL Robotics:

OFAI was among the pioneers in the research on personality and emotion models for social agents and robots. Current foci in AAL robotics-related research are cognitive abilities, character generation, and human-robot interaction with a special focus on gender and applications for older adults.

- Spatial Memory and Navigation Ability in a Physically Embodied Cognitive Architecture (FWF, ongoing)

- Inter- and Intra-speaker variability in multi-modal task descriptions and implications for human robot interaction (ÖAW, ongoing)

- CHARminG –Character Mining and Generation (FWF, ongoing): data mining of character models from dramatic dialogue and character-based dialogue generation

- PotenziAAL (FFG benefit, completed): The potenziAAL study undertook an analysis of robotics in the field of Ambient Assisted Living (AAL) with the aim of assessing the potential of robotic technologies for assisting older users and their carers. The present document is an outcome of this study.

- Robots' Ethical Systems: A Construction Manual (BMVIT, completed): theoretical bases, requirements, and architectures for ethical decision-making by robots.

- SERA: Social Engagement with Robots and Agents (FP7, completed). The project undertook one of the first long-term field studies with a simple robot in a fitness and activation scenario with older users.

- Virtual Biographer (BMVIT, completed): feasibility study on robots or virtual agents as listeners and recorders of lifestories and biographical narratives

- c4u – Companions for Users(m/f) (FFG Femtech, completed): study of gender-specific needs and interactivity with AAL robot companions

CURE[11] - center for usability research and engineering

CURE's mission according to the institute's website is to "develop innovative and usage oriented systems utilizing methodological and qualitative usability and usability engineering knowledge". Leading edge research activities as well as intensive industrial experience are brought in by the group to provide added value for users, producers and principals.

Contribution to AAL Robotics:

CURE's expertise in user-centered design and user involvement is a necessity in the development of state-of-the-art assistive robotic solutions. CURE took part in the following research projects relevant for AAL Robotics:

- CompanionAble: Integrated Cognitive Assistive & Domotic Companion Robotic Systems for Ability & Security (2008-2011)

[11] http://cure.at

AIT - Austrian Institute of Technology[12]

AIT is the biggest Austrian non-university research institution employing more than 850 people in various locations across Austria. The Health & Environment department studies biological systems that are relevant to human health and environmental systems as well as sustainable and considerate usage of resources with the goal of understanding and reducing the complexity involved.

Contribution to AAL Robotics:

Two departments of AIT (Health &Environment and Safety & Security) are and have been active in several research projects relevant for the field of AAL robotics:

- Larah: The nationally funded project (Location-aware Assistant Robots At Home) aims at providing older persons with an assistive robot, to provide support and safety in their own homes.
- I Walk Active (2012-2015): A robotic mobility aid based on a walking frame
- Companionable: Integrated Cognitive Assistive & Domotic Companion Robotic Systems for Ability & Security (2008-2011)
- Robots@Home: An open platform for home robotics (2007 – 2010)
- MOVEMENT (2004-2008)

Johannes Kepler Universität Linz, Institut für Robotik[13]

This "young" university (established 1966) hosts institutions for science, academics, business and the community. Over 19,000 students are enrolled in over 60 academic degree programmes. The institute for robotics at the JKU is active in a wide array of robotics research topics including mobile and industrial robots.

Contribution to AAL Robotics:

Regarding AAL robotics the institute was active in the development of prosthetics for a better walking performance in cooperation with Otto Bock Healthcare Products GmbH.

Universität Salzburg, Center for Human-Computer Interaction[14]

The Center for Human-Computer Interaction is a Research Group within the Department of Computer Sciences at Paris-Lodron Universität Salzburg. In particular, the Center investigates the interplay between humans and computers. Human-Computer Interaction (HCI) pays central attention to the analysis, design, evaluation and implementation of existing and future interactive (computer-)systems and interactive environments. Together with research and industry partners, the center aims to design and develop interactive systems, interactive services and future interaction approaches that foster engaging experiences by considering various factors. These factors of experience are understood as specific to the context in which they occur. Its main goal is to increase system usability and enhance the user experience while targeting a comprehensive understanding of the users' expectations, needs, and goals while taking into account societal and ethical aspects of technology.

Contribution to AAL Robotics:

The Center for Human-Computer Interaction has several years of experience in the areas of human-robot interaction (HRI) and ambient assistive living (AAL). In ongoing and past projects, researchers at the center worked on several research lines in assistive robotics. One of the current research topics is that of tele-operated medical robotics. In the ReMeDi project (Remote Medical Diagnostician), the center works together with partners from other European universities to design a tele-robotic medical device that enables doctors to examine patients over distance. One application of the technology developed in the project is the tele-operated medical care of elderly home-bound persons.

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[12] http://www.ait.ac.at

[13] http://www.robotik.jku.at/joomla16/

[14] http://uni-salzburg.at/index.php?id=38601&L=1

The HRI group at the Center for Human-Computer Interaction researched HRI with robots in public spaces within the IURO project (Interactive Urban Robot). The life-sized robot which was developed in the course of the project, is able to navigate through densely populated inner-city environments and to proactively engage in conversation with pedestrians. Numerous studies were carried out over the entire project duration, in order to evaluate and validate the robot and its social behaviourbehaviour.

University of Applied Sciences, Technikum Wien

With around 8,000 graduates and roughly 3,800 students, the University of Applied Sciences Technikum Wien is Austria's largest purely technical university of applied sciences.

The types of research range from student theses via bachelors' and masters' theses to contract research and funded projects.

Contribution to AAL Robotics:

The Department for Advanced Engineering Technologies carries out R&D projects on mobile platforms for industrial and service applications. A special focus of these projects is on service-oriented applications of mobile robots in a human environment. Furthermore, new methods of reliable 3D-sensing for autonomous systems are developed.

The Department of Embedded Systems (http://embsys.technikum-wien.at) serves as bridge between computer science and electronic engineering. Research and teaching activities focus on all practical aspects of embedded systems design and verification and cover domains like embedded control & navigation, ambient assistive technologies and assistive robotics with a focus on smart homes.

ACMit – Austrian Center for Medical Innovation and Technology[15]

ACMit is a translational research centre and combines multidisciplinary know-how with that of international experts in industry, clinics and academia. R&D aims at designing prototypes that are clinically tested and ready for commercialization. One of the R&D divisions is dedicated to "medical robots".

Contribution to AAL Robotics:

The company was active in the EU-FP7 funded project SRS (Multi-Role Shadow Robotic System for Independent Living).

University of Innsbruck - Intelligent and Interactive Systems[16]

Research at IIS is situated at the intersection of computer vision, machine learning and robotics. Much of the work undertaken is motivated by the perceptual needs of autonomous robots, and focuses on visual inference as it serves activities such as grasping. Other areas of expertise include the psychology and biology of perception, and video analysis for applications such as sports or human-computer interaction.

Contribution to AAL Robotics:

The institute has not conducted research on AAL robotics proper, but within relevant fields such as: machine learning, object recognition, grasping and manipulation of objects. The institute is currently active in the EU-FP7 research project "Squirrel" which aims to develop a robotic prototype to tidy up floors. This particular application scenario is also pursued by other research projects targeting older adults such as the EU-FP7 research project "Hobbit".

2.3.1.2 Key players Technology – Private sector

Some, in particular smaller and research-centred companies are already actively developing AAL robotic solutions.

It is worth mentioning that also several other robotic companies are active in Austria, but so far don't show any interest in stepping into the market of AAL robots. Among these companies are big international players such as ABB and KUKA as well as several smaller companies such as B&R Automation, Taurob, and Convergent Information Technologies.

[15] http://www.acmit.at/

[16] https://iis.uibk.ac.at

Blue Danube Robotics[17]

Blue Danube Robotics is a spin-off from the Vision for Robotics Group at the ACIN of the Technische Universität Wien. Current developments include a companion robot with the capability of physical support by means of a gripper ("Blue") and safety sensors protecting users from moving robotic parts.

Otto Bock[18]

Otto Bock is a large German company situated in Duderstadt with an office in Vienna, and employs around 3700 people worldwide. The company develops and markets a large number of products in the categories of prosthetics, orthotics, general mobility solutions such as wheelchairs and walking frames and neuro-rehabilitation solutions. Several products such as the "C-Leg" show characteristics of semi-autonomous robots.

Robart[19]

Robart is a start-up situated in Linz focusing on new, vision-based navigation methods for current service robots.

Profactor[20]

Profactor has a long record of R&D in industrial robotics. "The robot as co-worker and assistive colleague is the vision at PROFACTOR." As the idea of industrial "collaborative" robots overlaps with current research on companion robots, PROFACTOR is also active in research areas relevant for AAL robotics. The company participated in the EU-FP7 funded research-project SRS (Multi-Role Shadow Robotic System for Independent Living) but has not been active on further AAL relevant solutions since then, as the focus has shifted to industrial robotics.

Hella automation GmbH[21]

Hella automation GmbH is active in the development of smart home appliances, and has recently partnered with the Technische Universität Wien in the project "Hobbit – a mutual care robot".

2.3.1.3 Key players with experience in user aspects

End-user organizations are commonly included in research on AAL robotics as the knowledge about the needs, requirements and acceptance of robotics of primary and secondary user groups is necessary for design, development and evaluation of robotic solutions that target to assist non-expert users. The following institutions have been involved in one or more research projects and thereby gained expertise in the special requirements of primary users regarding robotic solutions that support them.

Seniorenzentrum Schwechat

The Seniorenzentrum Schwechat cooperated with the Technische Universität Wien and the research group for assistive technologies (raltec) and was active in the EU-FP7 project KSERA (2010-2013), and the nationally funded projects "PhysicAAL" (2013) and "PotenziAAL" (Q3/2014-Q2/2015).

Diakonie Erdberg

The Diakonie Erdberg in Vienna cooperated with the Technische Universität Wien within the EU-FP7 project Hobbit and hosted trials with older users.

Akademie für Altersforschung am Haus der Begegnung

The Akademie für Altersforschung am Haus der Begegnung cooperated with the Technische Universität Wien within the EU-FP7 projects "Hobbit" and "Strands".

Pflegewohnhaus Simmering

The Pflegewohnhaus Simmering gained experience with the robot "Paro" for older adults with dementia within a try-out period on their own initiative.

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[17] http://bluedanuberobotics.com/index.php/en/

[18] http://www.ottobock.at

[19] http://www.robart.cc/de/

[20] http://www.profactor.at

[21] http://www.hella.info/ga/service.html

2.3.1.4 Professional Organizations

GMAR - Gesellschaft für Mess-, Automatisierungs- und Robotertechnik[22]

GMAR was founded on January 12, 2015. The officiel kick-off event took place in June 2015. GMAR is one of the associations federated in OVE (Österr. Verband für Electrotechnik). Vice-President of the Robotics Branch is currently Prof. Markus Vincze, TU Vienna, who is himself involved in AAL Robotics in his research work.

ARP – Austrian Robotics Platform [23]

Also under the OVE umbrella, and as a sector also of OCG, the Austrian Robotics Platform was founded in 2014.

2.3.2 Robotics in the EU

This chapter gives an overview of robotics networks and organizations and current and completed research projects within the area of assistive robotics. A list of research institutions and companies working on robotics in general in Europe can be found at http://www.eu-robotics.net/membership/list-of-members/

2.3.2.1 Networks and Organizations

EuRobotics aisbl [24]

euRobotics aisbl (= Association Internationale Sans But Lucratif = International non-profit association) is a Brussels based international non-profit association for all stakeholders in European robotics. euRobotics builds upon the success of the European Robotics Technology Platform (EUROP) and the academic network of EURON, and will continue the cooperation between members of these two community driven organisations. The aim is the establishment of only one sustainable organisation for the European robotics community as a whole. One of the association's main missions is to collaborate with the European Commission (EC) to develop and implement a strategy and a roadmap for research, technological development and innovation in robotics. Towards this end, euRobotics AISBL was formed to engage from the private side in a contractual Public-Private Partnership with the European Union as the public side. In the euRobotics aisbl "Topic Groups" is a community-driven instrument to coordinate the activities in specific sub - domains of robotics . The objective of a Topic Group is to support the launch of tangible project proposals by members of the European robotics community (be they member of euRobotics AISBL or not), and to prepare the roadmap and project Calls that precede such proposals.

SPARC [25]

SPARC is a contractual Partnership of the European Commission and the European Robotics Community. euRobotics AISBL was founded in September, 2012, to provide the European Robotics Community a legal entity to engage in a contract with the European Commission.

The European Robotics Public Private Partnership (PPP) is the teaming up of the robotics industry, research, academia and the European Commission to launch a joint research, development and innovation programme in order to strengthen the position of European robotics as a whole. The programme will be jointly developed by the private side (robotics manufacturers, component manufacturers, systems integrators, end users, research institutes, universities) and the public side (the European Commission).

Thus, the main objective of the Robotics PPP is to boost current European robotics research, development and innovation. It also aims to assure competitiveness and industrial leadership of European manufacturers, providers and users of systems and services based on robotic technology, as well as fostering the excellence of its science base.

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22 http://www.gmar.at/
23 http://www.austrian-robotics.at/
24 www.eu-robotics.net/
25 http://www.sparc-robotics.net/about/

EUnited [26]

EUnited, the European Engineering Industries Association, is a direct company membership association supporting the global competitiveness of European equipment suppliers. EUnited Robotics is the only robotics association specifically organised to serve the robotics industry in Europe. Members are robot manufacturers, component suppliers, and system integrators creating a network of industry leaders. EUnited Robotics is the main contact between the European Commission and the European robotics industry.

echord++ - European Clearing House for Open Robotics Development Plus Plus[27]

echord++ is a single FP7 project, but its goals make it relevant to the whole robotics community, in particular open calls for "Experiments" and "Public end-user Driven Technological Innovation (PDTI)", with a currently open call in healthcare, aiming at a Comprehensive Geriatric Assessment (CGA) system.

SILVER - Supporting Independent Living for the Elderly through Robotics[28]

The EU-funded SILVER project (Supporting Independent LiVing for the Elderly through Robotics) searches for new, innovative ways to acquire public sector health services by utilizing a Pre-Commercial Procurement (PCP) process designed for optimally matching R&D with procurers' needs. The goal is to find new technologies to assist elderly people's ability to continue living independently at home. SILVER is a development project funded by the European Commission under the Seventh Framework Programme for research and technological development (FP7). The new technologies and solutions are sought by using a Pre-Commercial Procurement (PCP) process. In Europe, the PCP has so far been an under-utilized tool for promoting innovation. One of the aims of the project is to demonstrate the effectiveness of this approach to address societal and governmental needs. The PCP process is executed in three phases. The first phase is a feasibility study of the selected technologies and proposals. The most promising ideas will be developed into well-defined prototypes in phase two. The third phase aims to verify and compare the first real end products or services in real-life situations. The Phase 2 prototypes were presented to and tested by the consortium in April 2015. External experts together with the SILVER consortium procurers will assess the phase 3 applications and decide who the winning contractors will be in August 2015.

IFR – International Federation of Robotics[29]

The International Federation of Robotics (IFR) is a professional non-profit organization established in 1987 to promote, strengthen and protect the robotics industry worldwide. The IFR is also coordinator of the International Symposium on Robotics (ISR), one of the oldest conferences for robotics research, founded in 1970. The IFR's statistical department publishes the study *World Robotics* every year. This publication contains detailed statistical data for some 50 countries, broken down by application areas, industrial branches, types of robots and by other technical and economic variables.

In 2002, a Service Robotics Group was founded under the auspices of the International Federation of Robotics (IFR). The IFR has recognized, through its national affiliates, the growing commercial activities associated with service robots. At the same time, it has been found that there is little current support for the mostly small and young companies working or entering this area to assist them in market assessment and in raising their profile in the eyes of other industries, the media, and/or government bodies. In response to these facts, IFR operates the Group to further the interests of this emerging industry. The IFR Service Robotics Group is open to all interested service robot companies offering service robot products, components or related services. Regular meetings of the group are held on the occasion of the annual International Robotics Conference (ISR). Martin Hägele, Fraunhofer IPA, Germany, is the Chairman of the IFR Service Robot Group.

2.3.2.2 European Research Projects

Research projects were identified based on an analysis of the projects funded by the European Commission within the Framework and the Horizon2020 Programmes, which are listed in the

26 http://www.eu-nited.net/robotics/
27 http://www.echord.eu/
28 http://www.silverpcp.eu/
29 http://www. ifr.org

CORDIS[30] database. In addition, projects funded by another relevant research funding initiative, the "Ambient Assisted Living Joint Programme" (AAL-JP) are listed on the AAL-JP website[31]. The Cordis database was searched for the terms "robot elderly", "robot senior", and "robot older" and results were selected based on an analysis of the projects abstract on their relevance for the field of AAL robotics.

The AAL-JP website currently hosts the abstracts of 249 AAL projects which were manually searched for projects with the aim to develop or evaluate a robotic solution.

Web searches and searches on "Google Scholar" were undertaken to identify European projects funded by other funding schemes.

Additionally 5 AAL experts were asked within a focus group for further information on relevant projects.

Together 48 European funded research projects could be identified to be of relevance for the field, 40 were funded in either FP 6 or 7 or the Horizon2020 Programme, seven were funded in the AAL-JP, one was funded by the "Interreg"[32] programme.

Companion Robots

These projects research and develop multi-purpose robotic assistants for use at home.

- **RADIO** (Robots in assisted living environments: Unobtrusive, efficient, reliable and modular solutions for independent ageing)
  2015 - 2018 (3 years), H2020, http://cordis.europa.eu/project/rcn/194112_en.html
  RADIO develops "an integrated smart home/ assistant robot system, with the objective of pursuing a novel approach to acceptance and unobtrusiveness: a system where sensing equipment is not discrete but an obvious and accepted part of the user's daily life."

- **ENRICHME** (Enabling Robot and assisted living environment for Independent Care and Health Monitoring of the Elderly)
  2015 - 2018 (3 years), H2020, http://cordis.europa.eu/project/rcn/194090_en.html
  ENRICHME tackles the progressive decline of cognitive capacity in the ageing population proposing an integrated platform for Ambient Assisted Living (AAL) with a mobile service robot for long-term human monitoring and interaction, which helps the elderly to remain independent and active for longer.

- **MARIO** (Managing active and healthy aging with use of caring service robots)
  2015 - 2018 (3 years), H2020, http://cordis.europa.eu/project/rcn/194106_en.html
  MARIO addresses the difficult challenges of loneliness, isolation and dementia in older persons through innovative and multi-faceted inventions delivered by service robots.

- **GrowMeUp**
  2015 - 2018 (3 years), H2020, http://www.growmeup.eu
  GrowMeUp provides an affordable service robotic system able to learn the older persons needs and habits over time and enhance its functionality to compensate for the elder's degradation of abilities, to support, encourage and engage the older persons to stay longer active, independent and socially involved, in carrying out their daily life at home.

- **Teresa** (Telepresence Reinforcement-learning Social Agent), 2013 - 2016 (3 years), FP7, http://cordis.europa.eu/project/rcn/110722_en.html

- **VictoryaHome**
  2013 - 2016 (2 years), AAL-JP5, http://www.aal-europe.eu/projects/victoryahome/

- **MOnarCH** (Multi-Robot Cognitive Systems Operating in Hospitals)
  2013 - 2016 (2 years), FP7, http://cordis.europa.eu/project/rcn/107157_en.html

[30] http://cordis.europa.eu
[31] http://www.aal-europe.eu
[32] http://www.interreg4c.eu

- **SocialRobot** (SocialRobot)
  2011 - 2015 (4 years), FP7, http://cordis.europa.eu/project/rcn/101157_en.html

- **Hobbit** (HOBBIT - The Mutual Care Robot)
  2011 - 2015 (3 years), FP7, http://cordis.europa.eu/project/rcn/101982_en.html
  HOBBIT zooms in on the interaction between robot and owner/user with a new, more user-centred concept called "Mutual Care".
  Austrian participation: Technical Universtiy of Vienna (ACIN), Hella Automation Gmbh, Akademie für Altersforschung am Haus der Barmherzigkeit

- **Turntake** (Turn-Taking in Human-Robot Interactions: a Developmental Robotics Approach)
  2012 - 2014 (1 years), FP7, http://cordis.europa.eu/project/rcn/103670_en.html

- **Accompany** (Acceptable robotiCs COMPanions for AgeiNg Years)
  2011 - 2014 (3 years), FP7, http://cordis.europa.eu/project/rcn/100743_en.html

- **Mobiserv** (An Integrated Intelligent Home Environment For The Provision Of Health, Nutrition And Mobility Services To The Elderly)
  2009 - 2013 (3 years), FP7, http://cordis.europa.eu/project/rcn/93537_en.html

- **ALIAS**
  2010 - 2013 (3 years), AAL-JP2, http://www.aal-europe.eu/projects/alias/

- **SRS** (Multi-Role Shadow Robotic System for Independent Living)
  2010 - 2013 (3 years), FP7, http://cordis.europa.eu/project/rcn/93710_en.html
  The project focused on the development and prototyping of remotely-controlled, semi-autonomous robotic solutions in domestic environments to support elderly people. In particular, the SRS project demonstrated a system called "shadow robot" for personalized home care.
  Austrian participation: Profactor, Integrated microsystems Austria

- **KSERA** (Knowledgable SErvice Robots for Aging)
  2010 - 2013 (3 years), FP7, http://cordis.europa.eu/project/rcn/93796_en.html
  KSERA provides (1) a mobile assistant to follow and monitor the health and behaviourbehaviour of a senior, (2) useful communication (video, internet) services including needed alerts to caregivers and emergency personnel, and (3) a robot integrated with smart household technology to monitor the environment and advise the senior or caregivers of anomalous or dangerous situations.
  Austrian participation: CEIT Raltec (now: raltec), Technical University of Vienna (AAT)

- **Florence** (Multi Purpose Mobile Robot for Ambient Assisted Living)
  2010 - 2013 (3 years), FP7, http://cordis.europa.eu/project/rcn/93917_en.html

- **ROBO M.D.** (Home care robot for monitoring and detection of critical situations)
  2013, Interreg, http://www.innovation4welfare.eu/307/subprojects/robo-m-d.html

- **DOMEO**
  2009 - 2012 (3 years), AAL-JP1, http://www.aal-europe.eu/projects/domeo/
  DOMEO focuses on the development of an open robotic platform for the integration and adaptation of personalized homecare services, as well as cognitive and physical assistance.
  Austrian participation: Technical University of Vienna (AAT – former IS)

- **Companionable** (Integrated Cognitive Assistive and Domotic Companion Robotic Systems for Ability and Security)
  2008 - 2012 (4 years), FP7, http://cordis.europa.eu/project/rcn/85553_en.html
  CompanionAble addressed the issues of social inclusion and homecare of persons suffering from chronic cognitive disabilities prevalent among the elderly, a rapidly increasing population group.
  Austrian participation: AIT, Cure, AKG Acoustics

- **SERA** (Social Engagement with Robots and Agents), 2009 - 2010 (1 year), FP7, http://cordis.europa.eu/project/rcn/89259_en.html
  Austrian participation: OSGK (OFAI)

- **Robots@Home** (An open platform for home robotics), 2007 - 2010 (3 years), FP6, http://cordis.europa.eu/project/rcn/80548_en.html
  The objective of robots@home were to provide an open mobile platform for the massive introduction of robots into the homes of everyone.
  Austrian participation: Technical University of Vienna, AIT

Robotic Mobility Aids

These robotics research projects undertake R&D targeting applications that support the mobility of older users.

- **ACANTO** (A cyber-physical social network using robot friends)
  2015 - 2018 (3 years), H2020, http://cordis.europa.eu/project/rcn/194087_en.html
  Despite its recognized benefits, most older adults do not engage in a regular physical activity. The ACANTO project proposes a friendly robot walker (the FriWalk) that will abate some of the most important barriers to this healthy behaviour.
  Austrian participation: Siemens AG (CT)

- **Wander**
  2013 - 2017 (4 years), FP7, http://cordis.europa.eu/project/rcn/110041_en.html
  WANDER, investigates (1) the role of the upper body for balance and locomotion, to develop novel robotic interventions, (2) how robotic devices should optimally adapt to and co-adapt with the user, in a process of mutual adaptation, (3) optimization of training outcome in neurorehabilitation, provide assistance and balance training as part of a patient's daily life, blurring the border between "assistive" and "therapeutic" technology.

- **Axo-SUIT**
  2014 - 2017 (03 years), AAL-JP6, http://www.aal-europe.eu/projects/axo-suit/
  The AXO-SUIT is developed to comprehensively supplement the strength of elderly persons with

- **Europa2** (European Robotic Pedestrian Assistant 2.0)
  2013 - 2016 (3 years), FP7, http://cordis.europa.eu/project/rcn/110159_en.html

- **ALMA**
  2013 - 2016 (3 years), AAL-JP5, http://www.aal-europe.eu/projects/alma/

- **Mobot** (Intelligent Active MObility Aid RoBOT integrating Multimodal Communication)
  2013 - 2016 (2 years), FP7, http://cordis.europa.eu/project/rcn/106993_en.html

- **I Walk Active**
  2012 - 2015 (2 years), AAL-JP4, http://www.aal-europe.eu/projects/iwalkactive-2/
  In iWalkActive the user will be provided with an active, desirable walker providing cloud services and a drive based on brushless DC-motors.
  Austrian participation: AIT, ITH icoserve

- **Dali** (Devices for Assisted Living)
  2011 - 2014 (3 years), FP7, http://cordis.europa.eu/project/rcn/101220_en.html
  DALI developed the "c-Walker" to help older people to maintain their out-of-home mobility. It supports navigation in crowded and unstructured spaces. It collects sensory information, anticipates the intent of people and selects the path that minimizes the risk of accidents.
  Austrian participation: Siemens CT

- **Evryon** (EVolving morphologies for human-Robot sYmbiotic interactiON)
  2009 - 2012 (3 years), FP7, http://cordis.europa.eu/project/rcn/89034_en.html

- **Europa** (European Robotic Pedestrian Assistant)
  2009 - 2012 (3 years), FP7, http://cordis.europa.eu/project/rcn/89520_en.html

- **MOVEMENT**, 2004 - 2008 (3 years), FP6,
  http://cordis.europa.eu/project/rcn/71858_en.html
  MOVEMENT aimed at the development of a modular versatile mobility enhancement system. The core is formed by an intelligent mobile (robotic) platform, which can attach to a user definable selection of application modules (e.g. chair, manipulator, ICT Terminal).
  Austrian participation: Technical University of Vienna (ACIN, AAT, AIT), ARC, Otto Bock

Fetch & Carry Robots

The following list of research projects target robots that support older users by bringing, picking up or carrying objects.

- **Squirrel** (Clearing Clutter Bit by Bit)
  2014 - 2018 (4 years), FP7, http://www.squirrel-project.eu
  Clutter in an open world is a challenge for many aspects of robotic systems, especially for autonomous robots deployed in unstructured domestic settings, affecting navigation, manipulation, vision, human robot interaction and planning.
  Austrian participation: Technical University of Vienna (ACIN), Verein Pädagogische Initiative 2-10

- **RAMCIP** (Robotic Assistant for MCI patients at home)
  2015 - 2018 (3 years), H2020, http://cordis.europa.eu/project/rcn/194064_en.html
  RAMCIP researches and develops a novel domestic service robot, with the aim to proactively and discreetly assist older persons, MCI and AD patients in their every day life. Instead of simply being an obedient servant, the RAMCIP robot will have high-level cognitive functions, driven through advanced human activity and home environment modelling and monitoring, enabling it to optimally decide when and how to assist.

- **Robot-Era** (Implementation and integration of advanced Robotic systems and intelligent Environments in real scenarios for the ageing population)
  2012 - 2015 (4 years), FP7, http://cordis.europa.eu/project/rcn/102051_en.html

Telepresence Robots

The following projects target the R&D on robotic telepresence systems for older users.

- **Giraff+** (Combing social interaction and long term monitoring for promoting independent living)
  2012 - 2014 (3 years), FP7, http://cordis.europa.eu/project/rcn/101840_en.html

- **EXCITE**
  2010 - 2012 (2 years), AAL-JP2, http://www.aal-europe.eu/projects/excite/

Rehabilitation Robots

The following projects target R&D for robotics that support the physical rehabilitation.

- **ReTRAINER** (Reaching and Grasping Training based on robotic hybrid assistance for neurological patients: End users Real Life Evaluation)
  2015 - 2018 (4 years), H2020, http://www.retrainer.eu
  Austrian participation: Otto Bock, Technical University of Vienna

- **SCRIPT** (Supervised care & rehabilitation involving personal tele-robotics)
  2011 - 2014 (3 years), FP7, http://cordis.europa.eu/project/rcn/100772_en.html

Personal Care Robots

The following research projects aim to research and development on robotics for personal care.

- **I-SUPPORT** (ICT-Supported Bath Robots)
  2015 - 2018 (3 years), H2020, http://cordis.europa.eu/project/rcn/194089_en.html
  The I-SUPPORT project envisions the development and integration of an innovative, modular, ICT-supported service robotics system that supports and enhances older adults' motion and force abilities and assists them in successfully, safely and independently completing the entire sequence of bathing tasks, such as properly washing their back, their

upper parts, their lower limbs, their buttocks and groin, and to effectively use the towel for drying purposes.

Robotic Manipulation Aids

The following research projects focus on R&D for robotic manipulation aids.

- **eNHANCE** (Intention based enhancement of reaching and grasping in physically disabled people - personalized to maximize user performance)
  2015 - 2019 (4 years), H2020, http://cordis.europa.eu/project/rcn/194129_en.html.
  The eNHANCE project key objective is to symbiotically mechanically support and motivate people with motor impairments resulting from muscular or neural degeneration (e.g. stroke) to perform complex daily life tasks.

Basic research & supporting actions

These research projects either focus on basic research that supports several different application areas, or are umbrella projects that target different application areas.

- **HumRobCooperation** (Understanding human cooperation with humanoid robots: analysis from a social psychological perspective)
  2014 - 2017 (3 years), FP7, http://cordis.europa.eu/project/rcn/185831_en.html
  The aim of this project is to understand better people's social interaction with humanoid robots to predict humans' willingness to cooperate with them.

- **RAPP** (RAPP - Robotic Applications for Delivering Smart User Empowering Applications),
  2013 - 2016 (3 years), FP7, http://cordis.europa.eu/project/rcn/111123_en.html

- **ECHORD++** (European Clearing House for Open Robotics Development Plus Plus)
  2013 - 2018 (5 years), FP7, http://www.echord.eu
  ECHORD++ is a cluster project that includes smaller sub-projects that are of relevance for the field of AAL robotics

- **Silver** (Supporting Independent LiVing for the Elderly through Robotics)
  2012 - 2016 (4 years), FP7, http://cordis.europa.eu/project/rcn/102144_en.html

- **ECHORD** (European Clearing House for Open Robotics Development)
  2009 - 2012 (4 years), FP7, http://www.echord.info
  A cluster project that includes smaller sub-projects that are of relevance for the field of AAL robotics such as the "Astromobile" project
  Austrian participation: "Simon Listens" took part in Astromobile

- **Strands** (Spatio-Temporal Representations and Activities For Cognitive Control in Long-Term Scenarios)
  2013 - 2017 (4 years), FP7, http://cordis.europa.eu/project/rcn/107156_en.html
  STRANDS aims to enable a robot to achieve robust and intelligent behaviour in human environments through exploitation of long-term experience.
  Austrian participation: Technical University of Vienna (ACIN), Akademie für Altersforschung am HDB

Summary

Figure 7 indicates the number of annual projects on European level together with the annual funding by the European commission and the project partners.Since 2008 the number of active projects has risen strongly showing a growing research interest in the field of AAL robotics and funding opportunities. The total annual investment in the field by the European Commission and project partners shows the same trend. The decline in 2014 was caused by the one-year funding gap between FP7 and Horizon2020. The numbers for 2015 are preliminary as only projects starting upt to the end of Q2/2015 could be considered.

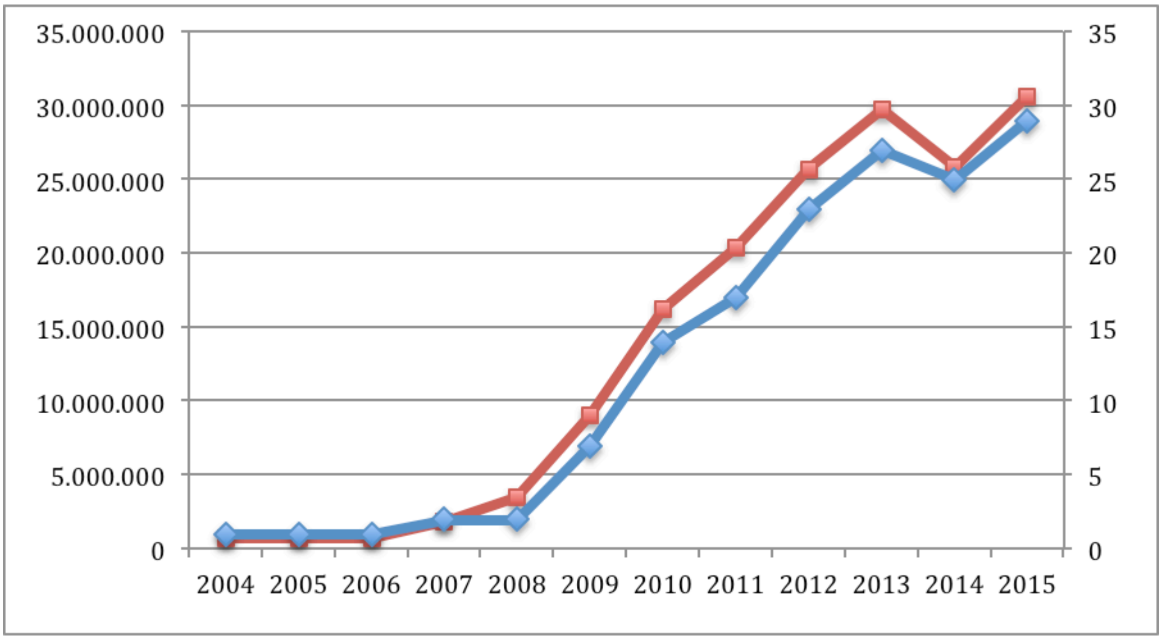

Fig. 7. Investment per annum (€) into AAL robotics research projects (red - left) and the number of ongoing research projects in the field per year (blue - right)

An analysis of the aims of the research projects shows that the development of robots that assist users at home, mainly by interaction and social support (companions) accounts for nearly half of the projects. The development of robotic mobility aids is the target for about a quarter of the projects. All other application scenarios combined account for less then a quarter.

No projects could be found that target R&D of emotional, household or entertainment robots. These domains are also most developed reaching the highest number of commercial products, leaving less space for further research. Additionally, all these applications can be integrated into companion robots. Figure 8 gives an overview of the robot categories targeted by current research projects.

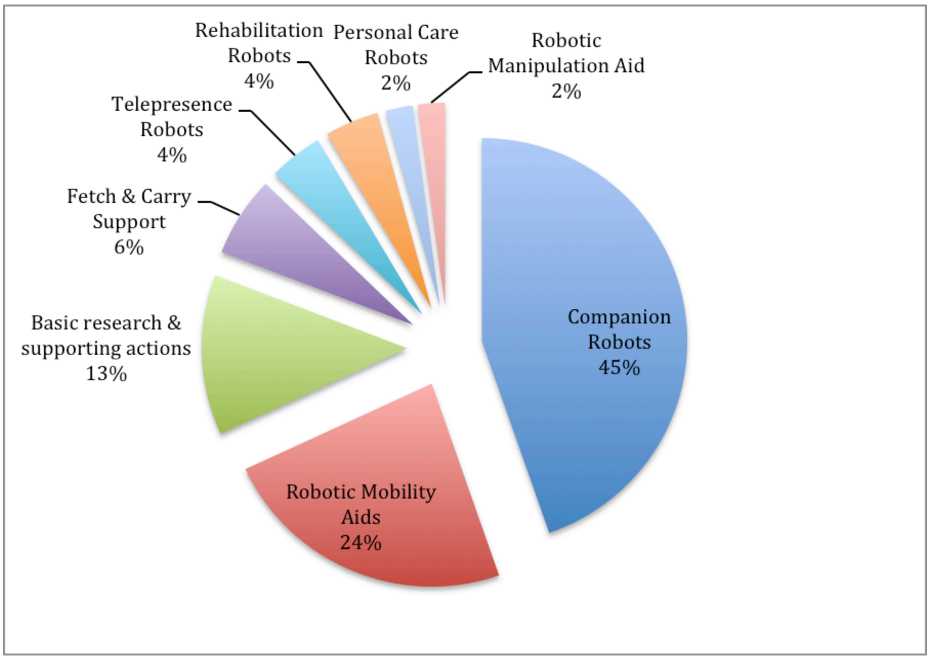

Fig. 8. Analysis of AAL robot research by robot categories

2.4 Summary

In this chapter a first definition, naming and categorization of systems within the newly described field of AAL robotics was undertaken. Ten key application areas could be identified, described and structured based on an analysis of current research prototypes and products and by means of an adapted concept of radial categories. This structured overview helps future researchers, but also all other stakeholders to quickly perceive the current state of the art in the field and the diversity of possible applications for AAL robotics and to identify blind spots in current R&D.

The European research scene was described based on an analysis of research projects from the beginning of the research interest in assistive robotics until the most currently started projects from the EU Horizon2020 programme. It could be shown that this sector is quickly growing and currently attracts European funding of around 30 million € per year for 30 active projects.

By analysing research prototypes and projects it could be shown that research is focused on questions concerning companion robots for usage at the home of older users. It appears that much research on this type of robots seems to run in parallel, as several research projects develop similar solutions and undertake comparable studies (e.g. regarding user needs, acceptance of robots) simultaneously.

AAL robotics in Austria is a small scene consisting mostly of research institutes and some smaller private companies. Austrian participation in EU projects is rather low and mostly undertaken by very few players (TUW, AIT)

Key results:

An AAL robot is a robot that

1. **assists the target group of older users including users with disabilities.**
2. **supports the target group during daily life or work.**
3. **improves or maintains the independent living of the target group.**

The ten main application areas of AAL robots are:

- **mobility support**
- **manipulation support**
- **personal care**
- **household tasks**
- **social assistance (companions)**
- **telepresence**
- **entertainment**
- **emotional support**
- **fetch & carry support**
- **rehabilitation**

European research funding has increased significantly since 2008, reaching 30 million € annually in 2015, for 30 projects. Nearly half of the projects (45 %) focus on companion robots, and some parallelism of aims and methods could be detected.

AAL robotics in Austria is a small scene consisting mainly of research institutions and some smaller private companies. Likewise, Austrian participation in relevant EU projects is comparatively low and relies on few players (TUW, AIT).

3 User needs

The analysis of user needs was undertaken by means of a literature survey on defined research questions which was augmented and verified with two focus groups, one with seven experts from care and one with five primary users. The detailed methods vary between the sub-chapters and are given at the beginning of each.

3.1 Primary user group

According to the definition of Active Assisted Living, primary users are “older users including users with disabilities”. The term “older users” is not defined clearly but user studies typically use inclusion criteria based on the chronological age of users such as 65 years and above. Differences between individuals increase with age and socio-economic differences persist in old age. The chronological age hence does not discriminate the target group well, nor does it reflect what people have in their mind when talking about “older users”.

Peter Leslett [Leslett1991] defined age differently, based on commonalities within age groups rather than the chronological age. He defined four phases of life; the *first age*, which is youth, is described by immaturity, dependence and education. The *second age,* which begins with entering working life, is characterized by personal freedom, responsibility, income and saving. The *third age* that begins when dropping out of professional life, is characterized by higher personal freedom, the chance to do “one’s own thing” and the reduction of professional and familial obligations. The *fourth age* is characterized by increased functional deficits and dependence on care.

Given Leslett’s definitions, active assisted living tries to target primary users in their third age with the goal to shift their transition into the fourth age to a point later in time by means of technological support.

As AAL aims in particular to delay the institutionalization, the special needs of primary users in the following chapter are derived from the reasons that lead to the admission of older people to care institutions.

3.1.1 Demographics

For this chapter, literature was scanned for reports about statistics on Austrian Demographics including gender, health, financial and socio-economic factors. According to the “Seniorenbericht – Gesundheit und Krankheit der älteren Generation in Österreich” [Winkler2012], a meta-study on health-related studies of Austrian seniors, contracted by the ministry for health in 2012, the number of older people in Austria (64+) is going to increase from 18 % in 2012 to 24 % of the whole population in 2030. Geographically, the same report states an east-west decline regarding mortality, disease and risk factors, in particular for males.

3.1.1.1 Gender & Health

Gender differences show that women are statistically healthier, have lower hospitalization rates and lower mortality. Because of their higher life expectancy of 83 years in 2010 compared to 78 years for men, in absolute numbers women represent the main group affected by age-related diseases. Women have more years of chronic diseases and functional limitations, their subjective feeling of health is lower, they have higher rates of mobility-relevant impairments, higher rates of accidents such as falls and higher rates of psychiatric diseases [Winkler2012].

Women in their fourth age mostly live alone, which puts them at a high risk of poverty, and – as the partner as a potential carer is missing – they are considerably more often in need of professional care [Winkler2012].

It is estimated that the current difference in gender distribution will decline to 55% of women in 2030 and 63% of women over 74. As gender dependent differences show a trend to decline over the decades, it is expected that the current low number of men in older age groups will rise in the future [Winkler2012].

3.1.1.2 Socio-economic factors

[Winkler2012] present data on the education and average income of older people. Education in Austria in this age group (65+) is below average, 55% of women and 27% of men have only basic education ("Pflichtschulabschluss").

The average pension (which does not cover the whole income) of people over 65 is reported to be around 1000 € per month in 2007. In December 2007 around 11% of older people who received pension also received allowances from "Ausgleichszulage", which is only granted in case the income is below a certain threshold indicating poor income. Again gender is relevant here, 69% of that group being women. Older women living in one-person households are reported to have the second highest risk of poverty (26%) after single parents.

[Aue2006] estimates the average yearly purchasing power of older people (65+) in Germany to be 19.691 €, which is lower than younger groups (40-49: 24.880€, 30-39: 22.881 €). The same source also reasons that the average purchasing power of people above 50 (21.244 €) is about 2000 € higher than for people below 50 although most products and market strategies target the latter group.

[Aue2006] reports the average monthly expenses of the age group 65-70 in Germany as the fourth highest with 2.108 € as compared to other age groups (45-55y: 2.494 €, 55-65y: 2.357 €, 35-45y: 2.290 €, 70-80y: 1.680 €, above 80y: 1.431 €)

[RegioData2011] also estimates the group of older people 50+ in Austria as the one with the highest purchasing power of 68 billion €, which represent 44% of the total purchasing power, although the group only accounts for 36% of the population. Summarising findings on income, it can be stated that the purchasing power and monthly expenses rise with age, culminate in the age group around 50-60 and then decline again.

Regarding the users' needs in AAL robotics, we can distinguish roughly solutions for primary users in their third age, who generally have a very high income and savings, are mostly healthy and active and are approximately equally distributed between genders, from solutions for users in their fourth age, who have a much poorer financial situation, are increasingly dependent on their relatives or care professionals because of health deficiencies and are predominantly female.

3.1.2 Needs of primary users

As one of the main aims of Active Assisted Living is *the prolongation of independent living at the own home*, the reasons that lead to an institutionalization of the main target group into care facilities are of importance to understand their needs and potential requirements of assistive solutions. Hence this chapter focuses on primary users at the transition between the third and fourth age. The reason for this focus is also related to an economic viewpoint, according to which the savings in care costs by reducing days spent in institutional care facilities could contribute to the cost-efficiency of AAL robotic solutions.

A literature survey was conducted to gain insight on the research question "Which are the most common age dependent reasons for older users to move into care residences?" and combined with qualitative data from interviews undertaken with eleven older users, three informal carers and two care professionals [Werner2008].

The reasons vary between users and depend on whether studies gathered data from subjects themselves or from secondary users. The following summary presents an ordered list of reasons given subjectively by primary users and was compiled by combining data from literature and interviews.

1. Health deficiencies
2. Social factors
3. Insufficient environment
4. Additional benefits of professional care
5. Financial reasons

3.1.2.1 Health deficiencies

In most reviewed literature health deficiencies are mentioned as the number one reason for institutionalization [Thiele2002][Hofwimmer2010][Werner2008][Pochobradsky2008]. Pochobradsky mentions dementia as the most prominent reason for institutionalization within health deficiencies. Thiele lists problems with walking (71 %), feeling of dizziness (53 %), heart problems (51 %) and dementia (43 %) as reasons. Further reasons are acute accidents such as femur neck fracture (12 % of cases) and issues with lifting and carrying objects [Werner2008].

Dementia is given as main reason not only because of its high incidence but also due to the fact that in case of severe dementia, people are at risk to cause harm to themselves, and need constant support.

[Winkler2012] give detailed data on the distribution of health deficiencies of the age group 74 plus; the most common deficiencies are listed in order of frequency:

1. *Mobility impairments* are the most common functional constraints. 44 % of women (men 28 %) have mobility problems during walking and / or climbing stairs, 18 % of which are unable to use walking aids due to the level of mobility constraints. Bowing and kneeling down are a problem for 60 % of women and 40 % of men (see also Figure 9).
2. Data on the prevalence of *dementia* is available for Vienna only and suggest about 3 % of older people above 75 and 24 % of people above 80 have dementia, hence a pronounced age-related increase.
3. About 13 % of older people report *depression* symptoms
4. *Cardiovascular diseases* lead to hospitalization in 10 % of women and 13 % of men.

Problems	Mobility aids	Men		Women	
		60 - 75	75+	60-75	75+
When walking	without	6,9	27,8	8,4	43,6
	with	3,1	12,2	3,9	15,3
	not available	0,4	0,8	0,4	2,2
Climing stairs	without	7,2	26,7	10,2	42,3
	with	2,7	8,7	3,0	14,3
	not available	0,9	1,2	0,9	2,2
Dexterity	without	2,0	8,0	2,5	9,4
	with	0,7	2,9	0,8	2,6
	not available	0,6	1,5	0,9	3,4
Rotational hand movements	without	1,7	6,8	4,1	8,4
	with	0,6	4,2	1,1	2,5
	not available	0,5	2,0	0,2	1,9
Bite and chew		11,6	28,3	13,5	32,1
Stretch hand and shake hands		0,9	2,7	1,0	2,7
Bowing and kneeing down		22,6	39,3	25,8	58,3
Lifting and carrying heavy bags		8,6	28,2	21,2	57,0

Fig. 9. Functional problems, translated from [STA2007]

Incontinence is prevalent in 24 % of women (20 % of men) between 75 and 84, Diabetes is prevalent in about 20 % of older people. Neither is mentioned as a reason for institutionalization. It can be assumed that older people still have means to manage these diseases.

Regarding Activities of Daily Living (ADL), about 10-20 % of older people between 75 and 84 report problems. Problems exist primarily in *bathing and showering* (22 %), *dressing* (18 %), *getting up and sitting down* (15 %), *toileting* (8 %), and *eating* (7 %). All these activities lead to a dramatic functional decrease depending on the age. For example, more than 50 % of women above 85 years report problems with bathing or showering.

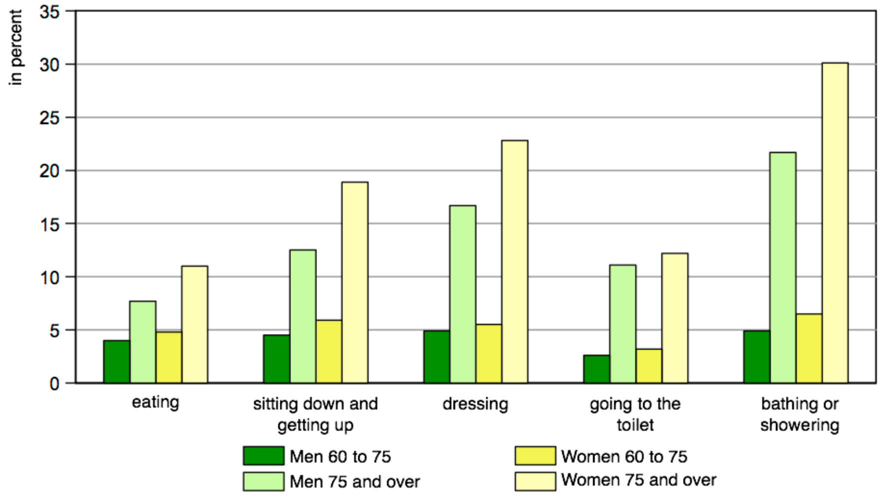

Fig. 10. Older people's difficulties with ADLs, translated from [STA2007]

In the group of 75-84 year old people, about 20 % report issues in conducting instrumental activities of daily living *(iADLs*). Problems with these activities are gender dependent. About 30 % of males in this age group report problems with *washing* and *preparing meals*; over 20 % report troubles in *shopping* and *household work*. These issues are not purely health-related but also involve social factors because these tasks are typically carried out by women. About 30 % of women have troubles with *shopping*, about 20 % find *preparing meals*, *washing clothes*, *household work* and *managing finances* problematic.

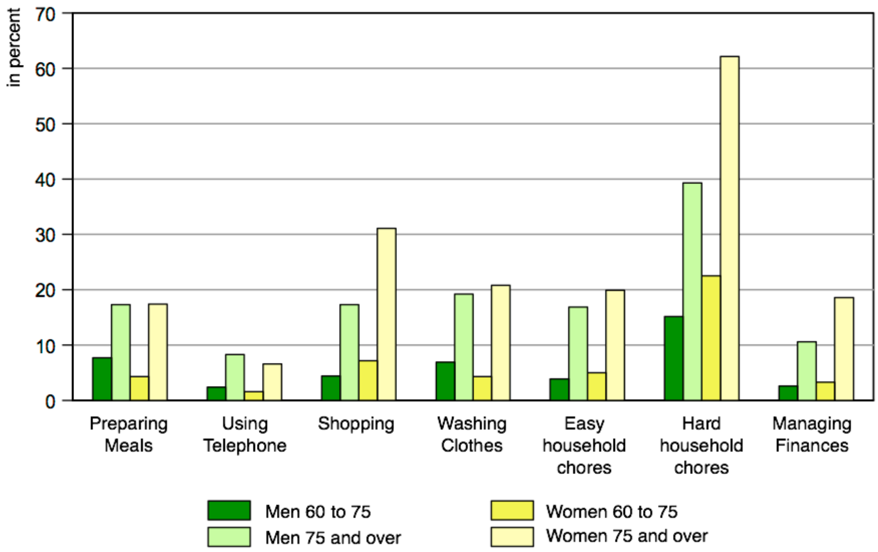

Fig. 11. Older people's difficulties with iADLs, translated from [STA2007]

3.1.2.2 Social factors

Isolation at home without the possibility to easily connect with family and friends is one of the most prominent non-functional needs of older people and mentioned in most of the reviewed literature [Rosenholz2015], [Munster015], [Thiele2002], [Hofwimmer20010], [Werner2008]. Associated with the feeling of isolation is the lack of reliable helpers in case of need. The lack of contact with neighbours, family and friends introduces safety issues for the older adults as they cannot expect to receive help quickly enough in case of an emergency such as a fall.

According to Statistics Austria [STA2007], about 76 % of older people (60+) expect their relatives to care for them. 15 % are cared for in care institutions, about 3 % rely on neighbours or friends, 7 % report not having anybody in case they would need help.

[STA2007] also reports that about 6 % of women and 2.5 % of men are either *"unhappy" or "very unhappy" with their personal relationships*. Regarding support by friends, about 8 % of women and 5 % of men report to be either "unhappy" or "very unhappy". These data show that because of their longer life-expectancy, isolation at home is strongly gender-related and concerns mostly women.

A second social reason often mentioned is the desire of the older people to *reduce the care burden* of their relatives, or social pressure of relatives because the need for support exceeds their capacities [Thiele2002], [Hofwimmer2010], [Rosenholz2015].

A lacking *quality of relationship* with informal caregivers due to conflicts including violence within the family might be an underestimated reason for both the informal caregivers and the older persons to consider professional care. Gröschel-Gregoritsch [Gröschel2013] reports of 6-10 % of intra-family violence between caregivers and older persons with dementia, and states further that the number of unreported cases might be high.

Moving in together with the *care-dependent partner* is another social reason reported by users [Werner2008].

3.1.2.3 Insufficient environment

Due to changing user needs and declining health, the own premises often become unsuitable for the older people. Typical environmental issues that contribute or even cause institutionalization are missing elevators, lacking heating (e.g. no central heating, partly still solid fuel based), toilets on the hallway and general lack of barrier-free design (stairs, door-sills, shower entrances etc.) [Thiele2002], [Hofwimmer2010], [Werner2008].

3.1.2.4 Financial needs

[Rosenholz2015] also reports of financial reasons, as it might be cheaper to move into a care facility, which, in case of a poor financial situation, is covered for by social welfare.

3.1.2.5 Additional benefits of professional care

In addition to the factors named above which demand professional care, users also take into consideration additional benefits they expect when moving into care facilities. Day care centers and residential care provide a *higher level of safety*, as care professionals are present day and night. Users report this fact provides a higher level of autonomy, as they are able to "risk" more if help is readily available. In addition, care centers provide services such as *regular and healthy meals, technical support, cleaning support, medication management* and also a higher level of comfort by means of *regular activities and events* and last but not least a *social network of residents*. [Munster2015], [Werner2008], [Hofwimmer2010].

3.1.2.6 Summary

Although it has been shown that mobility impairments and cognitive diseases are among the main reasons given by older people leading to admission into a care facility, it is clear that typically a combination of two or more factors are relevant [Hofwimmer2010] and the factors are interconnected, as shown in Figure 12, which gives a simplified interrelation diagram. Age-related – often chronic – diseases lead to functional impairments that inhibit the ability to conduct activities of daily living, increase anxiety and the need for safety and social support. Social deficiencies such as limited care support by relatives and isolation and poor environmental conditions aggravate the needs of the target group and facilitate their move into professional care.

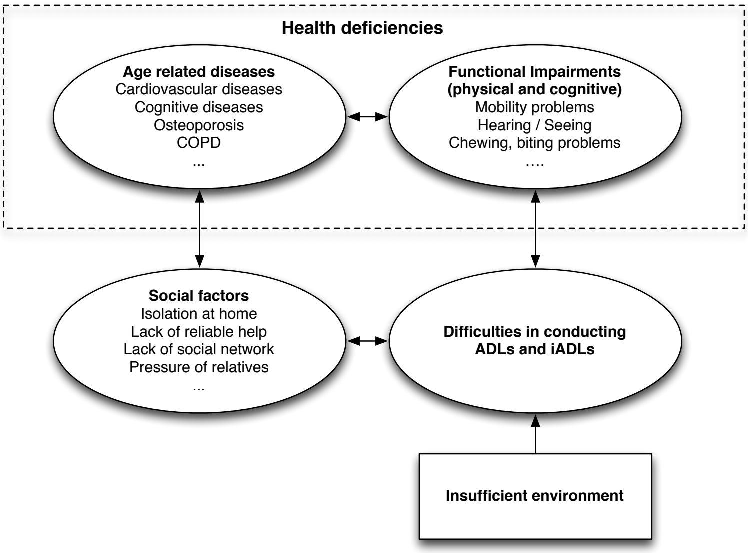

Fig. 12. Interplay of factors relevant for the move of older people into care residences

3.2 Secondary user groups

Secondary users are people conducting the care tasks thereby directly supporting the primary users. They are secondary users of AAL robots because technology that supports the primary users has a direct influence on the tasks to be conducted by the secondary users, and because some AAL robots also provide functionality that supports the carers, such as lifting the patient.

Secondary users can be split between formal and informal caregivers, which typically are members of the primary users' family (36.4 % partner, 34.7 % children, 14.7 % other relatives), friends or neighbours (16.8 %) [Nedopil2013]. The by far larger group are informal caregivers, which, according to estimations, represent 90 % of the total group [Blinkert1999].

All groups of secondary users have in common the often physically and emotionally demanding burden of caring. The user needs of secondary users can be derived from the specific strains and difficulties that come with the care of older users. The following needs were derived from literature, augmented with inputs from a focus group with seven care experts, and are common for all groups of secondary users.

3.2.1 Physical needs

As declining mobility is among the most prominent difficulties older users have to cope with, the demand of support by secondary users can be considered equally high. Turning elderly people in the bed, helping them out of the bed or into a wheelchair are the most demanding physical tasks of caregivers, which also need to be conducted often (also to reduce bedsore) and over a long period of time (often months to years). The specific conducted movements are often one-sided (also considering supporting handicapped people during walking). As a result, about 40 % of caregivers in Germany report back problems[33].

3.2.2 Emotional needs

High psychological demands and stress due to experienced sickness and mortality are common difficulties caregivers have to cope with. Stress due to time pressure is common for both informal and formal caregivers as care is time intensive and informal caregivers often have other duties in parallel such as regular work.

[33] http://www.heimversorger.de/node/229

Lack of societal and monetary acknowledgement and conflicts between primary users and secondary users are other issues caregivers have to cope with. Some also face violence towards them by the person looked after.

3.2.3 Particular needs of informal caregivers

In addition to the general demands mentioned above, Nedopil et al. give a list of particular needs of informal caregivers [Nedopil2013]. The list was augmented and validated in a focus group session with seven care experts.

- *Time pressure* due to high demands of care resulting in limited time for personal support
- *Isolation* due to time pressure, which restricts other activities and leads to lacking support by other people (friends, other relatives).
- *Disturbed night sleep* and lacking leisure time to revive,
- Informal caregivers do usually *not have any training* for the job.
- The *environmental conditions* at the primary users home are not ideal for care (stairs, etc.).
- The burden of *guaranteeing* the cared person's *well-being and safety*.
- *Financial issues* as care is cost intensive (e.g. part time professional care or full day care that needs to be supported)

3.2.4 Particular needs of formal caregivers

In addition to the general demands, [Nedopil2013] gives a list of issues that formal caregivers have to deal with on a daily basis. The list was augmented with comments of care professionals.

- A *high workload*, many organizational duties (e.g. documentation) and little time for personal contact. Strong time pressure due to a shortage of personnel and many people to take care of.
- *Conflicts* with the recipients of care, their relatives or within the team/hierarchy.
- Keeping relatives *informed* about demented patients' status, or financial support they can receive.
- *Working hours* that involve night-shifts and changes, often making it hard to adapt to.
- Strict *performance requirements* limiting the time per patient, resulting in stress.

3.3 Other user groups

The remaining user groups are often summed up as tertiary users but are very heterogeneous. These groups do not directly support the older people but have an interest in financing and support of older people and include:

- Care organizations, medical doctors and therapists
- Health funds, social services and health insurance companies
- Companies that develop, distribute or maintain health technology
- Politics (regional, national, international) policy makers and public administrations
- Providers of ICT infrastructure
- Media
- Standardizing Institutions and certification organizations.

3.3.1 Needs of other user groups

Other user groups are very diverse and hence their needs are heterogeneous. Some basic needs that are common among most other user groups were identified by Nedopil et al. [Nedopil2013]:

- The cost efficiency of the solutions (purchase cost, installation efforts, maintenance costs vs. cost of current care).
- Proof of the efficiency of the solutions on health and quality of life (often requiring extensive long-term studies).
- Ethical considerations such as privacy issues.
- The correlation with existing standards and possibilities of links to existing services.

In addition Glende et al. analysed the potential benefits (correlating with the above mentioned needs) and risks of assistive robotics for important other user groups. A summary of the central benefits and disadvantages identified is given in the table below [Glende2015].

Table 2. Benefits and risks of the implementation of assistive robotics for selected tertiary stakeholder groups. Derived and shortened from [Glende2015]

Stakeholder	Potential benefits	Risks and disadvantages
Social insurance institutions	• Higher efficiency in nursing and care (e.g. 24h care, telemedicine) • Image and competitive advantage • Reduction of care and medication costs • Securing the quality of service despite decreasing membership	• Missing proof of cost-saving potential • No standardized or stable environments (legislation, financing) • Unclear responsibility in case of accidents • Concerns about data safety • Technology might replace human relationships
Service and product providers	• Innovative image and competitiveness • Opening up of new markets • Further development of business models • Opportunity to integrate robotics with existing devices or services • Stable market growth	• Investment in robotics might not pay off • Unclear financing • Low willingness to pay by private and public sector • Missing infrastructure and training • Speed of market is high, big companies might overtake small enterprises • Vague or unclear legal conditions, liabilities and (quality) standards
Politics and legislation	• New job profiles, educations and jobs • Health resource savings • Compensation of skilled worker shortage • Innovation in technology, research and science • Increasing citizens' health	• Initially: increase instead of reduction of costs • Economic benefits unclear • Missing certification for robots • Difficulties in adjusting legislation to the field of robotics (reliability, liability) • Unclear which technologies may establish the market

3.4 How current R&D identify and cover user needs

3.4.1 Overview of methods used to analyze user needs

This section gives an overview of currently and commonly used methods to assess user needs and requirements in the field of assistive robotics. It reflects on best practice examples and possible hurdles to tackle rather than explaining the methods themselves and showing results of the reviewed studies.

The main source for the following literature survey was the IEEE Digital Library, which was scanned for research papers and journal articles using the keywords 'assist* robot* elderly needs'. After scanning the titles and abstracts of the resulting 83 articles, 16 remained as a starting point for the research. Papers were selected based on the detail and quality of information provided and eleven key publications were chosen for the review. The remaining articles referenced in this chapter have either been cited in these papers or have been recommended by experts in the field.

As there are hardly any reflections in these papers on how well the methodologies themselves worked out, three experts in Human Robot Interaction, who have been involved in various European robotic projects, have been asked to shortly reflect on the difficulties in assessing user needs in this area of research [PanekMayer2015][Oberzaucher2015].

There are a wide range of methodologies used to assess user needs and requirements in assistive robotics. Typically a short literature research is used as a starting point, e.g., [Ezer2009a][Glende2012] [Smarr2014] [Khan1998][Ezer2009b]. [Cesta2012a] draw their conclusions solely from literature. This chapter concentrates on methods involving target users into the research process. The following sections give a brief overview of how each method is usually applied in the reviewed literature and details differences.

Interviews and Questionnaires

Interviews and questionnaires are the most widely used research methods to obtain opinions and intentions of possible future users in the reviewed literature. Among interviews semi-structured interviews based on an interview guide, which give the researcher the possibility to go into more detail at certain questions, are the most common choice, as in [Bugmann2011][Frennert2013][Khan1998] [Ray2008].

While interviews have only been conducted with a limited number of people, questionnaires are a good choice, if the opinions of a large amount of people are to be collected. Typical ways to spread questionnaires are sending them by regular mail, handing them out at events [Ray2008] or creating a survey on the internet [Bugmann2011]. They usually consist of a set of questions or statements that have to be answered on a Likert scale basis for easier evaluation and comparison. Some leave space for comments and open answers though. [Frennert2013], [Khan1998] and [Ezer2009b] even let their respondents draw their own robot within the questionnaire.

There are different ways to introduce a robot in a questionnaire survey. Some use illustrations or pictures of a robot within or at the beginning of the questionnaire [Mast2013] to give the participant an idea and initial feeling of what is being talked about. Others show it only at the end [Khan1998] so as not to influence the participants too much beforehand. In [Ray2008] some robots were displayed at a stand (at a fair), and in addition, posters about their work with robots were shown while inviting visitors to fill in their questionnaire. Others just ask their respondents to imagine they had a robot at home [Frennert2013].

Interviews and questionnaires are often used in combination. In some projects interviews serve as a pre-study for larger questionnaire surveys [Khan1998][Ray2008]. [Frennert2013] made use of interviews the other way round and interviewed a group of people to get more detailed answers to their questionnaire findings.

Having an introductory questionnaire at the beginning of a group discussion [Smarr2014][Ezer2009b] or a hands-on interaction session [Dautenhahn2005] and/or a final questionnaire at the end [Bevilacqua2012] is also a commonly used strategy.

Focus Groups and Workshops

A focus group can be described as a meeting of a group of people to discuss a set of (research) questions in a formal or informal way. Workshops usually incorporate different techniques to activate the participants and elaborate on (research) questions in a creative and cooperative way.

In the literature, a typical focus group session is divided into three parts. First the project itself and its objectives are presented. This presentation is followed by an introduction of a sample robot by either showing videos [Bevilacqua2012][Smarr2014] or pictures [Mast2013][Boissy2007] of assistive robots similar to those that the project plans to use or develop. This can also include showing the robot performing certain tasks and exemplary interaction between robot and user. The purpose behind this step is mainly to create a basis of knowledge and a shared understanding among the participants.

The session then continues with a longer brainstorming and discussion phase that gathers the participants' opinions regarding specific research questions, and concludes with a summary by the moderator.

Assistive robotics being a delicate topic for discussion, since it raises ethical, social and societal issues, and users might already have a certain picture and opinion of robots in mind, some projects try to make people think about and imagine a future life with a robot companion in a more open and creative way. These methods are usually part of larger workshop sessions. [Frennert2013][Frennert2012] made their participants *"explore, look and feel"* by handing out boxes with pictures of robots and different handicraft materials and tools to create *"their own perfect robot"*. In a second step, they presented a set of so-called "attention cards", which showed a certain situation together with alternative actions the robot could perform in that setting.

[Glende2012] use creative methods like brainwriting (in contrast to brainstorming, participants first write down their ideas and then talk about them), Disney-Method (a kind of role play where participants are assigned different roles and reflect on a topic having this role in mind – usually these roles are "outsiders", "dreamers", "realisers" and "critics") and Picasso-Puzzle (a role play where the situation that is to be played by the participants is being constructed by cards being drawn by the participants from a set of puzzle cards [YOUSE2015]) within their workshops to make people imagine living with a future technology.

In some focus groups [Lehmann2013][Boissy2007][Cesta2012a], an actual robot was not mentioned at all to the participants. Instead the discussions focused more on everyday problems of independent living for elderly people and factors that contribute to loss of autonomy.

Ethnographic Studies

"Technology is not the only influence in designing new products - social dynamics, economics and environmental issues also play an important role"[Forlizzi2004]. [Forlizzi2004] tried to investigate how robotic products could assist older people in their daily lives by observing how these people form relations to products and how different components that play an important role (people, products, the environment and the community the person lives in) are related to each other. They visited 17 older people and investigated typical daily experiences and how products disturb or support activities. Elders described their homes and presented their favourite products and those that cause trouble during a "home tour" and were thereafter observed for one hour on how they interacted with products, doing key household activities, such as meal preparation and grocery storage. Besides interview data, Forlizzi et al. collected audio and video material and took field notes at every visit. This study was further supported by interviews with five visiting nurses and social workers.

[Mast2013] took a glimpse into 15 potential future users' homes to determine challenging environmental aspects via participant observation, diaries the participants wrote about their daily routines, photographs and interviews.

[Matsumoto2011] conducted an autoethnographic study where one of the project members recorded a life-log where each single action he performed during five days (action, time, duration, place, target, object and purpose) was stored on audiotape. The data was subsequently analyzed based on the international classification of functioning ICF [WHO2007] to investigate which actions were performed most frequently and therefore would be worth most being supported by a robot companion.

Discussion and Conclusion

The methods for gathering user needs don't differ from other research areas, but it is a very important step to think about if and how the future robot companion is presented to the participants during the research.

Questionnaires seem to be a favourite tool to collect the opinions of a large group of people and get comparable, quantitative results. It is easy to send out a package of questionnaires, but still there is no guarantee that they will come back. [Ezer2009a] reported that, out of 5000 younger and older adults, only 177 responded. They also state that they had to view their results under the light that "there might be a self-selection bias with only individuals having positive views of robots returning the questionnaire" [Ezer2009b].

Table 3 gives an overview on which methods have been used in the reviewed literature to target a certain research question. It can easily be seen that from this it cannot be concluded which method suits best for that question; to make such a statement, the papers would have had to also reflect on how well their methodologies worked out for reaching their research goals.

However, one conclusion that can be drawn is that the more the questions deal with actually living with and having a robot at home, the more it becomes important to reflect on that situation in more detail together with the possible future users (conducting focus groups) or even to visit their homes and to observe their way of living (ethnographic study).

Table 3. Overview of user research methods applied for certain research topics

Research Topic	Interview	Questionnaire	Focus group	Workshop	Ethnographic Study
Tasks / Services	X	X	X	X	X
Acceptance		X	X		
Fit into life / difficulties			X		X
Environmental challenges					X
Attitudes / how are robots perceived	X	X			
Appearance	X	X		X	
BehaviourBehaviour	X	X	X		
Where does the conception of robots come from	X	X			
Communication	X	X			
Robot experience		X			

The way robots are presented to the participants has to be carefully thought about. Some studies such as [Cesta2012a] avoided talking about robots to their participants at all. Although Smarr et al. state that they used this strategy *"to avoid bias of their views and attitudes due to the technology"* [Lehmann2013], it is not possible to tell in the end, which task robots would be accepted to take over or not. One of the interviewed experts explains that sometimes existing pictures and concepts of robots people have in mind – often originating in media and science fiction – have to be loosened up right from the beginning [Oberzaucher2015]. In [Bugmann2011] a robot with very human-like characteristics was given as an example for not putting any functional limitations on what the robot could do, in order not to bias the answers. The authors themselves reflected that a different introduction most likely would have led to different outcomes (e.g. a robot with wheels and no manipulators). Forlizzi et al. agree with that finding: *"The visual appearance will also affect the emotional and social relationship the seniors will form with the assistive robot"* [Frennert2013].

It is often hard to discuss about expectations and requirements of a technology that does not already exist; and having a robot companion at home is a topic that lies within the far future. [Boissy2007] state that it was very difficult for their participants to imagine how the proposed robotic solution could be useful to them:*„understanding of the concepts of in-home robotic telepresence in relation to their current needs was incomplete, even after numerous attempts by the moderator to guide the discussions"*. [Glende2012] tried to overcome this problem with a set of creative methods to involve users in the design process. Bevilacqua et al. [Bevilacqua2012] agree with that strategy: *"The use of creative techniques and focus groups for the services refinement have strongly supported the generation of new ideas and the uncovering of met and unmet needs."* A method that seemed to have worked well in Glende and Nedopil's studies is the Disney-method (as shortly described above). Panek and Mayer support that it is often hard for people to reflect on their own needs and deficits and therefore slipping into another role might help [PanekMayer2015]. They also suggest that organizing user involvement events (e.g. focus groups) in settings that resemble living space makes users feel more comfortable than a laboratory and helps them think about this future vision of having a robot at home [PanekMayer2015].

3.4.2 Overview of user requirements as identified by robotics projects

The following section summarizes the requirements of primary and secondary users identified in research projects on AAL robotics.

The identified functional requirements on AAL robotics can broadly be split into four categories:

- Compensation of physical and cognitive deficits
- Health Management
- Safety and Security
- Support of Social Interaction

Compensation of physical and cognitive deficits

The robot should do things its users are unable to do and thereby compensate their perceived cognitive and physical limitations [Frennert2012]. Support with physically demanding tasks [Glende2012][Zsiga2013] like help with standing up [Glende2012], reaching high & low or carrying groceries [Frennert2012], and doing household work [Bevilacqua2012][Khan1998] like cleaning and dusting [Frennert2012][Khan1998] are among the favourites in this section.

On the cognitive side, the wishes go from help to find misplaced mobile phones, glasses or keys [Frennert2012] to help with bureaucracy by reading out and translating text [Glende2012]. Another desire mentioned were reminders about appointments, medications, planned invitations and trips [Frennert2012].

Health Management

Tasks regarding health management encompass reminding of medication, bringing medicine [Bevilacqua2012], consulting on health issues through information, motivating for a healthier lifestyle and monitoring of health conditions [Glende2012]. Controlling smart home components was also mentioned as an application envisioned for assistive robots in this context [Glende2012].

Safety and Security

Being an "easy target" for assault or burglars, and having a higher accident risk, the majority of the older people involved in the researched studies would wish for a system that keeps watch– especially during the night – and alerts others in case of emergency [Bevilacqua2012][Frennert2013]. Examples were the detection of burglary, fire, or falls and other accidents [Glende2012] Robots could also help feeling more secure outdoors, or support risky or difficult movements. [Bevilacqua2012]

Support of Social Interaction

Social interaction is extremely important for this group of people and plays a critical role in keeping them healthy, happy and independent. Cognitive and physical decline drastically reduces older people's activities and can have damaging effects on social integration [Forlizzi2004]. A robot could therefore act as a medium for connecting and supporting relationships [Bevilacqua2012] and for keeping in touch with family and friends [Frennert2013] [Glende2012]. According to Glende et al., assistive robots could also take over social tasks that relatives or carers can't do, like playing games or training new skills [Glende2012], but a robot should only act as additional help and never replace a caregiver [Zsiga2013].

Although it would be possible to gain a companion by having a robot at home [Zsiga2013], Frennert et al.'s studies point out that a robot will always be seen "as a machine but not as a friend", as there is a stigma attached to having a robot as a "friend" (for people who are lonely, fragile and disabled; being dependent on a machine). Still some anxiety of getting too dependent and attached to the robot exists [Frennert2012]. By contrast, a robot as a servant is seen as acceptable and satisfactory [Frennert2013].

Users also expressed worries of robots replacing human contact and were afraid that, if they had a robot, their relatives would not visit them since they had the robot as company. On the other hand, one advantage in comparison with human care was seen in the robot's dependability: it would not gossip and talk behind one's back. *"With a robot I know what to expect. When letting some unknown human into your home you do not know what to expect"* [Frennert2012].

3.5 Acceptance of AAL robots

In general, primary users in the reviewed studies showed high willingness to use a robot in case of need [Bevilacqua2012][Khan1998]. The majority would not find having a robot frightening [Frennert2013] and it would be seen as a great help for individuals living alone [Zsiga2013].

An astounding finding was that whereas older adults in general showed a rather open and positive attitude, secondary users (relatives and formal carers) were more critical towards assistive robots [Zsiga2013].

People would even make adaptations to their home to accommodate the robot [Frennert2012]. It was stated that they would be willing to move furniture, teach it about their habits and environment and would show the robot to friends and family [Frennert2013].

Acceptance factors

Numerous acceptance factors for technology uptake were identified so far and several acceptance models were developed and are widely used to assess the acceptance of technology. Most prominent are the UTAUT model [Venkatesh2003], the models TAM to TAM3 [Venkatesh2008], and – specifically developed for assistive robotics – the Almere model developed by Marcel Heerink [Heerink2010]. These models have the goal to study and predict the use or "intention to use" of a specific technology and propose several influencing factors and their relations among each other.

The following factors that are common among acceptance models and known to have an influence on the acceptance and uptake of technology in general and assistive robotics in particular were identified:

- *Functionality* (Usefulness and perceived usefulness) – whether or not the robotic device solves a user's need(s).
- *Usability* (Ease of use) – the degree to which one believes that using the system would be free of effort.
- *Robotic behaviour and appearance* – The robotic behaviour including interaction with humans (HRI) and the robots appearance and general design.
- *Safety* – operational safety as defined in ISO13482:2014 (safety requirements of personal care robots).
- *Costs and financing* – The cost-efficiency and affordability by the target group.
- *Ethical aspects* – Including friendship and possible relations with robots, becoming dependent on technology and stigmatization, see also chapter 5.6 Ethical Issues in AAL Robotics.
- *Legal aspects* – Legal and regulatory aspects solving e.g. who is liable in case the robot causes harm, see also chapter 5.5 Legal issues in AAL Robotics.
- *Social aspects* – Social influence of people who are important to the users and their opinions regarding the use of AAL robots.
- *Privacy* – Data protection and security.
- *Psychological aspects* – such as the users' attitude towards technology, anxiety towards robotic solutions and initial effects of excitement.

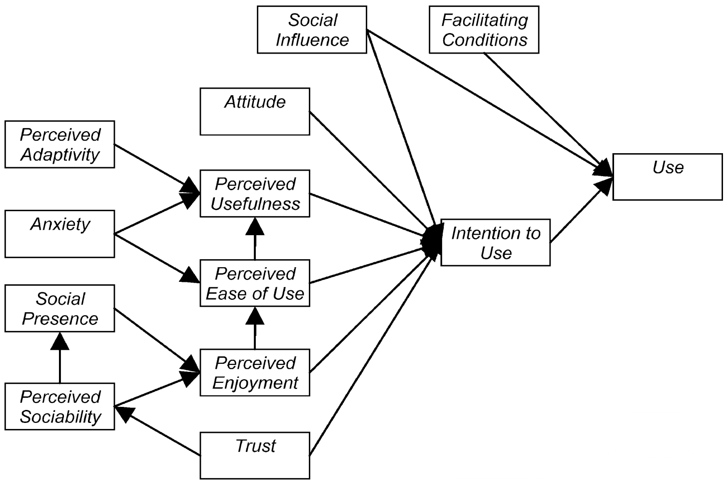

Fig. 13. The "Almere Model" by [Heerink2010] containing several of the mentioned constructs and their relation among each other

It is not possible to make a general statement about the acceptance of AAL robots among older users because of the differences between robotic solutions, the complexity of the mentioned acceptance factors and their interrelation, and the lack of long-term acceptance studies for most of the described robot categories. Recent surveys such as the Eurobarometer[34], which try to capture people's opinions towards robots in general, are heavily biased because of the people's lack of knowledge and common misunderstandings regarding robots which are often only known from science fiction TV.

There is yet another factor to take into account regarding perception of robots: It is likely that certain future robotic technologies will not be perceived as robots, which makes the question of acceptance of robots irrelevant in their case. Already existing robotic solutions such as the "Resyone", the "AKS TORNEO", "Liftkar" (see Appendix) and others are on the market, without being perceived primarily as robots. Common appliances such as washing machines or coffee-makers already pass most (if not all) criteria for robots, and are definitely assisting our daily living, which would make them AAL robots. These devices are very well accepted on the market and integrated into our daily routines.

3.6 User requirements by categories of AAL robots

Because of the afore-mentioned difficulties in assessing the acceptance of AAL robots, two focus groups with end-users and care-experts were undertaken to gain insight about the user requirements in relation to the different types of robots. The first one was held with seven care experts (managers of care institutions, registered nurses and care researchers), in the second one five older adults (three female, two male) took part in intensive discussions.

The following section summarizes the outcomes of the discussions, and presents and compares the importance of each AAL robot category for primary users, secondary users, and a group of 19 robotics experts which filled out a questionnaire during a workshop at the 2015 European Robotics Forum.

3.6.1 Household Robots

Primary Users

An interesting observation within our focus group was that this seemed to be the only category highlighting gender differences. While the men participating in the discussion would love to have one of these robots as it would take over their work, the women complained that, at the current state of the art, they were not doing the work well enough (e.g. window cleaning robots can't reach the corners of a window) and were therefore only moderately useful. So they emphasized that household robots could support doing things around the household (which is very much appreciated), but could not take over the work.

[34] http://ec.europa.eu/public_opinion/archives/ebs/ebs_382_sum_en.pdf

Secondary Users

In the current older population, these robots are of minor relevance. Future generations who are already used to them will need them more. The secondary users considered paid and/or unpaid human helpers as the main alternative to household robots. Human help would be preferable because of the social contacts it provides, while robots could be a solution for people suffering from age-related social phobias. The secondary users also articulated the risk of household robots to take over tasks which could, if done by older people themselves, contribute to training their physical and cognitive abilities. They saw, however, the potential of household robots to relieve informal caregivers.

3.6.2 Emotional Robots

Primary Users

The need of such a service varies a lot between individuals. This category was seen as very useful for people with dementia and people living alone in their own homes. Apart from one lady all participants could imagine using a robot from this category in case their mental status was such that they would benefit from them. They stated that people using these kinds of robots might feel needed again and less alone. Emotional robots are currently used in the presence of another person, so they stated that the contact with this person could be an additional benefit.

Secondary Users

This category was rated as very useful for people with dementia and people living alone in their own homes. Some participants stated that they might not be too useful in institutional settings as there are enough possibilities for personal contact. ("a 'regular' cat would be sufficient for an institution.") by contrast, others stated that with highly demented people a ribit contact could even be better than personal contact with other people. The extent to which this group of robots can enhance independence of older people was rated as quite low, unless the robot could motivate its owner to move or to walk. Those kinds of robots could also help improve or at least maintain cognitive skills to a certain degree. It was also stated that there could be a lot of indirect benefits, e.g. when a person feels good, he/she dares to do more. Compared to pets, emotional robots offered the advantage could be used anytime, didn't cause any mess and need not be walked like e.g. dogs. Compared to dolls, their advantage was the ability to react or interact. On the negative side, problems with hygiene were mentioned (robot would need to be washed a lot) as well as a high potential of conflicts, if more people share one robot. Furthermore, the fact that people usually establish a strong emotional relationship with such kinds of robots could cause serious problems should the robot break.

3.6.3 Socially Assistive Robots (Companions)

Primary Users

The focus group participants found these kind of robots especially useful for people living alone and their relatives. They reckoned that such a solution could increase safety at home a lot (e.g. detection of falls) and stated that seeing the person you are talking to was way better than a regular phone call. Although some functionalities could also be offered by a regular PC or a tablet PC, they stated that most older people were not familiar with these kinds of technologies and would find a robot easier to use. Furthermore it was discussed that a relationship could develop between te robot and the older person and so make that person feel better or at least less alone. People using such a robot needed to be mentally fit though, and most flats would not suit the robot's needs (doors closed, obstacles on floor, etc.). The participants also feared that people might feel observed by the robot, and one participant even said that he would be afraid if there were a robot moving around in his flat.

Secondary Users

Care experts think that the need for socially-assistive services is currently rather low but will increase in the future as the number of carers continues to decline, and the acceptance of robotic technology in general increases. They assume that approximately 30 % of older users at home could benefit from socially assistive robots. The rest of the age group would either require more assistance (physically) or might not be able to use the robot for reasons of dementia. Although they see its service and support functionalities more useful to support independence of older people living at home, they can imagine that a main benefit of this category could be enhanced social inclusion, together with a comparatively high usability and hence acceptance level. The participants assumed high costs for such solutions and stated that, among other technologies, smart phones would fulfill most of the services offered by socially assistive robots and would have the additional advantages of being portable and not being expensive, large (space to operate could be a problem in apartments), and heavy. Especially those robots that allow people outside the user's flat to "look into" the flat raised concerns of privacy, though it was admitted that this feature could help increase the feeling of safety and thus possibly the level of independence.

3.6.4 Personal Care Aids

Primary Users

Robotic solutions within this category were rated as very useful for older people and it was emphasized that they would also ease the burden of both formal and informal carers. The robotic toilet, for example, would be very convenient and enhance safety if it does away with the need to walk to the toilet during nighttime. For use at home, some devices would need to get smaller though.

It was criticised that the devices in this category seem to require an additional person to operate them (e.g. either to put food on the plate or to help with transfer from bed to the robotic toilet)

Secondary Users

Most of the participants found this category to be "very useful", especially regarding personal hygiene and monitoring of medical data, e.g. vital parameters or insulin level. Some saw a more realistic scenario of use for these robots in the support for carers in a care institution rather than for at-home-usage. The participants estimated that around 30-40 % of the older population could need such a solution and, for personal hygiene, 70 % of those needing it would need such technology urgently.

Especially in this category there has to be a compliance by the person in need. Accepting being fed by someone else or even a machine can be a big problem. Currently feeding a person takes a lot of the carer's time, but it also gives an opportunity to enhance the social component of their job as this time is also used for chatting with that person.

Just like the primary users, the participants in this group criticized that many of these solutions probably were not appropriate for private homes as human support was still needed. The process of washing a person e.g. also includes undressing and dressing, but these robots (so far) don't support that part. Additionally they emphasized that especially the robotic solutions in this category needed to be kept clean all the time for hygienic reasons.

3.6.5 Robotic Manipulation Aids

Primary Users

All participants were glad that they were in a physical state where they did not have to make use of such devices, but said that they could be very useful for people with motor disabilities. So they did see not older, but mainly handicapped people as the target group. They found these kind of robotic aids great as they allowed somebody to do what he/she could not do without and could help being less dependent on other people.

Secondary Users

Robots in this category were considered extremely useful by the care experts. They would have wished for a finer-grained distinction between robots assisting with deficits in strength vs. deficits in dexterity, though. The need for such robots, in their view, rises with age, reaching as much as 90 to 95 % of the 80+ population.

Non-robotic alternative solutions could cover certain specific needs, as do e.g. shopping trolleys, or special cutlery, as well as other devices known from occupational therapy.

If these robots are technically mature and affordable, they will be of high practical usefulness. The secondary users themselves would use them once they needed them. Generally, these robots could support independent living in a decisive way. Costs and need for technical support were seen as the potential drawbacks.

3.6.6 Robotic Mobility Aids

Primary Users

Having the possibility to be mobile was recognised as being very important for the independence of older people, and therefore the participants rated this category as very useful. Especially the robotic bed was seen as very useful and one participant stated that these kinds of robots would be great, because "it takes me home in case I don't know where I am living anymore." In contrast, they did not want the robot to take over every mobility-related task. With regard to the self-driving car, they agreed that the "doing it on your own" was important when driving a car and they would rather take a taxi if they could not drive on their own anymore. They also stressed that, if the robot gave navigational instructions, they would have to be better than current car navigation systems which can become very annoying.

Secondary Users

Care experts found this category to be very useful for primary older users (indoors and outdoors) and highlighted that such solutions could have a strong impact on their independence. Although the average opinion was that around 50 % of all older adults could need such robots, it was also stated that current motorized wheelchairs and walking frames did already provide some of the functionality of this robotic category, and e-bikes were also mentioned as a possible support in this respect. Carers – both formal and informal – could also profit a lot from not having to lift or carry a person (solely) by themselves, although technologically simple solutions are already used, such as platforms to turn patients, boards to slide users from bed to wheelchair and metal frame based lifting aids that allow users to stand up from bed. As an advantage over current solutions, they could imagine a higher flexibility of use. Objections were that the living environment probably need to be changed to allow the robot to work properly, that the battery might expire while in operation, and that the user's independence might also diminish somewhat as he/she became denpendent on the assistive solution.

3.6.7 Fetch & Carry Support

Primary Users

The participants rated robots within this category as "moderately useful" for older people. Carrying the waste outdoors and helping with grocery shopping can be very helpful, but for supporting their mobility they could also use a wheeled walker (with included basket) instead. They imagined robots supporting fetch and carry tasks to be more useful (and easier applicable) in care facilities.

Secondary Users

Care experts found the need for fetch and carry support to be only fairly relevant although very much depending on the particular user needs. Fetch and carry services are currently mostly done by neighbours, relatives or attendants. Although these kinds of robots could increase the independent living of a person, personal help was thought to be more valuable and the participants feared that taking over these tasks by a robotic solution might reduce social contacts. They added that they found this category to be more relevant in urban than in rural environments. Furthermore, the increased independence could also lead to negative effects, for people using such services for personal comfort could neglect to maintain mobility.

3.6.8 General Remarks and Comparison of Categories

One issue that was raised by the involved care experts was the dependency of users on the service(s) provided by the robot: what happens in case the robot is not operational? There were also concerns that the transfer of tasks to an assistive robot could affect negatively the abilities of its user as there is no need to do the task him-/herself anymore. These arguments hold for all supportive technological devices though.

Being asked if they would use robots of different types themselves, care experts in general answered that they would, except for personal care and fetch and carry supporting robots, which one or two would rather not use. The group of older people could all imagine using robots from all categories in case they needed their support, except for one person who would not want to use an emotional robot.

Fetch and carry robots though were commented on with "we might use them, but rather choose some of the other categories before."

At the end of the focus group sessions each participant was asked to fill in a questionnaire to collect their individual impressions about the presented robot categories. Additionally, a group of technicians and researchers working in the field of robotics were asked to do the same after a workshop conducted by the project team at the 2015 European Robotics Forum. The results of these questionnaires are summarized below.

Household robots are known by 6 out of 7 care experts. Personal care aids are completely unknown. Emotional and socially-assistive support is well known (5 out of 7), physical assistance such as fetch&carry, manipulation and mobility aids are quite well known (4 out of 7).

The general impression of AAL robots among the involved care experts is positive; 5 out of 7 experts considered their first impression to be positive or very positive, 2 out of 7 were neutral regarding the use of robots for older users. The overall impression of all individual categories was rated between neutral and very positive. Emotional support and mobility aids were rated slightly better than personal care aids and manipulation aids; however the differences were not significant given the high variance.

Among the older users taking part in our focus group the overall impression of the presented categories was very positive. All of them range between "neutral" and "very positive". The lowest average value was 3,8 out of 5 for emotional robots and robotic manipulation aids and the highest 4,4 for personal care robots, which was also reflected in the results of the category rankings in Figure 14 below.

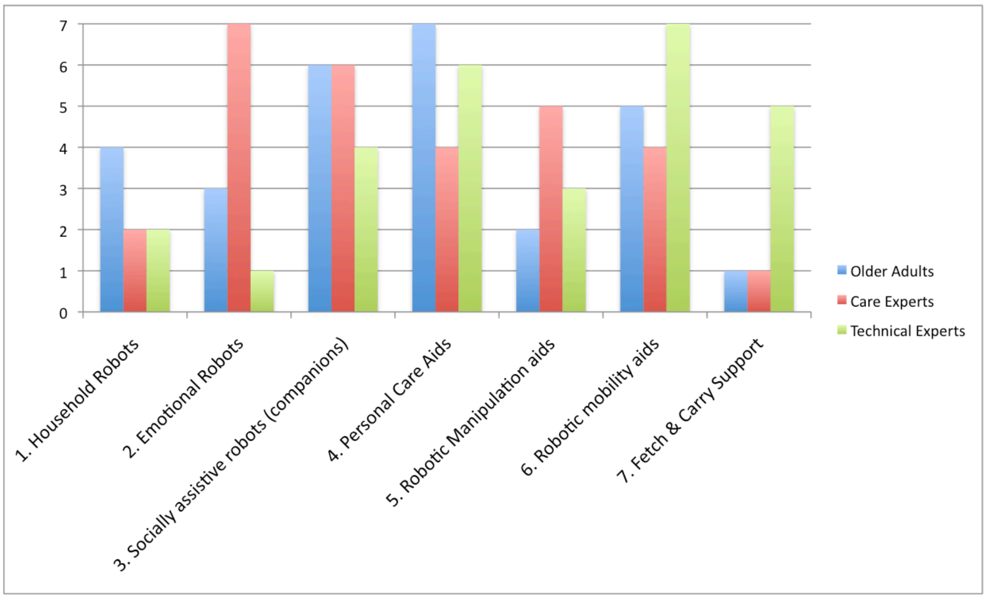

Fig. 14. Ranking of AAL robot categories by user group (y-axis: 7 = most useful, 1 = least useful)

The focus group participants were explicitly asked to rank the categories from "most potential to help older people" to "least potential to help older people". Emotional support was ranked very positively by care experts. Fetch& Carry and household robots seemed to have less potential. Interestingly researchers and technicians see the potential of emotional robots and mobility aids lower and would also recommend spending less research efforts into emotional robots. This result is also backed by earlier results of Sibylle Meyer [Meyer2011] who found that 72 % of care managers would use the robot seal "Paro" compared to only 34 % of technicians.

Given that care providers are among the target group of AAL robotics, this mismatch of opinions points to a lack of focus of current developments.

Our group of older adults also ranked emotional robots at the end of the field (rank 5/7), whereas robots supporting personal care were rated as most helpful, with socially assistive robots following very closely on second place.

Comparing all three participant groups, it is interesting to see that technicians and researchers rated fetch and carry support as way more useful than the other two user groups did (3rd most helpful category in technicians' and researchers' view and least helpful for both older adults and care experts). The result for robotic mobility aids is similar.

3.7 Uptake of AAL robots

In 2011 Elizabeth Broadbent et al. published an article highlighting the low uptake of robots e introduced to eldercare facilities, citing web-sources from 2007 and 2011 on initiatives that dropped out of commercial production [Broadbent2011]. However it seems the uptake of robots by primary and secondary users has increased recently, as has the commercial availability of AAL robots.

Susanne Frennert and Britt Östlund recently published a paper on the uptake of robotic vacuum cleaners by older primary users and found that seniors were "enthusiastic about adopting the technology" as it was beneficial for their daily activities, helped them to cope with everyday life and to "conserve energy for more meaningful activities, such as meeting friends and spending time on hobbies" [Frennert2014].

Another example of current uptake is given by Tommy Deblieck, manager of QBMT, a Belgium company selling assistive robotics services [Deblieck2015]. Their product "Zora", a companion robot aimed to support seniors and caregivers at care centers, is currently used in 88 institutes hosting 6000 elderly people in Belgium and the Netherlands. Because of the positive uptake, the company are currently extending sales to several other European countries.

The well known therapy robot "Paro" by Takanori Shibata (AIST) has been sold commercially in Asia, Europe and Northern America since 2004, and about 4000 units were sold worldwide in 2014 [Globalspec2015].

3.8 Summary

3.8.1 Summary of user needs

The group of older people is a very diverse user group showing strong differences in needs and financial aspects depending on age, gender and the current life situation. Hence the chronological age, which is currently most often used as inclusion criteria of user studies does not describe the target group well. Peter Leslett's definition of age groups seems to fit the purpose better as it is based on the current situation of the users, and was adopted for this study [Leslett1991].

A user need analysis showing the most prominent and frequent needs of primary, secondary and tertiary users was presented.

Regarding *primary users* the analysis focused on the group of older people at the transition between the third and fourth age, as this phase seems to be critical both from quality of life and financial perspectives. This point when older people become dependent represents the most relevant entry point for assistive robotics as the transition is typically undertaken because of clear demands that at least partially could be handled by AAL robots and could justify the possibly higher costs of such solutions.

The main primary user needs can be categorized into needs regarding declining health, social situation, environmental situation and financial situation (ordered by frequency). It is clear that a robot will only be able to satisfy a subset of needs and hence can help either a part of the user group, or - more importantly - users partly (meaning, personal help would still be required but to a lesser extent, thus enhancing autonomy).

As for *primary users' needs, health deficiencies* such as mobility and dementia are sufficiently considered in current research.

Social factors (isolation at home, quality of personal relationships, social pressures) are considered but evidence of the efficiency of solutions targeting social factors is missing, also ethical issues come into play in particular regarding isolation at home and the quality of personal relationships, which is considered not replaceable by robots [Turkle2011].

Environmental factors are considered, but can only partly be solved by robotic solutions. On the one hand solutions that support climbing stairs can reduce environmental problems. On the other hand, because of their size and inability to cope with certain obstacles in unstructured home environments (see chapter 4), current mobile robots such as companions even introduce further environmental challenges.

AAL robotics seem to have a high potential to support *secondary user groups* (informal and formal carers). In particular mobility solutions and solutions supporting lifting and carrying patients target the important physical needs of this group. Additionally, emotional problems such as stress can be reduced by lessening physical demands. However it is as yet unclear to what extent the quality of life of secondary users can be enhanced, as studies on the impacts of AAL robots are largely missing.

The needs of *tertiary user groups* are rarely considered in current research. The cost efficiency of solutions is mostly unclear due to their limited technology readiness levels. In Chapter 5 we give several scenarios that show a positive cost efficiency for certain AAL robot solutions.

The second major user need of tertiary users, i.e. evidence of efficiency of the solutions for health and quality of life, requires long-term studies that so far have only been undertaken for emotional [Wada2003] and rehabilitation robots [Krebs2000], showing positive impacts.

3.8.2 Comparison of user needs and user requirements identified in current R&D projects

When comparing the primary users' needs gathered from literature about the transition between third and fourth age and the user needs as identified by robotic projects, several aspects seem to be of interest:

- *Health deficiencies*: physical deficiencies are well studied, while for cognitive deficiencies, only mild cognitive impairments are considered, probably because researchers doubt that complex robotic solutions would be usable by people with dementia. The only exception are emotional robots which target also people with more severe dementia.
- *Health management*: Application scenarios for health management are well studied, but it seems that this scenario is over-represented, given that the need is rather secondary (e.g., not among the main reasons to change to professional care).
- *Safety and security:* Solutions targeting safety and security needs are very well in the focus of the robotics research community although for some of the main use cases (burglar detection, fall detection) the additional benefits of robots seem rather vague compared to traditional burglar alarms and non-robotic smart home systems.
- *Social factors*, in particular isolation at home, are well covered by current research. As an important result, studies point out that a robot should not aim to be a friend, but always remain a tool for its users [Frennert2013].
- *Financial factors* were hardly considered in user studies, in particular not those of secondary and tertiary users.

3.8.3 Summary of acceptance factors and requirements by robot categories

Most user acceptance studies show high acceptance of and willingness to use the tested AAL robots. Several acceptance factors and their interrelations are described in studies, but valid results on long-term acceptance are scarce and can best be given by the actual uptake of products.

Opinions on the usefulness of robotic solutions vary between stakeholders. In particular, researchers and technicians seem to have a biased vision of what users find useful. This goes especially for Fetch & Carry support, which is thought to be of importance in research, but both primary and secondary users downgraded it because of limitations they see in the application; and emotional robots on which research has a low expectation are found promising by the actual users.

The explanatory power of this analysis is limited because the number of users in the focus groups was small (five and seven respectively). The conclusions regarding the different opinions of users and researchers / technicians are therefore in further need of validation. The under-estimation of emotional robots by technicians at least has already been backed up by a larger sample in [Meyer2011].

Key results:

Main *primary user needs* can be classified into needs regarding (by order of importance)

- **health deficiencies**
- **social factors**
- **environmental factors**
- **financial factors**

Robotics R & D deals sufficiently with health deficiencies (e.g. mobility, dementia) and social factors, although evidence of effectiveness is lacking for the latter. Environmental factors can only partly be solved by robotic solutions, and risk to be limiting factors for them. Financial factors are largely neglected in user studies carried out by robotics researchers, while health management needs seem over-represented as compared to their secondary role as reason for institutionalization.

AAL robotics have a high potential to support *secondary user groups* (formal and informal caregivers) through direct (lifting, carrying) and indirect (patients' mobility) physical support. Secondary positive effects on emotional well-being, stress reduction and quality of life of these users can be assumed, but evidence is still lacking.

Needs of *tertiary users,* in particular cost efficiency, are rarely taken into account by R&D. Long-term studies to produce evidence of positive impacts are still rare.

4 Technical potentials and limitations of AAL robots

This section contains information on technical and methodological challenges in the development of AAL robots, analyses the state of the art in R&D and gives an overview of current technology readiness achieved by different robot categories.

The results presented in this chapter are based on an extensive literature review that investigated relevant research projects in Europe (see also section 2.3.2.2) and analyzed their results for current technical and methodological difficulties. For already completed projects, papers and public deliverables were searched for a) on the projects website, b) by contacting responsible investigators, c) by searching in the publications of institutions which were responsible of the evaluation tasks within the project and d) by searching in the projects' list of publications typically provided in the public deliverables.

4.1 Key technical challenges and functionalities

Three main capabilities of AAL robots can be extracted from current research prototypes and commercial products.

- Physical support
- The robot's social presence and its influence on emotional and psychological aspects such as attachment and regulation of emotions.
- The robot's unique interaction capabilities enabled by the capability to use gestures and mimics, facilitating a human-like way of interaction.

Robotic applications that do not harness these key capabilities can usually be replaced by simpler or cheaper solutions such as smart-phones or wearable technologies and hence have to justify the typically higher resources needed.

To enable the use of these key capabilities, the "Robotics 2020 Multi-Annual Roadmap" [eurobotics2015] has identified nine *key robotic abilities* (see Figure 15) that come with their own *key challenges*.

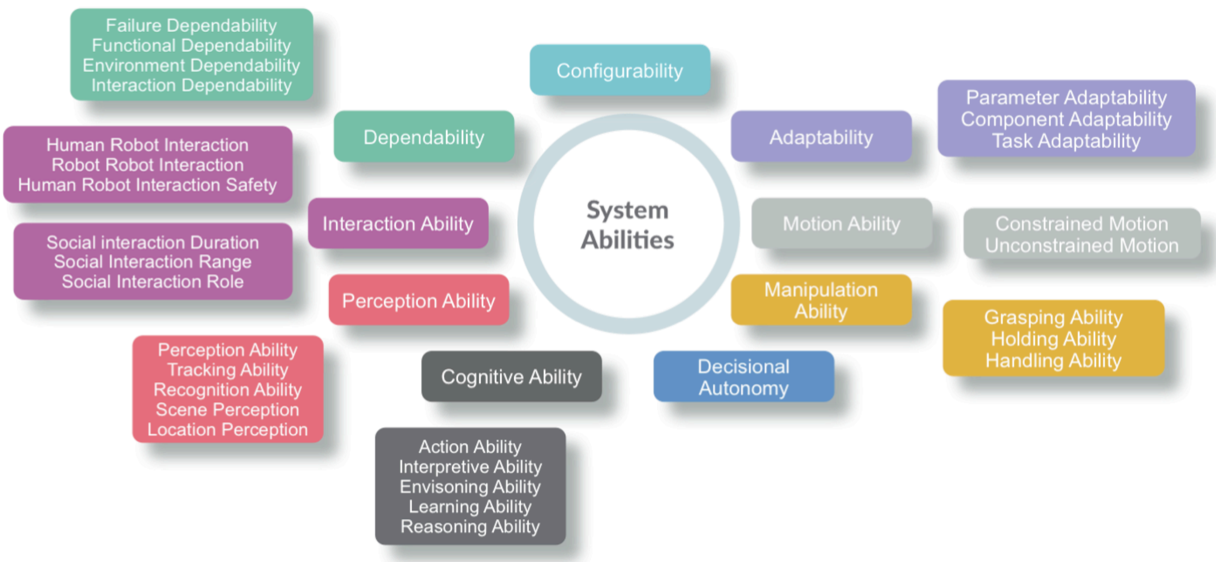

Fig. 15. System abilities as in [euRobotics2015], each "ability" comes with its own challenges

These key robotic abilities are described in detail in [eurobotics2015]. The following paragraphs give an overview of the defined abilities, present the state of the art of barriers related to these abilities from recent findings, and their relevance for the field of AAL Robotics. The robotic abilities "integratability" and "power autonomy", particularly relevant for AAL robots but not listed in the euRobotics Multi-Annual Roadmap, were added.

4.1.1 Configurability

The primary user group of AAL robots are older users at their own homes showing a *multitude of different needs*. The ability of robotic solutions to be configured to serve the particular need of the current user and to take into consideration the specific user requirements would not only enhance the acceptance of AAL robotics but also be a prerequisite for the usefulness of such devices. The configuration of AAL robots in many cases has to be undertaken by (informal) care-givers *without a technical background,* introducing the need for a *simple and intuitive configuration*.

Current research platforms and commercial products typically show a very limited configurability as they restrict the functionality to specific use cases and choose a limited subset of the target group in order to enhance reliability.

4.1.2 Adaptability

The ability of AAL robotic systems to adapt the functionality to the needs of the user is an important factor, as the needs of older users are known to *change over time*. Additionally AAL robotic systems need to be adaptive to *changing environments* because home environments change during operation, e.g. changing furniture, changing light and weather conditions, and other people or animals. It is currently not well researched how systems can provide this adaptiveness as *long-term studies are rare* within AAL robotics.

4.1.3 Motion ability

Given that mobility impairments are the most relevant limitations of the primary target group, the ability to move (and potentially support/carry) users is among the most central functionalities of AAL robots and also presents the most demanding challenges, as moving robotic parts can also be a *potential danger* to the users. Motion ability requires means to safely control the motions and prevent humans from physical harm. Solutions for this issue that are currently under research involve compliant movements that are either too weak or slow to cause physical harm or are regulated e.g. to stop in case of human contact.

The demands on motion abilities of mobile robots for AAL are high and are typically *not met by current prototypes*. Challenges include moving over steps (door-sills), stairs, carpets, and navigational aspects such as tracking the user(s) and navigating through a cluttered environment [Lucia2013]. The ability to navigate raises the need for high-level cognitive abilities as the robot needs to determine where to move to and how to get there in real environments. [Kosman2013] reports an issue found during the evaluation of a companion robot due to a lack of sensor robustness and accuracy when detecting small or slim obstacles such as the legs of chairs.

How motions are carried out in terms of speed and movement patterns is also a current research topic within HRI. The demands of movements for physical HRI are high in particular as the robots' movements need to be *smooth* enough to support e.g. gesturing, *fast* enough to express emotions, and at the same time *weak* and *slow* enough in order not to cause a safety issue.

4.1.4 Manipulation ability

The ability to grasp, hold and handle objects is necessary in particular for fetch & carry type robotic solutions and manipulation aids. As objects to grasp *vary in shape, color, fragility and density*, grasping is a complex task relying on high-level perception and cognitive functionalities, which are still in the state of research and therefore typically not robust enough for applications in the field. Recent studies found difficulties in grasping objects standing in corners or too close to other objects / walls, the impossibility to grasp books lying flat instead of standing upright, and damage of grasped objects [Lucia2013].

4.1.5 Decisional autonomy

Autonomous decision-making based on fuzzy or incomplete data is necessary for mobile AAL robots because of the limitations of perception and cognition abilities. Safety relevant applications that should prevent the user from harm such as medical alerts have high demands on decisional autonomy as the AAL robot has to decide between triggering a potentially annoying false positive alarm and saving the user. Robots that display human-like HRI have high demands on decisional autonomy to generate a convincing, enjoyable socially intelligent interaction experience.

AAL robots that act autonomously typically also have to decide on questions that target the well-being of their users. In this regard several *ethical and legal hurdles* have yet to be solved. (see also chapters 5.5 and 5.6)

Current *decisional autonomy is limited* as could also be shown by [Kosman2013] who reports of troubles of the evaluated companion robot to correctly identify that it had navigated successfully to its goal, thus driving away or in circles with negative impacts on user acceptance.

4.1.6 Cognitive ability

Real environments are uncertain and dynamically changing, which requires robust technology that can deal with uncertain data. Probabilistic reasoning, learning and other AI algorithms have high potentials, but they currently often lack the robustness for long-term usage in real-life. An example that creates high demands on cognitive abilities is human-like HRI that needs to understand the intentions of users in order to act socially intelligent.

4.1.7 Perception ability

The ability to correctly perceive the environment is a key challenge for mobile AAL robots as they act in *highly unstructured environments* (at users' homes) and hence not only have to perceive their surroundings including a high number of everyday objects, but typically also to recognize the users and differentiate them from other people, objects or animals. To aggravate these hurdles several objects typically present in users' homes are known to be particularly *hard to recognize by current sensors* such as coffee tables and stools because of their small size and often thin legs, objects made from glass or reflecting materials such as mirrors. The limited field of vision of optical sensors (cameras or 3d cameras) is an issue as they allow robots to perceive only a small section of the surroundings that becomes smaller the closer the robot moves to the observed scene.

As with all robotic abilities, the demands on perception are strongly varying with respect to the application domains. Whereas a dedicated household robot needs only a low perception ability of its environment, a humanoid companion with human-like interaction capabilities would need to correctly perceive not only the user to interact with, but also the intentions and current needs of the user which is currently far from state-of-the-art.

Typical challenges for mobile robotics include: Non-optimal lighting conditions for robot cameras or problems of detecting objects on windowsills due to backlighting through windows [Lucia2013]. It also depends on the type of sensors used whether some materials are difficult to detect, e.g. glass by laser scanners [Kosman2013].

4.1.8 Interaction ability

AAL robots typically need to interact closely with primary and secondary users who receive assistance from the robot. High social interaction skills and natural human-robot interaction were shown to be beneficial for the acceptance of robotic solutions also as the particular user groups involved are not trained to work with robots and expect simple and natural technical interfaces. Current robotic systems are typically limited to execute pre-defined actions autonomously when interacting with users leaving a high technical potential unused. Robots are typically found to be too slow due to mechanical and cognitive reasons, see also [Lucia2013].

4.1.9 Dependability

The described abilities mostly depend on algorithms that, due to the complex nature of the unstructured environments the robots are used in, use statistical models for reasoning. This means that every sub-task the robot does has a likelihood to fail, which sums up to relevant failure rates as soon as the complexity of tasks and the number of sub-tasks increase. The longer the robot is in operation, the further it travels and the more tasks it undertakes, the higher is the likelihood of failure, which leads to dependability issues.

For this reason a "Robot Marathon", an endurance challenge, was undertaken with companion type robots within the EU FP7 project "Strands" (see also chapter 2.3.2.2). The aim of this marathon is to keep the commercial Scietos A5[35] based robots running without expert help for as long as possible and to drive the longest distance indoors. In 2014 the best runtimes achieved were around 24 hours and the furthest average distances covered were around seven kilometres.

Another example is given within the KSERA project where the companion type robot was trialed in a living lab setting. Out of 529 test cases measuring the reliability of robotic functions during the user trials it was found that only around 85 % of test cases regarding the navigation & localization, 90 % of test-cases regarding speech interaction and around 75 % of test-cases regarding face detection were completed as planned [Lemberger2012].

Considering an application in the medical sector or at home with older users possibly depending on the robot's services, it becomes clear that the reliability is still a major issue, in particular for companion type robots. *Vulnerable users might depend on the proper functioning of the robotic service.* A care organization can only transfer tasks to robots if they are reliable and stable enough to be trusted to provide the intended functionality, which implies extensive (clinical) trials of AAL robots in real-life environments.

The severity of this issue is due to the complexity of robots and their demand on complex cognitive functionality, which explains why certain simpler types of robots such as entertainment, emotional and household robots do not face this issue to the same extent.

4.1.10 Integratability

AAL robots have to be integrated into unstructured environments that were not built for housing autonomous machines. Environmental factors such as: "How can the system be integrated into one's premises?" "Do the premises have to be barrier-free and are there modifications (automatic doors, furniture, door sills, carpets, wiring for automatic lawn mowers, …) necessary?" A typical requirement of users regarding this factor is pointed out in qualitative studies such as those by [Frennert2012]: "I do not want the robot to take up too much space in the room and I must be able to put it away into the closet". Similar challenges reported for applications of companion robots include: too much space required by the robot to move, and damage to objects, walls or robotic parts during movement [Lucia2013].

[Soroka2012] studied the environmental challenges for mobile service robots at home or in a hospital environment and found the following main obstacles:

- *Doors* in their variability (push-pull, slide, automatic, glass, solid wood, etc.) are a major challenge. How the robot opens and closes them and how the robot avoids blocking doors needs to be taken into consideration. By the application of home automation technologies, such as automatic door openers, this issue can be handled.
- *Windows* are a challenge for robots that rely on laser based sensors such as the LIDAR sensor which fails to detect glass.
- *Movable objects and furniture* are challenges as they might not get picked up by the robot's sensors (e.g. because of their size being too small for the sensitivity of the sensors or their material or colour). Their change of place may not allow the robot to pass by or to find an object it tries to deliver to the user. Integratability was an issue in the SRS project where furniture and curtains had to be removed in order to train the robot to the flat's surroundings, and paths had to be made wide enough for the robot to move [Lucia2013].
- *Floors* can be made of different materials of which in particular long carpet piles present a problem for some platforms. The major issue are small steps such as door sills that some robots cannot overcome. For example the companion robot of the Florance FP7 project was reported to not being able to roll over even small door sills [Kosman2013] and carpets hindered the movement of the robots in general in the SRS project [Lucia2013].
- *Stairs and elevators* present a significant challenge for the deployment of a robot in a house (considering also the typical weight of a companion robot of rather tens of kilos). Stair climbing robots are still in an early research state and elevators would need technical interfaces

[35] http://metralabs.com/index.php?option=com_content&view=article&id=67&Itemid=66

for robots to be controlled via M2M communication. Stairs also pose a safety issue to robots as they might fall down.

- *Users and other people* can also be considered moving obstacles and are challenging as they require the robot to navigate around them in a socially acceptable way. Furthermore people typically move faster than today's mobile robots, requiring the robot to react quickly and e.g. to move out of the way. Scheidling et al. found that in a care residence the speed and size of the used mobile robot led to a knot of older users with walkers queuing up behind the robot as it was moving slowly through narrow passages [Scheiding2015].

4.1.11 Power autonomy

Energy efficiency and power autonomy is crucial for mobile robot applications as lack of power autonomy leads to times of non-operability, and, in case of mobility aids, even to the risk of leaving the user stranded halfway to their destination. Self-charging systems that allow robots to autonomously recharge and to stay at least partially active while charging are state of the art.

4.2 Methodological issues of current research projects

Bemelmans et al. found that the methodology used to study the effects of assistive robots in current research suffers from limitations, is rather vague and often not replicable, which limits the scientific value of presented evidence [Bemelmans2012].

This chapter is focused on the particular kind of multi-purpose companion robots as they are currently focused on by AAL robotic research projects as shown by the large number of scientific projects within this field. Out of 16 already completed collaborative projects on European level, only three did not work on companion type assistive robots.

This section presents several methodological issues that were brought up by the authors of reviewed evaluation reports of research projects or became evident during the review process itself.

4.2.1 Lack of technical robustness and functionality of prototypes

Several projects reported technical issues that influenced the end user evaluation in particular regarding the measurements of user experience and acceptance [Pigini2013][Schröter2014]. The issues were mainly due to a lack of robustness and reliability of prototype-level components and the complex integration of many prototype parts multiplying individual probabilities of failure. Pigini et al. report the usage of complex scenarios as an issue. The same authors also report that during some evaluation phases, high numbers of the scenarios demonstrated to the users (up to 70 %) showed technical issues. Users noted issues and reports also suggest that this influenced the evaluation results [Pigini2013]. Schröter et al. found that in particular speech recognition rates were dissatisfying and users therefore did not use this, often preferred, mode of communication, but an alternative input via touch-screen on the robot [Schröter2014]. This implies that one of the core aspects of companion robots – the multi-modal human like interaction – could not be evaluated.

Heylen et al found that a poorly designed robot frustrated people and hence biased results on acceptance [Heylen2012].

In addition to lacking robustness, also the functional capabilities of current prototypes did not allow for real-life trials as was shown by Pigini et al. who report of necessary changes of the environment to successfully integrate the robots. In one case objects made from glass needed to be covered, as the robotic sensors could otherwise not recognize them. In other furniture needed to be displaced to allow the robot to navigate along obstacle-free paths [Pigini2013][UWE2013].

Low technical reliability and functionality is an issue particularly in early prototypes, nevertheless users were involved early in the design and evaluation process to gather early results on user experience such as in [Pérez2014] and [Pigini2013]. It is difficult to assess whether such early user interactions can provide valuable input given the influence of technical malfunctions on the perceived usability and overall impression on the participating users.

4.2.2 Difficulties in conducting user trials with older users

Older users are a very heterogeneous group with strong inter-individual differences. These differences seem to not been taken care of by parts of the literature base as most reviewed projects report to select their participants mainly based on the chronological age, which assumes they would have otherwise similar conditions. This is not the case as also Britt Östlund argues: "… chronological age is not a sufficient measure for older people's life situation" [Östlund2014]. This issue leads to heterogeneous user groups within the trials making it hard to derive design conclusions from experiences and results gathered, which was also found by Payr et al. [Payr2013].

Aside of technical issues, the inclusion of vulnerable participants does give the risk of either a higher number of user dropouts or the need to strip down the initially planned trials to methods suitable for this particular user group. Rehrl et al. report changes in the test flow leaving important parts of planned trials out because the poor health-status of participants did not allow their further involvement and hence further investigations [Rehrl2012].

4.2.3 Lack of accepted methodologies

Feil-Seifer et al. critique that "Although it is difficult to compare robotic systems designed for different tasks, it is important to do so to establish benchmarks for effective and ethical SAR design." [Feil-Seifer2007]. Currently it seems not feasible to compare results between studies because a respective methodology is lacking. Hardly any standardized research instruments were used in the reviewed literature implicating that the research field of assistive robotics is still in an "exploratory" state where qualitative methods and subjective measurements are predominant. Ganster et al. raised this point as well [Ganster2010].

In addition to missing methodologies Amirabdollahian et al. argue that some of the few existing and commonly used methods are not appropriate for long-term real-life trials as neither the Almere Model nor the earlier UTAUT model [Venkatesh2003] are specific enough and based on lab studies rather than real-life studies. The authors argue that the used constructs in the Almere model are not sufficient to predict future use as "… self-efficacy and self-esteem moderate the relation between intention to use and actual use" but are not included in the model and additionally in general: "What people respond in a questionnaire about the intention to use in general does not comply with their actual use of the system in the long run." [Amirabdollahian2013]. However literature reviewed used this method mainly to gain insights on acceptance factors, not to predict future use.

4.2.4 Issues regarding long-term field trials

Only a limited number of studies were able to perform field trials [Heylen2012].

None of the reviewed field trials so far reached a minimum duration of two months, which would be necessary to gain information on acceptance without bias of initial excitement by participants [Broekens2009]. However Britt Östlund et al. very recently report of currently undergoing trials with the Giraff robot that target this issue [Östlund2014].

[Heylen2012] found that real-life trials at users' homes do not necessarily reduce experimental biases of typical experimental procedures such as socially accepted answers and biases in engagement with the prototype. [Heylen2012] argue as well that although real-life experiments were conducted in real-users' homes, the character of an experiment to the users was still evident and according to interviews, users also behaved differently during interaction phases having the nature of a research project in mind. This conclusion was however not confirmed by qualitative analysis of observational (video) data [Payr2013] which revealed that users showed natural interaction behaviour most of the time. Still, the situation is not comparable with the situation after deciding to acquire a robot and using it at home by own determination.

4.2.5 Further issues

Impact measurements, such as measurements on the user's quality of life or the users care were undertaken in short-term user trials in a living lab situation. Impacts are typically measured within long-term investigations by means of pre-post measurements such as shown by [Cesta2013] and

[Pérez2014]. It seems an open question whether measured impact factors over short term can provide valuable information on later long-term impacts in the field.

Authors report the high time requirements of individual short-term user trials which allow for only approx. two trials a day, because of large efforts to set-up and control the robotic prototypes. This directly limits the number of users involved. The number of primary users that participated in trials was hence low; typically about 10 in short-term and 4 in long-term evaluations.

Finding information on evaluation methods and study results from user trials on companion robots is surprisingly difficult although this information represents one of the main outcomes of such research projects. This might be due to the fact that the evaluation phase within the funded projects mostly takes place at the end of the projects, hence publication of the results might not be possible within the project's lifetime, which raises a funding issue. Another likely reason is that researchers do not feel comfortable with publishing evaluation results because of the mentioned common methodological issues and their impact on the quality of the results.

4.3 Analysis of the technology readiness of current research projects

By analysing the literature on evaluation methods from European robotics projects, typical evaluation phases could be identified and related to the model of technology readiness proposed by the "National Aeronautics and Space Administration" (NASA).

"Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology" [NASA2015]. In particular for projects with the aim to develop an assistive companion robot, the technology readiness influences the aims and methodologies selected for evaluation, as the common main goal of the evaluation is to derive new design guidelines for later stages of development according to the user-centered design process. The model was adopted by scientists within the robotics community, in particular by the team at euRobotics within the "Multi-Annual Roadmap" [euRobotics2015] to describe the future goals of robotics research, and is hence an established model to describe robotic prototypes. See also **Fehler! Verweisquelle konnte nicht gefunden werden.** for an overview of the levels of technology readiness. The highlighted items in the table show the levels of technology readiness achieved by current research projects.

Table 4. Technology readiness levels as proposed by NASA [Nasa2015] and customized to robotics by [euRobotics2015].

TRL	Description
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	**Technology validated in laboratory**
5	**Technology validated in relevant environment**
6	**Technology demonstrated in relevant environment**
7	**System prototype demonstration in an operational environment**
8	System completed and qualified
9	Actual system proven in operational environment
10	Commercial

As the technology readiness of a prototype can be best estimated when assessing the methods used for evaluation, including the test settings and users involved, reports of European projects on companion robots were analysed.

The following methods were found in literature and represent the current state of the art of end-user evaluation of AAL robots with respect to the technological readiness of the prototypes.

TRL-4 – TRL-5: Technology validated in laboratory or relevant environment

At these technology readiness levels the following evaluation methods can be typically found: functional tests [UWE2013], [Merten2012], usability evaluations by experts (e.g. using Nielsen's Heuristics [Nielsen1990]) [Schröter2014], [UWE2013], [Nielsen1990], system pre-tests with project-affine users [Pigini2013] and integratability tests to gather information on potential issues with integration of the AAL robot to real environments [Pérez2014].

TRL-6: Technology demonstrated in relevant environment

Workshops, focus groups and group discussions are often undertaken to gain insights on prototypes in this stage of development [Cesta2013][UWE2013]. Short-term scenario-based user trials under controlled conditions are the most common evaluation method that are typically conducted in living lab laboratories mimicking real environments [Kosman2013], [Lucia2013], [Ihsen2013], [Fischinger2014]. Longer user trials under controlled conditions were undertaken inviting users to stay in controlled environments over night, or inviting the same users several times to gain deeper insights into effects of the robotic system in the longer term [Schröter2014].

TRL-7: System prototype demonstration in an operational environment

Field trials were undertaken by some projects and in particular by using either off-the-shelf robotic systems or functionally minimal robotic solutions, e.g. with restricted ability to interact (compare also [Leite13]).

Out of 13 analyzed research projects on companion type robots at European level, most reached technology readiness level five or six. Three European FP7 funded projects (ExCite, Accompany and SERA) were able to conduct field trials with users and hence reached TRL-7. The currently running European FP7 funded project "Hobbit" was not included in the analysis as results are not yet published, but real-life trials with end-users over the duration of three weeks in two countries were planned and are currently being conducted.

4.4 Summary

4.4.1 Summary of key technological capabilities and issues

High demands on key robotic abilities make the field of AAL robotics a challenging research topic. It is generally recognized that multiple step changes are necessary in particular for mobile AAL robots to provide an identifiable benefit to the users.

The levels of ability needed depend on the application area. Simpler robotic solutions such as emotional robots have lower technical demands and can hence achieve higher technology readiness levels, reaching even commercial level such as the Paro robot.

Table 5 gives a rough overview of the demands on robotic abilities by different robotic categories. The demands on robotic abilities vary strongly between robotic categories, which is the technical reason for the differing technology readiness levels and might also explain the focus on Socially Assistive Companion robots in current R&D, given that this is a particularly demanding research field.

Table 5. Estimation of demands on robotic abilities by different AAL robot categories (low demand, *** high demand)*

Demands on robotic abilities	Configurability	Adaptability	Motion Ability	Manipulation Ability	Decisional Autonomy	Cognitive Ability	Perception Ability	Interaction Ability	Dependability	Integratability	Power Autonomy
Household Robots	*	*	**	*	*	*	*	*	*	**	*
Emotional Robots	*	*	*	*	*	*	*	**	*	*	*
Socially Assistive Robots	***	***	**	*	***	***	***	***	**	***	**
Personal Care Aids	**	*	**	*	*	*	*	*	***	**	*
Robotic Manipulation Aids	**	*	**	***	*	*	***	*	***	*	**
Robotic Mobility Aids	***	***	***	*	*	***	***	*	***	*	***
Fetch & Carry Support	***	***	***	***	**	**	***	**	**	**	***
Rehabilitation Robots	***	*	***	*	*	*	*	*	**	*	*
Telepresence Robots	**	*	***	*	*	*	*	*	***	***	**
Entertainment Robots	**	*	*	*	*	**	**	**	*	*	*

4.4.2 Summary of methodological issues

Several methodological points for discussion were found, which were raised partly already by other authors, such as the common lack of technical robustness and consequences thereof, lack of scientific quality regarding the selection of research methods, partly caused by a general lack of commonly accepted methodologies that would allow for comparison of data between research projects and low number of published results in general.

Technical issues hinder evaluation of the user experience and acceptance of companion robots. Due to the complex technical nature of assistive robots involving artificial intelligence with less than 100 % accuracy and reliability as well as non-product grade hardware components it seems clear that technical issues were and will be present in most evaluation phases. This is to be taken into account by the acceptance and usability researchers who have to ensure a system which seems perfectly working to the user in order not to bias the evaluation results in particular on acceptance and user experience.

Even in large European Projects funded extensively by the European Commission and lasting for three years or more, the ideal of the user-centred design process to reiterate several times the cycles of design, development and evaluation until the prototype is mature enough to advance to the next step of productization does not hold. Most literature reports only one or two main trial phases with the integrated prototype implicating a maximum of two cycles within the process. The reason for this seems to be the exceptionally high technical complexity of prototypes and high research efforts needed from different disciplines, resulting in long development times.

Out of 16 researched projects in the field of assistive robotics, only three did not belong to the field of companion robotics, which shows that the research field is currently heavily focused on this particular type of robots.

4.4.3 Summary of technology readiness

The following graph gives an overview on the technology readiness levels of current products and prototypes and shows that certain categories of robots are technologically more advanced than others.

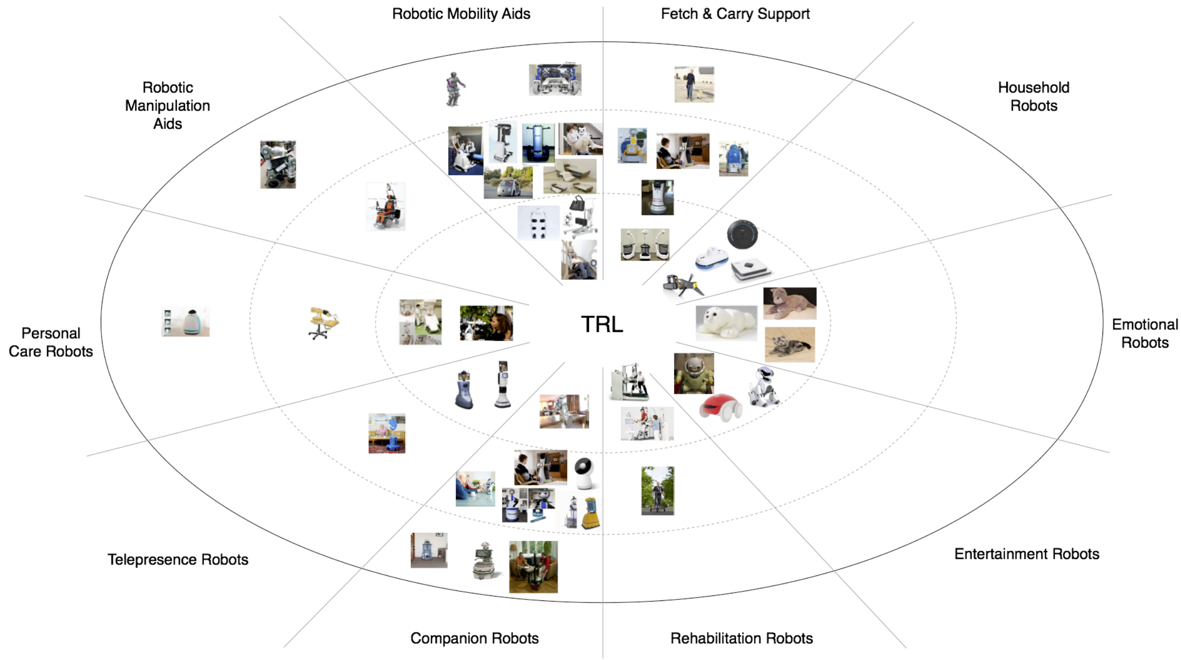

Fig. 16. Overview on current robotic solutions and prototypes by technology readiness level (inner circle = TRL 10, middle circle = TRL 5-9, outer circle = TRL 1-4)

<u>Key results:</u>

High demands on key robotic abilities, varying by robot categories, make the field of AAL robotics a challenging research topic. The particularly high demands on mobile socially assistive robots make them both an attractive research field and a field still far from developing marketable products.

Household robots and emotional robots, as well as some robots for the institutional market (rehabilitation, mobility/lifting&carrying) have already been commercialised.

As a rule of thumb we can state that, because of the complexity of AAL solutions (vulnerable target group, unstructured environment, complex user needs), the more a solution corresponds to what we understand to be relevant for AAL, the further away it is from the market.

5 Market potential of AAL Robotics

Departing from the current meager state of data on sales and predicted sales of AAL-related robots, this chapter extracts information from studies on market potential of AAL robotics from the related fields of AAL technologies and robots in healthcare. A critical review of these studies shows that their assumptions only partly hold for AAL robotics. After presenting and discussing some examples of commercial or near-commercial AAL robots, this study proposes a scenario-based approach which simulates purchasing decisions for two of these robots. The chapter also summarizes legal, ethical and standardization issues which are considered to be of relevance to the productization of AAL robots.

5.1 Current sales and forecasts

In the IFR statistics for 2013 [IFR], most of the robot types that are included in the category of AAL robots in this study fall into the group of "service robots for personal and domestic use".

In 2013, about 4 million service robots for personal and domestic use were sold, 28 % more than in 2012. The value of sales increased to US$ 1.7 billion (€ 1,5 billion). So far, service robots for personal and domestic use are mainly domestic (household) robots, which include vacuum and floor cleaning, lawn-mowing robots, entertainment and leisure robots, including toy robots, hobby systems, education and research. IFR predicts that sales of all types of robots for domestic tasks (vacuum cleaning, lawn-mowing, window cleaning and other types) could reach almost 23.9 million units in the period 2014-2017, with an estimated value of US$ 6.5 billion (€ 5,8 billion).

In 2010, the Japanese Ministry of Commerce published forecasts of robot sales that also predict a huge growth in the sector of service robots, however without breaking it down into more detailed robot categories: [36]

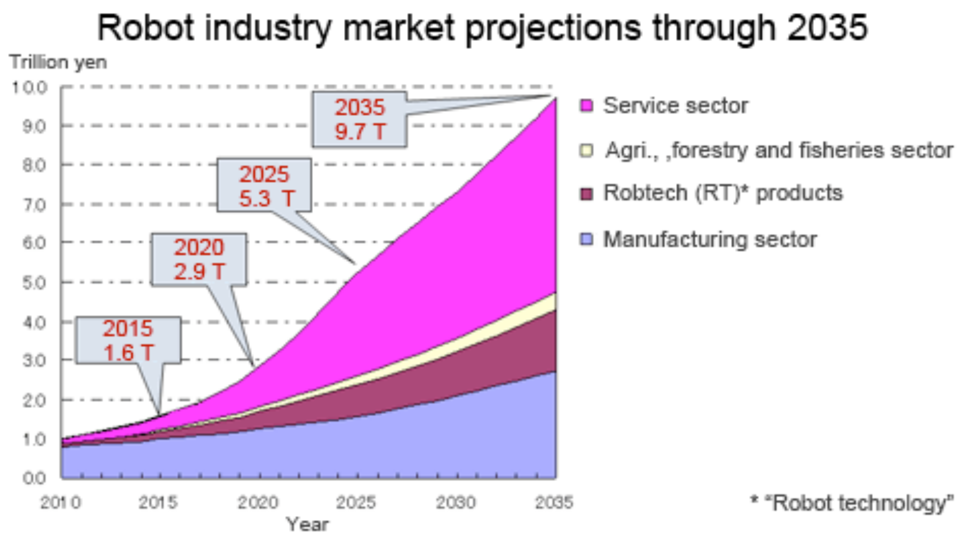

Fig. 17. Japanese robot market projections, 2010, http://www.meti.go.jp/english/press/2013/pdf/0718_01.pdf

Compared to the impressive numbers for the entire field of service robotics, the numbers of robot types that are more related to the field of AAL look very modest. In 2013 a total of about 700 handicap assistance robots were sold, up from 160 in 2012. Sales of robots for elderly and handicap assistance are predicted to reach about 12,400 units in the period of 2014-2017. IFR predicts that "this market is expected to increase substantially within the next 20 years"[37], but does not make any more concrete statements about numbers or value.

[36] http://www.meti.go.jp/english/press/2013/pdf/0718_01.pdf
[37] All data from IFR: www.ifr.org

5.2 Studies on cost-effectiveness and business models

Three studies were found to be relevant for the present study and are reviewed in this section: two of them concern AAL technologies in general, while one study deals with the whole field of service robotics, including a case study on care robots to which we refer here. The goals of these studies are different: development of AAL business model types, health-economic market potential of AAL technologies, and cost effectiveness of care robots in institutional settings, respectively.

5.2.1 Study on the Development of AAL Business Models

This study, contracted by FFG-benefit, developed three types of business models.[WPU2013] Two of these models concern a complete domotics and telecare solution. The price of this solution is estimated at € 2800 with a monthly contribution of € 40. In scenario 1, initial costs are borne by public authorities while the clients have to pay the monthly fee themselves. Through compulsory inclusion of the AAL solution into the service package of the care provider, market penetration is guaranteed. In these conditions, a company providing the operational services in cooperation with the system integrator could approach the break-even point. If clients have to finance the initial costs through their monthly fee, the amount would reach a level which would not be acceptable to most clients.

In scenario 2, the same initial costs have to be borne by private households. The study concludes that only big companies in a related field, e.g. telecom providers, would have the financial capacities, target audience, and expertise, to launch the product successfully. The market would probably remain limited to higher income groups. The chances of success would depend on the services offered and on the value that older people and their families attribute to them.

The AAL solution in scenario 3 is, at € 1900 cheaper, because it addresses pre-care services that promote comfort and healthy lifestyle for older people who have no need for care applications. The later upgrade to telecare remains an option with this system. The type of business model is basically the same as for scenario 2, as are the risks and chances.

The conclusions of the study are optimistic but only on condition of public financial intervention on the AAL market. The appeal to public authorities, however, is not backed up by a macro-economic calculation how funding of AAL solutions can lead, in the long-term, to decreases or at least to a slow-down of increases in public spending for health and care.

5.2.2 Market potential of AAL Technologies

The study on the market potential of AAL Technologies carried out by the Fraunhofer Institute in 2009 [Berndt2009] tries to fill this gap at least in parts.

As in the previous study, one of the assumptions was that healthcare related AAL technologies would have to be refunded by the social security and care insurance system. The authors apply the methods that are usually used in health and care systems to evaluate whether a new method or device should be accepted to the list of covered services. Such a decision should be based on the evidence that the new product either leads to an increase in quality adjusted life years (QALY) or maintains the standard at lower cost. New methods and devices are therefore calculated on the basis of the cost per QALY.

The study considered three AAL products: telemonitoring, an electronic pillbox and the eShoe [Oberzaucher2010]. From the point of view of health economics, AAL technologies carry the risk of relatively high process costs that are not compensated by savings through longer time at home, reduction of mobile care costs, reduction of emergency cases and stays in hospitals, or mobile medical services. The higher costs of AAL technologies compared to the status quo therefore require good evidence that they lead if not to savings, at least to better cost-benefit relations.

For telemonitoring in the case of cardiovascular diseases, there is evidence of positive effects on mortality, but the actual influence on the economically important parameter of residence time in hospitals still remains unclear. The benefit of the electronic pillbox could be seen in increased therapy conformance and the reduction of errors in medication, but evidence for these effects is missing. The eShoe promises prevention and recognition of falls as well as reduction of fear of falling. Real effects and the role in the framework of complex prevention and anxiety reduction interventions are still uncertain.

The authors conclude that evidence for health economic effects of AAL technologies is scarce, maybe with exception of telemonitoring. Available data are insufficient e.g. for acceptance of individual AAL technologies in the list of services covered by the statutory health insurance funds. ([Berndt2009], p. 62-63)

The player that first comes to mind when it comes to participating in financing of AAL technologies are the statutory health insurance companies. From their perspective, it is possible to determine the cost categories to be considered, namely all types of costs covered by health insurance: acquisition and maintenance, medical services related to AAL technologies.

However, if people are enabled to live in their own homes longer with the help of AAL technologies and thus contribute to save costs for mobile and stationary care, it is the care insurance company that benefits and not the health insurance. Therefore, the study concludes that these are no valid arguments for health insurances to invest in AAL technologies. ([Berndt2009], p. 48)

5.2.3 EFFIROB Study

[EFFIROB2011] undertook an analysis of the cost-effectiveness of service robotics for the German Federal Ministry of Education and Science. Although the title of the study includes all kinds of service robotics, i.e. also private and domestic, the analysis covers only scenarios of professional application fields. One of these scenarios shows some overlap with the field of AAL Robotics as defined in the present study, namely: lifting and carrying patients. In what follows, we will summarize this scenario and the results of this analysis, with a focus on methodological questions.

[EFFIROB2011] used a combination of methods to arrive at predictions about cost-effectiveness of different service robots:

- Axiomatic Design was used to break up the functionality requirements and design parameters of the service robot system. For the case study on carrying and lifting patients, the activities of care workers, the environment where they take place and the objects that they use were listed in detail. This leads to the functional requirements for the robotic systems in the areas of perception, manipulation, and mobility.
- On the basis of these requirements, a conceptual design for a robot was made and its production cost calculated.
- Life Cycle Costing was used to estimate the cost of the service robot. The authors assumed a service time of 12 years for the robot and added, to the purchase price, costs of energy, personal, installation, maintenance and replacement parts. The purchase price was composed from the known prices of existing components and from estimated prices of prototype components.
- Market structure analysis: assumptions were made about the potential buyers of such a robotic system in Germany and about their financial capacity for such investments.

The result of the analysis is discouraging: the authors see no market potential for service robots for lifting and carrying patients. The argument goes as follows:

- The cost of the robot is around 130.000 €. However, this is only a quarter of the estimated life cycle costs. For a service life of 12 years, the total life cycle costs are distributed to the main cost factors as follows (Fig. 18):

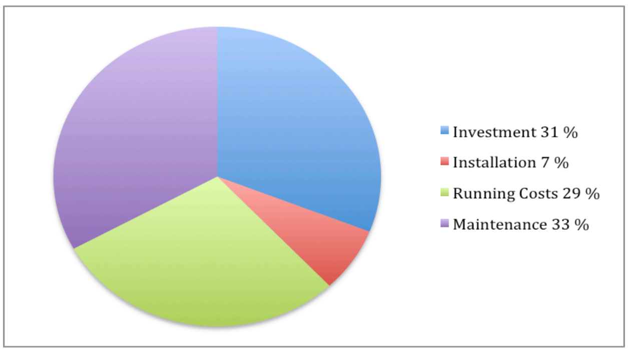

Fig. 18. Breakdown of life cycle cost for a care robot; modified from [Hägele 2011].

- Given that there are already non-robotic lifting and carrying aids, the robot does not lead to a reduction in personnel cost (save in those cases where now two persons are needed for the tasks of lifting and carrying).
- The robot leads to qualitative improvements in the caregivers' work, but these are considered secondary in the investment decisions.
- The number of patients in care facilities and the need for care will rise, but this will not lead to larger amounts of money to be available for important investments. Additionally, only large care institutions (of which there are only few even in Germany) would be able to make such a big investment.

These results seem to lead to the conclusion that, if service robots of this kind have not even a market potential in the professional service sector, it will be utterly useless to even think about the private and domestic sector for the next couple of decades.

Two remarks about the study and its conclusions need to be made, however:

1. The robot design is based on the requirements specifications (Anforderungsermittlung) and REFA-based time and motion studies. The assumption behind using such methods is that the service robot will have to execute a task done by humans in its entirety. The task described here, however (lifting a patient from the bed, carrying him/her to the bathroom, giving a bath, etc.) is by several degrees more complex than the task specifications that were the basis for the successful development of industrial robots. The consequence is, in this case, an extremely complex and expensive robot design.

2. Although the Axiomatic Design Method which the authors have applied puts the markets and customers first (Customer Domain), in their scenario it only follows functional analysis (Functional Domain), not without consequences: customers (in this case primarily care institutions) would probably put the non-functional requirement of cost-effectiveness first, and would weigh the functionality requirements with a view to their value.

The conclusion that robots for lifting and carrying patients have no market potential – which contradicts the overall positive expectations for the field of care robots – becomes less surprising in view of these methods and their application.

But even if the predictions on cost-effectiveness were more positive, the method would not be directly applicable to personal care and domestic robots: it would not be possible to offset the robot's cost against personnel costs. The study does not cover existing markets e.g. of robotic vacuum cleaners whose commercial success is attributed to "fascination and curiosity" ([EFFIROB2011], p. 11), neglecting the customers' value expectations as a motivation for buying the robot.

5.2.4 Conclusions with special regard to Austrian conditions

Both studies on AAL market potential [WPU2013, Berndt2009] come to the conclusion that public funding and subsidies will be necessary to achieve a massive roll-out of AAL technologies. The appeal to public funding is justified by the longer term savings through reducing times of institutionalized care. Even if the assumptions of savings hold and the effects on health economy turn out positive, the system of health and care financing and provision is complex and slow to react. In Austria, not only federalism is a severe obstacle [WPU2013], but also the separation between the care and the health sector. Medical treatment is covered by health insurance to which the labour force and the employers contribute, while the care allowance is paid directly and centrally by the government. Even in Germany, where both sectors are partially funded on an insurance base, they are not sufficiently coordinated (see [Berndt2009], p. 48). To give an example of the consequences of this separation, we list the different kinds of mobile care services:[38]

- medical care (medizinische Hauskrankenpflege): on prescription, limited duration, with the main purpose of reducing time in hospital; delivered by certified nurses and strictly limited to medical treatment and care.
- home nursing (Hauskrankenpflege): no prescription needed, no time limit, also delivered by skilled nurses.

[38] Fonds Soziales Wien, http://www.fsw.at/

- home assistance (Heimhilfe): no prescription, no time limit, delivered by semi-skilled home helpers and caregivers, including household, personal care and social attendance (medical care interventions only by doctoral order)

Only medical care, the first type, is covered by health insurance, although it is provided by the same type of qualified personnel. Both home nursing and home assistance have to be paid by the patient (in part, because these services are subsidized by public bodies, especially regional authorities).

The federal care allowance is granted on the basis of medical diagnosis, but is not earmarked either for appliances or for services (or, as a matter of fact, for any expenditure at all, which is why it often ends up as a welcome addition to old-age pensions). The existence of the care allowance would serve as an argument against funding the purchase of AAL robots (and other technologies): recipients are free to spend this allowance on whatever kind of care or service or device they need, thus leading to a marketization of care. [Bönker2010] This statement has to be qualified in the sense that health insurance does indeed subsidize many different types of appliances that serve primarily in care and not in therapy.

A more realistic scenario then is that AAL robots will have to compete with alternative solutions in mobile care (services and appliances), including other AAL technologies, for the money of the clients and their families in what is called the "second health market" [Becker2012]. They will have to survive on the consumer market (even if subsidized), and any business model will have to take this market into account. and by making robots relatively more appealing economically as compared to care services.

5.3 Care- and AAL-related robots on the market

In this section, we will present a few examples of personal service or care robots that are already on, or very close to the market. We selected examples of which the price is known as a basis for the scenarios in section 5.4.

5.3.1 JIBO – Desktop robot

Fig. 19. JIBO

JIBO is a little pod with a motorized swivel, equipped with cameras, microphones and a display. It recognizes faces and voices, and can act as a personal assistant by setting reminders, delivering messages and offering to take group photos. It also serves as a telepresence robot for video chat.

It is being developed by a team headed by Cynthia Breazeal of MIT, known for the social robot head „Kizmet". The social intelligence of Kizmet was transferred to an intentionally abstract form which nevertheless gives the impression of a face. In terms of AI, it is claimed that it recognizes and distinguishes faces, has language processing and emotion recognition, and will be able to learn.

The company has not only been successful on the venture capital market, raising around 25 million US$, [39] it has been partially financed through crowdfunding. The campaign was very successful in that the company was able to collect, until now, over three million US$ in the form of over 4800 pre-orders.[40]

[39] http://venturebeat.com/2015/01/21/jibo-closes-25m-round-for-its-personal-robot-a-cross-between-a-tablet-and-a-puppy/

[40] https://www.indiegogo.com/projects/jibo-the-world-s-first-social-robot-for-the-home#/story

The price that has been announced is US$ 749 (€ 690) for both home and developer editions. The date when shipping will start had been set at spring 2015 but seems now to have been postponed to spring 2016.

The concept of a non-mobile, pet-sized desktop robot reminds strongly of the discontinued Nabaztag (later called Karotz). The intended application scenario as a sort of family reminder, messenger and friendly companion at least is very similar, though the JIBO adds emotional intelligence, wireless operation, and connectivity that corresponds to the requirements of the smartphone era (the obsolescence of the Nabaztag/Karotz' technology seems to have been an important factor why the last owner, Aldebaran, gave up on updating the technology[41]). The Nabaztag was sold 62,000 times in Europe soon after being launched in 2006[42]. It mainly sold as a toy for early robot adopters. Early plans for Karotz updates underlined its practical uses for home surveillance and messaging, but it seems that buyers had never been driven primarily by practical motives.

It can be assumed that the people who have financed and pre-ordered JIBO mostly belong to the same target group as the early adopters of the Nabaztag, namely people primarily interested in new technological gadgets and toys. Practical uses, we have to assume, come second for this group. In a critical article these practical uses are presented as questionable when compared to smartphones and tablets.[43] The question will be, as with the Nabaztag, whether the emotional and playful aspects of the JIBO will play a large enough role in the consumers' decision to ensure a successful market life of the robot.

With regard to AAL, we assume that the JIBO could play the role of a realtively cheap companionable frontend to smart home technologies, with telecommunication and maybe monitoring functionalities (much of this will depend on the openness of the JIBO platform for additional and specifically AAL-related applications). On this market, it would have to compete with intelligent virtual assistants.[44] The use case would be in the domains of attendance (see below), and pre-care services, with possible applications in telecare.

5.3.2 Pepper – Mobile companion

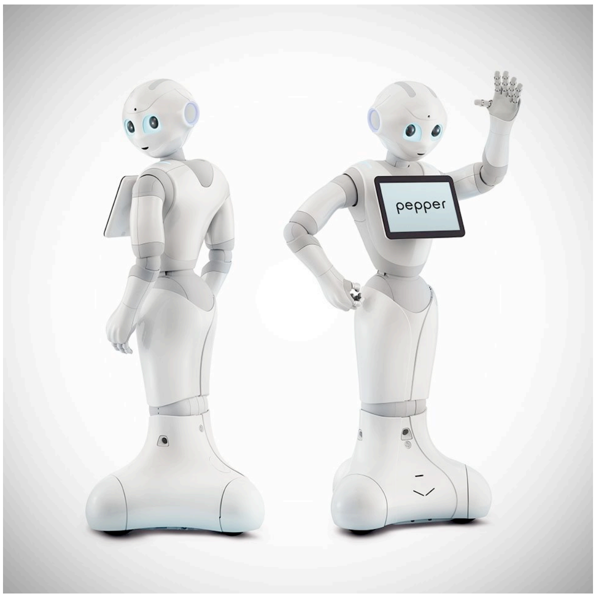

Fig. 20. Pepper

Pepper, developed by Aldebaran Robotics, is mobile, featuring a three-wheeled platform, and has arms. The robot is about 120 cm high, weighs 28 kg and is equipped with cameras, microphones, speech recognition and a sociable intelligence. It is currently deployed as an attraction in the shops of Aldebaran's majority owner SoftBanks in Japan, a leading telecom provider. SoftBank Corp. says it will sell its new humanoid robot at less than the cost of production.

The Japanese telecommunications giant has started offering 300 of the robots to developers in spring 2015, at an upfront price of ¥ 198,000 (about € 1480). Monthly fees, however, will range up to ¥ 24,600 (€ 184) for a three-year contract. Consumer sales have been postponed to summer 2015.[45]

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[41] http://www.01net.com/editorial/630557/r-i-p-nabaztag-2005-2015/
[42] http://www.techrepublic.com/pictures/desktop-toys-the-nabaztag-is-one-lame-rabbit/9/
[43] http://time.com/2994153/jibo-robot/
[44] http://www.therobotreport.com/news/why-are-jibo-pepper-and-other-robotic-assistants-so-important
[45] http://www.engadget.com/2015/02/23/softbank-pepper-pricing/

The monthly costs comprise a basic service fee of ¥ 14,800, which will offer cloud artificial intelligence capabilities, using SoftBank's mobile network. That way, the robots - and app developers - can learn from each other by gathering data on what their owners do with them. About 100 apps are said to be available from the start. SoftBank will also offer an "insurance plan," at ¥ 9,800 a month, providing support and preferential pricing on repairs.

The company envisions Pepper as a companion for the elderly, a teacher of schoolchildren and an assistant in retail shops, among other uses. From the viewpoint of AAL, it seems as yet very unclear what services Pepper will be able to deliver to the elderly, besides being a sociable presence. It can move, but there are no data about its tolerance for uneven ground. It has arms, but to date these are obviously mainly used for expressivity: there is no information available whether it already has capabilities of object recognition, gripping or carrying. Presumably, such functionalities still remain to be developed. The company apparently offers the robot and the services only on the Japanese market to start with,[46] plans for international shipping are not known yet.

At a total price (including the monthly fees) of over € 8000, it is very questionable anyway whether Pepper would be successful on the consumer market. Rather, it is conceivable that it will replace the NAO in research and development labs. With its more practice-oriented mobility solution, Pepper will certainly be an option for AAL-related research and especially for field tests. Again, this will depend on the possibility to implement AAL-related applications.

5.3.3 Resyone – Robotic Bed and Wheelchair

Fig. 21. Resyone

The third example is of a very different nature. Resyone is a robotic care bed with inbuilt wheelchair developed by Panasonic. It was the first robotic application certified as conforming to the ISO13482 standard for personal care robots. The mattress is split in half, with one side remaining firmly in place when the other half is separated to form the body of the chair.

A patient simply needs to move over a few inches to one side, and with a few adjustments he/she will be sitting upright in an electric wheelchair. A single caregiver assists during the transformation process, significantly reducing the burden on staff.

This description points to the primary market targeted by Panasonic, namely hospitals and care institutions. The bed addresses the known health problems of caregivers caused by lifting and moving patients, and also reduces the need for a second caregiver to help with the load.

Since June 2014, the Resyone bed has been commercially available at a price of € 8400.[47] While this is still a multiple of the current prices for home care beds (ranging from € 500 to € 2000, approximately), it adds functionality for lifting and transfer to the wheelchair which is a major issue in particular for aging informal caregivers. It would therefore be interesting also for the private AAL market.

Just as for traditional care beds, rental options would probably be available for such a bed. For a lifetime of 10 years, we estimate that monthly fees of € 150 to € 250 could be realistic. This is much more than what is currently charged on a monthly basis for a traditional simple care bed (€ 50[48]) by distributors of health and care products.

[46] http://www.softbank.jp/robot/price/
[47] http://www.ft.com/cms/s/0/e98a5d08-4ae1-11e4-839a-00144feab7de.html
[48] http://shop.fruehwald.net

5.3.4 Roomba

Fig. 22. Roomba

The robotic vacuum cleaner Roomba, by iRobot, has become the icon and flagship of domestic robotics. Although the high market potential of cleaning robots for both industrial and domestic use had been known for about 20 years, early cleaning robots were not successful, until "the situation changed significantly when a little inexpensive device, more of a toy than a cleaning machine, named Roomba, came onto the market in 2002." [Prassler2008]. The company, founded in 1990 as an MIT spin-off, had started out with industrial and defense robot development. Today, domestic robots generate almost 90 % of sales.

From 2002 to 2006, the company had sold already two million Roombas, by 2014 there was a basis of over ten million Roombas installed worldwide[49]. iRobot is still the market leader in the segment of domestic robots despite the strong competition that has emerged, among them not just imitations, but also rivals in performance [Prassler2008]: "This…success, however, has little to do with Roomba's performance as a cleaning device … It exclusively has to do with Roomba's price." The key obviously is the price, although the first Roomba models also attracted early adopters of high-tech gadgets: there seems to be a price limit even to what early adopters are ready to spend for objects of (at first) doubtful use.

The striking fact about Roomba's initial success, however, seems to be that worries about acceptance were superfluous. The question suddenly was no more whether people would accept a robot in their homes at all, but simply if price and performance were right. Surprisingly, the Roomba which does not have any intentional features of an animate or intelligent being, but simply looks like a disk, even lead people to develop social-emotional relationships with it. [Sung2007] In this sense, Roomba certainly has paved the way for other kinds of domestic robots and also, we can assume, for future AAL robots.

5.3.5 ZORA

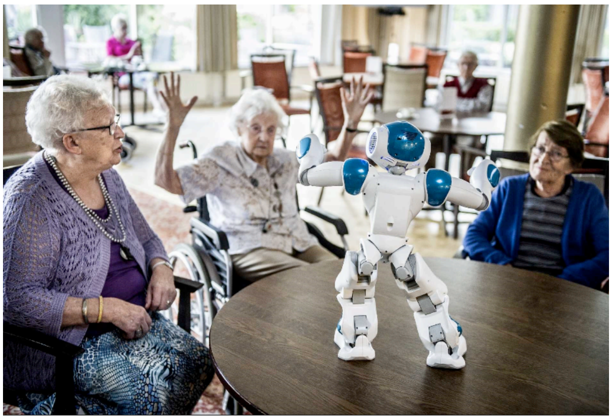

Fig. 23. Zora

Zora is a software application running on the NAO robot. It is marketed by the Belgian company QBMT mainly to eldercare institutions.

The role of Zora is to animate physical training and to serve as a conversational receptionist. It does not work autonomously, but is driven by a kind of authoring system running on tablets. The authoring system allows the care personal to edit scripts of utterances and choreographies of movements, or else it can be remotely controlled in a WoZ mode of operating.

According to the company, there is currently an installed base of 88 Zoras at an accelerating growth rate. Zora is sold for € 15000, or leased at a monthly rate of € 270.

[49] http://news.investors.com/technology-click/020614-689235-irobot-stock-irbt-jumps-on-q4-results-2014-guidance.htm

The appeal of Zora is the small size and child-like appearance: older persons easily get attached to it. Additionally, it is an attraction which brings more visitors, especially family with children, to the eldercare homes. QBMT have also started a project where schools, and later on also adults in a company-based volunteer programme, can communicate with inhabitants of the eldercare home via Zora.

Although some caregivers are initially worried either about being replaced by the robot or having additional work with the unfamiliar technology, they report positive results after a few months of familiarization and use. For example, with Zora answering repetitive routine questions of the inhabitants (e.g. about the weather, and the menu of the day), they find more time and energy to have "real" conversations with the old people. People also tend to open up in the interaction with Zora and to tell more about themselves than they would with formal caregivers .

With the company's policy to replace broken robots instantly, the lifecycle cost of a Zora will be considerable (the NAO not being famous for its robustness). However, te company are currently (mid-2015) negotiating to take over NAO production from Aldebaran and Aldebaran's majority owner SoftBank, and so plan to have the whole production chain under control, with the possibility to make changes to the hardware.

5.4 Markets for AAL robots

In studies on acceptance and marketability of AAL solutions, a huge gap appears regularly between what users would accept as functionality and what they are effectively ready to pay for such services. [WPU2013] In terms of markets, this means that they do not expect a high value from them, or, in other terms: it is not what they need. Studies of the needs for assistance in the older population are abundant (see chapter 3), but needs (Bedürfnisse) are not the same as wants: wants are needs once they are directed toward certain goods or services for their satisfaction (Bedarf).

The availability of money and the readiness to allocate it to need satisfaction has an influence on wants: without it, needs remain without satisfaction. This is a widespread phenomenon with regard to needs arising from age-related deficits: it is a common observation that people (have to) live without the services and products that would help them to maintain their lifestyle and to compensate for their deficits. The reasons are manifold, from the refusal to acknowledge age-related needs via a real to a subjective lack of money (i.e. the value of the assistance is considered less than that of other things). Once there is a want, however, there are several options of goods and services that can be taken into consideration. These are, in most cases, not simple substitutes of each other, but have distinctive roles and functionalities, corresponding to the numerous different problems that can appear in old age, in any combination of sensory, cognitive and physical shortcomings together with morbidity. The market for aids and appliances for therapy, medical care, and special needs features thousands of different products. It relies only partially on coverage by health insurances, especially when consumers opt for products with more than the basic functionality, comfort, or appearance.

We have to distinguish between different markets or market clusters for AAL or AAL-related robots. In the examples above, very different market segments were addressed: early adopters and high-tech gadget lovers, care institutions (Resyone), private households, and R&D institutions. As yet, dedicated AAL robots for home use have not been introduced to the consumer market, but we assume a segmentation along similar lines: a market cluster for products for comfort and pre-care services, probably with „lifestyle appeal" to attract early adopters, on the one hand, and a market cluster for care and health related robots on the other. It is important to keep these markets separate, because robots will not only be different but will also sell for very different reasons:

- The *„lifestyle" market*: this is the market for new household and lifestyle robots. New robots will meet little competition to start with. Appearance is important, the price, to some degree, is secondary: in any case, it is accepted that it is considerably higher than that of the device that is the closest substitute. In principle, these are robots that people could "do without", but which become trendy. The robot has to offer enough functionality to provide a rational justification for the purchase. Distributors are probably robotics and electronics shops to start with. If these robots are successful on the niche market and become more affordable, they move toward the mass consumer market, becoming available in general department stores and online shops. They have made their way to the mass market when they are sold along with conventional household, garden, and entertainment appliances and with their non-robotic competitors. Existing examples of this type of robots are vacuum cleaners and other cleaning robots. This market is also targeted by JIBO.

- The *"assisted living" market*: robots are seen as improved and innovative versions of existing assistive products, in many different areas: mobility, personal care and hygiene, household, and safety. In this market, robots directly compete with traditional products with comparable basic functionality (and often appearance). Functionality is the decisive factor in this market: the value added to the related conventional device must be considered big enough to justify the higher price, e.g. by substituting not just one, but several devices and/or services. Consumers in this market do not shop for „a robot", but for a device that helps them better than conventional ones. The existing suppliers of medical and care aids would be the logical distributors also of these robots. For products that are costly or only temporarily needed, they already have rental systems in place, and have well-established relationships with care providers and health insurance companies. For some types of robots, care providers themselves could become distributors on a rental basis, especially where hotline, emergency, and tele-medical services are involved, which some of them operate already (e.g. emergency bracelets).

Note that some of the „lifestyle robots" have the potential for AAL applications, such as JIBO or sen.se's Mother (which is hardly a robot, but a hub for diverse sensor signals[50]), in the same way as older people can benefit from the mass-marketed household robots. It is possible that studies in which user were asked how much they were ready to pay for AAL systems did not separate these markets: participants could have regarded them as "lifestyle" products which they did not actually need and on which they were not ready to spend much consequently, while researchers were much more aware of the assisted-living aspects of the product. For AAL robots, with much higher prices, this method of hypothetical pricing would not be very useful: would people be ready to spend 500, 5000, or 15000 € on a robot? Users would not be able to tell, and would probably find any price too high. The price of AAL robots is most frequently mentioned as the biggest obstacle when it comes to predict the market potential. In this study, we focus on what we have called the "assisted living" market: it is much smaller and more segmented than the potential lifestyle market, but here we know much more about the needs of the potential buyers, and the alternatives they can choose from to satisfy these needs.

We have therefore chosen a scenario-based approach to simulate situations in which users have to make purchasing decisions. The common assumptions for both scenarios are:

- There is no specific public funding for AAL technologies including robots. Public funding comes, where applicable, through the care allowance
- Additionally, families can count on the special financial support for 24h care (which originally was introduced in Austria as an incentive to legalize clandestine employment that flourished in this sector).
- The scenarios highlight a specific situation in which a change of care and living arrangements becomes necessary, caused by a deterioration of the current care and living arrangements.
- In such a situation, decisions about additional expenditures have to be made, for the purchase of (additional) care or of assistive technologies.
- The robots in question are available on the market, at current prices

5.4.1 Scenario A: Attendance

A 2011 report on mobile care in Styria[51] comes to the conclusion that there is a gap in the mobile care services. Nurses provide medical and personal care, less qualified caregivers also help with the household. The duration of their visits is 45 minutes on average. However, especially informal caregivers of dementia patients would need longer visits to have time off from care. Let us call this form of care „attendance". Such an attendant would not need to provide personal or medical care, nor household activities. Its task would be to be present, to watch over the patients, possibly to prevent them from certain dangerous activities, maybe to contribute to entertainment, and to call for help in

[50] https://sen.se/store/mother/
[51] http://www.landtag.steiermark.at/cms/dokumente/11399730_58064506/48e73fd3/16_668_1_BE.pdf

case of emergencies. The duration of attendance could vary from one to several hours. Probably there are numerous patients who do not need caregivers during nighttime, but could do with mere attendance. Mobile care providers cannot satisfy this need for low-level care: on the one hand, they are short on personnel, and on the other, the professional caregivers are over-qualified (and hence too expensive) for this service.

For the informal caregiver (e.g. the patient's spouse or children), there are several options to satisfy this need for attendance (care allowance level 4, prices are examples[52])

- 24-hour-care: given that the state subsidizes 24-hour-care (as an incentive to legalize previous illicit employment of migrant careworkers), this solution is currently, and paradoxically, the cheapest in mobile care: after deducting care allowance and the subsidy, prices start at € 1000 (up to almost € 2000 when offered by well-known high-quality care providers) per month. However, a precondition for this service is that the caregivers have to be provided board and lodging at the client's place. Where this is not possible, 24-hour-care is not an option.
- Daycare: 8 hours, 7 days a week cost nearly € 2000 per month (care allowance already deduced). The caregiver does not stay overnight, so that attendance at night is not ensured.
- Formal caregivers on an hourly basis: if paid per hour (at rates from 15 to 25 €), this solution would be much more expensive than 24-hour-care.
- AAL Technology: The solutions are too divergent to determine, at the current state of technology, a standard price for the equipment that would be needed in this scenario. [WPU2013] assume prices around € 2000. Telephone hotline, maintenance etc. have to be paid for monthly. Several studies found that users would be ready to pay between 40 and 70 € per month for such a service.
- Robot companion: compared with an AAL solution, the robot offers the added functionality of being mobile and, hopefully, social. This means among other things that it can be proactive e.g. in reminding or warning the patients, or inquiring about their wishes or troubles. Mobility is an advantage staying near the patient and for interacting socially, but could be substituted by sensors in different rooms. As a frontend to an AAL system, the robot itself needs only restricted sensory capacity. As a mere attendant, the robot need not be able to fetch and carry things, so that it needs no arms. Without the need for mobility, a JIBO-like device, if connected to sensors distributed in the apartment, at € 800, would do. As monthly cost for emergency hotline etc. we assume again € 40 to 70 (although monthly costs e.g. for the emergency bracelet hotline are considerably lower).

A solution with suitable AAL equipment together with a low-end robotic frontend turns out to be less costly than professional caregivers in any arrangement. The added value of the technical solution is its availability around the clock, thus giving the informal caregivers more freedom.

5.4.2 Scenario B: Aging caregivers

76 % of eldercare is provided by informal caregivers in Austria [BMS2014]. Over half of them are themselves already retired, two thirds are women (see section 3.2). The physical burden of caregiving increases with the age of the caregiver. When the caregiver drops out, transfer to a care institution is imminent. Lack of a caregiver is one of the main factors for early admission to stationary care. [BMS2014].

An older woman who provides care to her husband experiences, at some point in time, increasing problems with lifting him and helping him transfer to the wheelchair. Which options for a solutions do exist?

- Professional care: the assistance of a formal caregiver is welcome, but it cannot be provided more than once a day. The transfer from bed to wheelchair has to be made much more often.
- Daycare: except for the heavy physical tasks, the woman is still capable of providing the necessary care, to manage the household etc. Daycare that is only needed for a specific task seems to be exaggerated and expensive. The same is true for 24-hour-care.
- Admission to a care institution: this is the solution that the couple want to avoid or at least to delay as long as possible.

[52] from different sources, e.g. Pflegedienst 24 http://www.pd24.at/?gclid=CIndju_9_cUCFezKtAodwVYAig, Fonds Soziales Wien http://pflege.fsw.at/,

- Mechanical aids: patient lifters, from € 1000 upwards, are mostly used in hospitals, but can also serve in private households, if there is enough space for moving and operating them.
- Robotic bed: a bed-wheelchair combination such as Resyone would currently be an expensive solution (over € 8000), but it would offer the advantage that, in contrast with all other solutions, the patient can operate it without help and thus can transfer independently from bed to wheelchair and back.

In this scenario, the robotic solution is – at present and probably for some time in the future – more expensive than others. The buying decision – provided that the purchasing capacity is present – will depend on how much value the consumers would attribute to the immaterial benefits of dignity and independence for the patient.

The question of cost is a different one if the robotic bed can be rented. Our rough estimation of a monthly rent - € 200 - is based on the current price, 10 years lifetime, including installation and maintenance, and overhead costs. This is the equivalent of 8 to 10 monthly hours of a (non-medical) caregiver, with the difference that the robotic bed is available around the clock.

We assume that the existing professional care arrangement would not be replaced by the robotic bed. In the buying decision, it competes with other *additional* expenditures either for goods or for services which become necessary because of the changed life situation, i.e. the physical condition of the caregiver. Assuming, as a basis for the estimation, the same prices for care arrangements, the robotic bed is, when rented, the cheapest solution.

5.4.3 Target cost management in AAL robotics

Our scenarios show that the decision to buy or rent an AAL robot will not come „out of the blue“, in contrast with the purchase of lifestyle, comfort, or gadget robots. The purchasing decision is made in the context of

- changes in the health state of the user
- changes in health, social, physical or psychological condition of the caregivers
- alternative solutions on the market, both goods and services
- already existing care management solutions, including mechanical aids and/or adaptation of the premises

Consequently, the question what people would be ready to pay for a robot cannot be answered on hypothetical grounds. People who go shopping for a robot have a certain (new) need and are prepared to spend (additional) money on its satisfaction. They will tend to decide in favour of a robot, even if it is – within limits – more expensive, if consumers appreciate the added value they expect from it compared to conventional solutions. The success of vacuum cleaners lets assume that, in the case of expected added value, the fact whether or not the new device is a robot will be secondary. We can further assume that people will not appreciate if the robot duplicates functionalities which are already provided by other devices or services, or can be procured better and cheaper in other ways. Less functionality can be an advantage in such cases: the robot not only fits in better with existing care settings, but also, and most importantly, costs less.

Given that most AAL robots have not yet left the labs, it may seem premature to discuss sales prices of robots. However, there exist methods, for example Target Costing and Design-to-Cost, which take exactly this approach which reverses the usual method of calculating sales prices on the basis of development and production cost.

Target Costing considers the costs of a product over its whole lifecycle from development to disposal. For the purposes of this study, the most relevant aspect of this approach is the inclusion of development in calculation. The goal is to develop products at allowable costs that have the functionality desired by the consumers. The focus is on the question what the acceptable price for the product would be. In this way, cost management is integrated into product planning and development which is based on knowledge about the market and the future users.[53]

[53] http://www.controlling-wiki.com/de/index.php/Target_Costing#Anwendungsbeispiel

Target Cost Management distinguishes three phases: definition, splitting, and achievement of target costs. The third phase mainly concerns manufacturing and will therefore not be considered further here.

Target cost definition: The planned sales price is estimated through market research. Once target profit is deducted from this target price, the allowable costs are known. There will result a gap (drifting costs) between allowable and actual costs. Target costs are determined by closing this gap as much as possible through the search for cost reduction potentials in all phases of the product lifecycle.

Target cost splitting: the overall target costs are distributed among components and/or functions of the product. If the target costs do not lead to a realistic match between demand and resources for individual components/functions, the product development misses market needs. The goal of this phase is therefore to achieve market-oriented specifications of the product features and to compare them to consumers' wishes and needs, in order to ensure an allocation of resources that converges with consumers' expectations of value and utility. In our context, the analysis of the contribution of individual components to expected utility on the one hand and to costs on the other is of particular relevance. The question that has to be answered is: which features and components are important for the consumers and what are they prepared to pay for it?

Different components of the product contribute to different degrees to the features or capacities named and/or ranked by consumers. Designers have to evaluate the part a component, function or material contributes to the feature that consumers wish to find in the product. From the weight of a component in satisfying consumer wishes and its cost, the target cost index can be calculated which represents the proportion between costs and consumer benefit of the component:

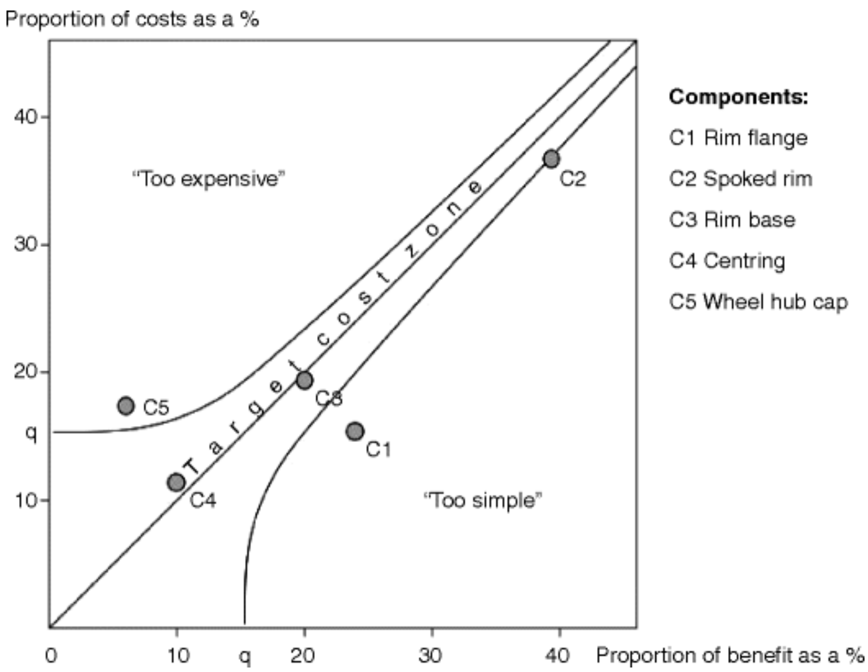

Fig. 24. Example of a target cost analysis diagram

- For a proportion of 1:1 or close to it, the component is „worth" its costs (in the diagram: C4, C3, and C2)
- Components with a proportion of benefit:costs > 1 (C1 in the diagram) are cheaper than the consumer would expect. They can compensate for other components where cost reduction potentials are limited.
- Components with a proportion of benefits:costs < 1 (C5 in the diagram) are too expensive. They cost more than they are valued by the customer.

This is the point where the target cost approach becomes relevant for design: a costly, but not overly desirable component can either be re-designed to reduce its cost, or it can be eliminated altogether, leading to a leaner design that concentrates on the most important needs and wishes of consumers, and finally delivers a product that meets demand and is successful on the market.

As an example from AAL robotics, we assume that a company is developing a companion robot as attendant. The companion is mobile (on wheels) and has arms (like e.g. Pepper). Market research among a carefully defined target group, e.g. informal caregivers of dementia patients, reveals that potential consumers do not think that Fetch & Carry tasks are particularly relevant (see also 3.6.7): the users may be still capable of fetching things themselves, or else the caregivers are present often enough to serve them. On the other hand, robot arms are expensive and contribute considerably to the overall cost of the robot. The price, calculated traditionally from costs plus margin, would be much higher than what the target group would be ready to pay. In this case, the target cost approach could lead to the decision to build this specific robot model without arms, hence much cheaper.

5.4.4 The risk of over-engineering

Over-engineering is a well-known problem in many sectors. It is caused by perfectionism and addition of functions (called „feature creep" in software engineering) that not only make the product more expensive, but possibly also less reliable. [Wild2005] reports 32 % cost reduction in industrial printers and 12 % in welding robots thanks to efforts to eliminate over-engineering. In AAL robotics, the robotic bed Resyone provides a striking example.

Fig. 25. Resyone: 2009 prototype[54]

At the beginning, there were conceptual models and prototypes of a robotic bed that could do it all. At one stage, the bed had arms and a canopy. The bed's robotic canopy automatically rose when the unit transformed from bed to wheelchair. Additional features included a screen that acted as a TV, a controller for home appliances, and a home security camera viewer.[55]

The version shown in Fig. 25 was one in a series of prototypes that flopped over the years.[56]

The version that now finally comes to market looks much more like a normal bed (see 5.3.3). While the original concept was aimed at the domestic market, the target group are now hospitals and care institutions. The dimensions therefore now correspond to the standard hospital or care bed so that it can be easily integrated.

The canopy and all additional functionality were removed. The bed now splits simply in half instead of into five parts – of which each, in real life, would have required its own piece of bedsheet. The final version is the result of rigorous re-engineering, obviously in cooperation with the target group and the formal caregivers who will have to work with the bed.

"What the engineers want to develop doesn't often match what's needed on the ground. That gap had long been difficult to fill," Mr Kawakami, who headed the Resyone project, is quoted.[57] "For nursing care robots, it's hard to know how much is cheap or expensive. What's needed is a properly priced robot with minimum functions." The difference in price between the prototype version and the bed as it is now marketed can only be guessed. Given that the target cost method was originally developed in Japan, we assume that it (or some similar approach) was rigorously applied in the re-engineering process.

[54] http://phys.org/news/2009-09-panasonic-bed-wheelchair.html; a video showing the bed in operation: https://www.youtube.com/watch?v=2WlUuGGdgyg
[55] http://www.cnet.com/news/panasonics-robotic-bed-transforms-into-wheelchair/
[56] http://www.cnbc.com/id/102072329
[57] Financial Times, 8.10.2014, http://www.ft.com/cms/s/0/e98a5d08-4ae1-11e4-839a-00144feab7de.html

In robotics, over-engineering can also be the outcome of an engineering approach that takes human task execution as its model. The concept of a robotic patient lifter and carrier presented in [Hägele2009] (see above, section 5.2.3), based on the analysis of the tasks as carried out by human caregivers, results in an estimated price of over € 100.000 which misleads the authors of the study to conclude that care robots could not achieve cost-effectiveness. Admittedly, the task of the authors was not to design such a robot, but the result shows that price and market predictions on the basis of faulty engineering have to be viewed with caution.

5.4.5 Summary

Robots, even at current prices, have the potential to compete with products and services on the home care and assistive technologies market, on condition that their functionality fits closely a) the needs of consumers in specific situations of age-related change of lifestyle and/or care, and b) the alternative products and services on the market. These findings have important consequences for engineering and product development, insofar as market segments have to be much more precisely defined and thoroughly studied in order to actually design robots that satisfy the consumers' needs and value expectations.

5.5 Legal issues in AAL Robotics

As yet, there exists no specific legislation on personal care robotics. In this chapter we summarize the current discussions and point to regulation initiatives that are currently under way.

The most extensive discussion of ethical and legal aspects in connection with service robotics so far has been undertaken in the framework of the EU project RoboLaw.[58] The results of the in-depth case studies (including companion robots and exoskeletons in orthotics) are available in a public deliverable.

The input for advances in regulation in robotics comes from the researchers and the industries that operate in this sector. They are motivated by concerns regarding safety, risks and liability. Both a lack and an excess of regulation in these domains can act as barriers to innovation and development: "A widely spread perception reveals the concern that premature and obtrusive legislation might hamper scientific advancement and prevent potential advantages from happening, burden competitiveness or cause economic or other inefficiencies. At the same time, somehow paradoxically, it is accepted that the lack of a reliable and secure legal environment may equally hinder technological innovation. Therefore the propensity to avoid excessive regulation clashes with an opposite urge to fill in a legal gap that affects legal certainty and causes people to act in an ambiguous environment where rights and responsibilities cannot be clearly acknowledged or predicted." [RoboLaw2014] The need for early regulating initiatives is backed up by a different argument in [Simshaw2015], namely that problem cases and damages that arise from a lack of regulation can lead to a backlash in the form of overly restrictive legislation.

[RoboLaw2014] identifies three main reasons why robots are special and need specific regulations:

- Robots are *complex* systems: a multitude of people and institutions may be involved in their production and application.
- Robots are increasingly *autonomous*. They are not only capable of decision-making, but will be able to learn, so that they can show emergent behaviours that have not been programmed.
- Robots will be used by a large *variety* of potential users in very different *uncontrolled* contexts which cannot possibly be predicted by designers and engineers. Moreover, users can influence and interfere with the robot's behaviour.

5.5.1 Themes for regulation

Regulation for robots need not be re-invented from scratch, though, as current regulative frameworks already cover numerous aspects. Five common legal themes can be identified as having the broadest bearing on robotics regulation:

[58] Regulating Emerging Robotic Technologies in Europe: Robotics facing Law and Ethics. FP7- 289092, 2012 – 2014. http://www.robolaw.eu

1) *health, safety, consumer, and environmental regulation*: An extensive set of EU-based health and safety requirements is relevant for robots and robotic technologies. For industrial robots, specific regulation (for instance ISO standard 10218) has been developed. In contrast to industrial robots, which are applied in a controlled and well-structured environment, service robots are applied in less structured environments for a wide range of tasks, often by people with no specific training. As robotic applications move from the structured, professional environments of industry into hospitals, homes, shops, and the street, a new wave of regulation will have to be developed to cope with the specific health and safety issues that emerge in these new environments.

2) *liability (including product liability and liability in certain sectors)*: Robots cannot be held liable themselves for acts or omissions that cause damage to third parties under existing legal regimes. Currently, manufacturers, owners or users of robotic technologies may be held responsible for damage caused by robots, if the cause of the robot's behaviour can be traced back to them and if they could have foreseen and avoided the robot's behaviour. However, it is hard to provide evidence of the link between human behaviour and damage caused by robotic technologies, particularly in cases where a person cannot distinctly control the actions of a robot. The damage may also be the result of a multitude of factors, given the complexity of robots' functioning and their interaction with unpredictable environmental factors.

3) *intellectual property rights* (both to the robot itself and to works created by the robot); There are no legal provisions that specifically apply to robotics, but existing legal regimes and doctrines can relatively clearly be applied to robotics. A second IPR-related question is whether robots themselves are capable of producing copyrightable works. The UK has dedicated legislation with a positive stance to computer-generated or robot-generated works, whereas other countries lack such legislation and seem to deny the possibility of such protection.

4) *privacy and data protection*; Many robots will contain information technology and many of those are likely to process sensor data. When these data concern individuals, the processing of these data by robots is subject to data protection regulation, involving requirements relating to, among other things, transparency, security, and lawful and fair processing. Especially in this domain, the authors see solutions in "regulation by design", e.g. through encryption, or through obtaining informed consent through human-robot-interaction. [Simshaw2015] point out the difficulties that can arise with AAL robots that (also) have tele-medicine and e-health functionalities: storage and transmission of health data are governed by other, stricter laws than consumer personal data. They therefore call for a harmonization of the two domains. A different solution could be the strict separation, in the robot, of medical services and data streams from other personal data. In Austria, the corresponding law is the Gesundheitstelematikgesetz 2012[59] which regulates the transfer of health-related data and issues concerning the electronic health record (ELGA).

5) *capacity to perform legal transactions*, e.g., whether intelligent agents can enter into contracts: robots will become more sophisticated and may have to be equipped with a capability of rendering basic services beyond pure material care, such as assistance in purchasing food, drugs, newspapers, or bus tickets. For such applications, it could be useful if robots would have the capacity to perform legal transactions. On the other hand, such a change would entail a whole string of further regulatory requirements, e.g. about litigation, or a robot's property. [Asaro2007] discusses the problems of making robots responsible for their actions which would entail that they are given "moral agency". Moral agency is, in principle, not exclusively attributed to humans, but also e.g. to corporations as legal entities, while the case of robots would be clearly different still. The same would be true for a status of "quasi-person" as it is attributed to children who are protected as persons but do not have the same active legal rights as adults.[60]

5.5.2 Kinds of regulation

The diversity of legal issues shows that there might never be a homogeneous corpus of "robotic law". Instead, the deployment of service robots will probably lead to changes and adaptations in many different areas of regulation. Regulation, however, does not automatically require legislation, which is a

[59] https://www.jusline.at/Gesundheitstelematikgesetz_2012_%28GTelG_2012%29.html

[60] For a more comprehensive discussion of moral agency in artificial intelligent systems, see http://plato.stanford.edu/entries/computing-responsibility/

slow process hardly capable of keeping pace with the dynamics of technological development. Among the alternatives and additions, [RoboLaw2014] mentions:

- *"Soft Law":* Technical and safety norms and standards, that are formulated by administrative or non-governmental agencies, technical standard-setting bodies such as ISO and the European Standard Organizations (such as CEN & CENELEC), and professional associations, have increasingly become a tool for regulation in many science-centred sectors, and exert a decisive influence on the application of the law (see section 5.7). However, norms and standards cannot cover all needs for regulation: the focus of ISO, for example, is on safety standards for robots, but issues concerning the impact on fundamental rights deriving from every application to end-users or respect for their other interests not merely related to safety are not included in this form of regulation.
- *No-fault settlement*: The RoboLaw case studies discuss the problems that emerge when current product liability regulation is extended to robots, and in particular to prosthetic/orthetic robots. The authors hold that technical standards and norms are sufficient to ensure product quality and safety, so that the complex and sometimes impossible search for the responsible party in an accident involving a robot (owner, producer, third party ...) should be abandoned in favour of no-fault compensation on the basis of funds or insurances.
- *Normative Technology*: The concept of techno-regulation and propositions such as "code as law" and "normative technology" [Yeung 2008] highlight the fact that technologies can play a regulatory role. Norms can be directly incorporated into technology in the sense that a command and the compliance to it are imbued in the technology itself. For instance, "privacy by design" – which means that data protection safeguards are built into products and services from the earliest stage of development – is deemed to become an essential principle in the EU data protection regulation. As robots have to function in complex social environments, an increasing body of research and literature is investigating the utility and the feasibility of implementing in the machines an entire set of ethical and legal requirements, so that they behave according to social and legal rules. [Leenes2014], [Trappl 2015], see section 5.6.4.

Recently, the European Parliament has established a working group on legal issues of robotics.[61] Rapporteur is Madeleine Delvaux, who said in an interview, "We need a new European standardisation. We also need to consider liability, the protection of personal data and the prevention of hacking. Some robots, for example industrial ones, are already covered by a machinery directive, but it covers only speed and some technical parameters, but not the machine's intelligence. We need to test robots more to see how they act and what kind of accidents can arise from their interaction with humans. Then there is the question of equal access. If robots really make life easier, we need to ensure that everybody can afford them."

5.5.3 Summary

AAL Robotics should encourage the discussion of legislative and regulatory issues relating to the field as early as possible. Legislation processes are notoriously slow and lag behind realities, while the lack of regulation can lead to uncertainty in consumers, harm the market chances of AAL robots, and lead to over-restrictive reactive regulation.

5.6 Ethical Issues in AAL Robotics

Ethical values and legal principles are usually closely related, but ethical obligations typically exceed legal duties. Though law often embodies ethical principles, law and ethics are far from co-extensive. The law does not prohibit many acts that would be widely condemned as unethical. And the contrary is true as well. The law also prohibits acts that some groups would perceive as ethical.[62]

Robots raise specific ethical questions because they are

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[61] http://www.europarl.europa.eu/news/en/news-room/content/20150422STO43701/ html/ Mady-Delvaux-Robotics-will-bring-about-a-revolution

[62] http://ansteadsue.tripod.com/ethics.htm

- complex: many different designers, engineers, and companies can be involved in both hardware and software components; the origin of (mis)behaviour becomes hard to track
- autonomous: by definition, robots are capable of decision-making and operate increasingly autonomously; ethics are rooted in the decision-making architecture, not in the resulting behaviour itself
- everywhere: while industrial robots are used in controlled environments, often physically separated from humans, service robots operate in open, unpredictable and basically human environments where situations can arise that are virtually unpredictable.
- nice: humans don't need much to attribute features of animatedness and agency to robots. Even Roomba, the vacuum cleaner, is personalized and cherished like a pet by many users [Sung2007], although it does not intentionally evoke any associations with living beings. Zoomorphic and anthropomorphic robots evoke a semblance of life even easier, and with it expectations and social behaviours.

Different branches of ethics in and of robotics have to be distinguished: descriptive ethics, cultural ethics, robot ethics, and machine ethics.

5.6.1 Descriptive ethics

This is the field which studies human ethical values empirically, e.g. by experiments which require ethical decisions, or judgement of observed behaviours. [Malle2015] have conducted an experiment in which they compared judgements of human vs. robotic behaviour. Their results show that people expect less ethical behaviour from robots and are more forgiving towards robots. Another experiment with special relevance for AAL Robotics, involving users, formal and informal caregivers [Jenkins2014] revealed that informal caregivers are more inclined to transgress ethical limits e.g. when it comes to restrict the autonomy of the patient.

5.6.2 Cultural ethics

This field is commonly understood as the comparison of cultural ethical values and the study of cross-cultural conflicts arising from their difference. With regard to robotics, this field raises questions about the change of ethical values that is or will be brought about by the presence of robots in society, and is concerned, among others, with questions of moral agency and responsibility, human-human and human-robot relationships, and ultimately the definition of human-ness which has seemed undisputed and easy in the past.

5.6.3 Robot ethics

Robot ethics, as it is currently understood, is a special branch of engineering ethics. Beside the general application of professional codes of conduct in robotics R & D, specific guidelines have been suggested for human-robot-interaction.

Ethics of engineering, ethics of technology (technoethics): the field raises ethical questions about design and development of technologies in general, and has led to the adoption of ethical codes by most engineering associations, such as the IEEE.[63] They cover not only professional conduct, but also questions about the consequences of engineers' and researchers' work for safety, health, and individual and collective welfare which also apply to robotics.

Ethics of Human-Robot Interaction: Riek and Howard [Riek2014] distinguish four areas of concern to researchers:

- *Therapeutic robots:* HRI practitioners often deploy robots in therapeutic settings with vulnerable populations, e.g. children with autism or older adults. These therapy recipients can often develop strong psychological and emotionally important bonds with the robot, the severing of which at the end of a project can have serious harmful effects on the subject, perhaps negating any therapeutic benefit the subject might have experienced or even leaving the subject in worse condition than before the research began.

[63] http://www.ieee.org/about/corporate/governance/p7-8.html

- *Physical assistance*: In a similar vein to therapeutic robots, robots intended to provide physical assistance to people with disabilities present a unique set of ethical challenges to HRI practitioners. Human clients in such settings constitute a vulnerable and dependent population whose physical and psychological needs must be respected in HRI design and implementation. Specific areas of potential concern include: (a) the involvement of robots in particularly intimate activities such as bathing and sanitation; (b) direct physical contact between robots and humans, as in lifting patients in and out of beds and wheelchairs; and (c) the high probability of patients' forming emotional bonds with robots in environments otherwise sometimes comparatively lacking in human companionship.

- *Robotic interrogators*: As more social robots are marketed and human-robot interaction becomes more frequent and occurs across a wider array of settings, an ever more common role will be that of the robot interrogator, with robots functioning as diagnostic aids, conflict resolution intermediaries and in similar roles. While one might reasonably expect patients in a nursing home setting, or their legal guardians, to grant consent, this will not even be feasible with the routine deployment of robots as receptionists, conversational partners or entertainers. As Calo [Calo2012] points out, such interactions raise questions about risks like unintended information disclosure. Accordingly, the burden for managing risk shifts ever more from the human to the HRI practitioner.

- *WoZ experiments*: One further issue that regards research and experimentation specifically is the "Turing Deception" created by WoZ experiments [Riek2014], where a participant cannot determine if they are interacting with a machine, a specific person, or a person masquerading as another person.

[Westlund2015] report cases of WoZ experiments with children which raise ethical questions both about deception and disclosure of secrets. [Deblieck2015] reports cases of installed robots (ZORA) which create an illusion of autonomy while being operated in a WoZ-like mode, motivate emotional relationships, and have already induced older primary users to disclose information that they had kept secret from caregivers.

[Riek2014] summarize their considerations in HRI Ethical guidelines, among them:

- The emotional needs of humans are always to be respected.
- The human's right to privacy shall always be respected to the greatest extent consistent with reasonable design objectives.
- Human frailty is always to be respected, both physical and psychological.
- Wizard-of-Oz should be employed as judiciously and carefully as possible, and should aim to avoid Turing deceptions.
- The tendency for humans to form attachments to and anthropomorphize robots should be carefully considered during design.
- Humanoid morphology and functionality is permitted only to the extent necessary for the achievement of reasonable design objectives.
- Avoid racist, sexist and ableist morphologies and behaviours in robot design.

The IEEE-RAS (Robotics and Automation Society) has installed a Technical Committee (TC) on Roboethics, which aims to provide the IEEE-RAS with a framework for analyzing the ethical implications of robotics research, by promoting the discussion among researchers, philosophers, ethicists, and manufacturers, but also by supporting the establishment of shared tools for managing ethical issues in this context.[64] The afore-mentioned working group of the European Parliament will without doubt be confronted with ethical questions in their efforts to prepare legislation.

5.6.4 Machine Ethics

Researchers are developing robots that are intended to be partners in the workplace or companions for older people or persons with special needs. These robots will have to have moral competence [Malle 2014], [Scheutz2014] and be equipped with ethical systems, because they should be able

[64] http://www.ieee-ras.org/robot-ethics

- to act cooperatively, especially in complex social situations, and
- to understand the decisions of humans.

Robots will follow ethical principles, but we have to distinguish where these come from: ethical behaviour can either follow implicitly from the implemented decision processes, or it emerges as a consequence of an explicitly designed ethical system. Ethical principles for robots and ethical principles for designers, developers and deployers differ in their aims and addressees, and therefore are not necessarily identical. In what follows, we are concerned with explicit ethical systems. Additionally, it has to be kept in mind that ethical systems of robots will also differ according to their types: the ethical system of a self-driving car with the user inside will have to be different from that of a companion robot interacting with the human user on a body-to-body or face-to-face basis.

The first question in machine ethics is: which ethical system would be usable by robots? [And2007] [And2011]

Asimov's Three Laws of Robotics

The first ethical system that has ever been proposed for robots are Isaac Asimov's Three Laws of Robotics, initially formulated in the short story "Runaround" from 1942, which later was included in the collection "I, Robot" [Asimov1950]:

- First Law: A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
- Second Law: A robot must obey orders given it by human beings, except when such orders would conflict with the First Law.
- Third Law: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Later, Isaac Asimov added one more law which he named the Zeroth Law Of Robotics and therefore has to precede the First Law (naturally, the except-phrases had to be changed accordingly):

- Zeroth Law: A robot may not injure humanity, or, through inaction, allow humanity to come to harm.

Many of Asimov's robot novels and short story involve illustration and discussion of the Three Laws, and conflicts arising between their very general formulation and their application in concrete situations. By formulating them as a hierarchy of rules, however, Asimov already had the idea of a system that should allow a robot to decide and to act in any case at hand.

Utilitarianism

Another ethical system is based on Jeremy Bentham's Utilitarianism [Bentham1907]: the maxime of action here is to act in such a way that the maximum good for all persons involved is achieved, where "acting" means to choose the appropriate actions from all possible ones. As it is difficult to define the "good", it is replaced by the concept "utility" in most applications of the theory. The concept of utility is used in decision or game theory, where, in experiments, amounts of money are used as its measure. The optimum action is found by computing, for each potential action, the sum of the products of its utility for each person, multiplied by the probability that each person experiences this utility, and by then choosing the action with the largest sum.

Medical ethics

A third ethical system with potential for robotics is medical ethics. Medicine may have been the first discipline with an applied professional ethics, because of the potentially severe consequences of medical decisions, but probably also because, with medicine's focus on human life and health, it seems easier to formulate. This ethical system is called "Principlism" [Beauchamp1979] and consists of four ethical principles:

1. Autonomy: Respect the autonomy of the person. Not so long ago physicians decided about a therapy, be it conservative or by surgery, without asking the patients because they thought they knew better. Today it is unthinkable e.g. to begin with a surgical intervention without explaining the potential risks to the patient, in detail. In addition, patients have to sign a declaration of informed consent.

2. Beneficence: Your action should bring benefit to the person.
3. Nonmaleficence: Your action should not harm the person. This is a condensed version, in one word, of the Latin commandment “primum non nocere”, in English: “It is most important not to harm.”
4. Justice: At first glance a quite surprising principle. However, it is an equally important one: Consider in your action the social (= fair) distribution of benefits and burdens. This principle becomes ever more topical in times of economic constraints on health care systems.

Contrary to Asimov’s Laws, these principles are not per se ordered in a system or hierarchy, so that it is not clear what relative weights have to be attributed to them and how conflicts between them in a given situation should be resolved. The medical professions seem to be able to work and to make decisions on their basis nevertheless, but for a robot’s ethical system they are under-specified.

Implementation

Possible platforms for the implementation of ethical systems are discussed in [Trappl2015], ranging from ROS (Robot Operating System) via the LIDA Cognitive Architecture to a BDI framework and logic programming. The book chapters show that there is still a long way to go from ethical principles to an implementation in a robot’s software that would allow this robot to decide and to act in ways that are acceptably ethical from humans’ point of view. [Allen2000] have already proposed a moral Turing Test to evaluate robots’ ethical systems: an observer has to judge ethical decisions made by humans and robots in the same situations. If the observer cannot determine correctly whether a human or a robot made the decision in more than half of the cases, the robot would pass the test. The problem with this test is that it would rely on humans’ judgements which are far from sure and equivocal: a robot could also be recognisable as such by making “better” decisions than the average human.

With self-driving cars already on the roads, the need for robotic ethical systems becomes urgent. At any time, the car may be confronted with a dangerous situation where a decision has to be made instantaneously e.g. between inflicting harm on an animal vs. a pedestrian, on a big, safe car vs. a small one (or a motorcycle), on the owner inside vs. a human outside.

With AAL robots, the ethically problematic situations will probably be more subtle, but not necessarily less dangerous. Concerns for autonomy vs. health of the user could be one such conflict, e.g. the decision on calling in external help or not. [And2015] discuss a principle-based ethical system that they claim to be able to solve such problems.

5.6.5 Ethics and society

The project RoboLaw’s roadmap also included other aspects that were deemed essential contributions to the governance of science and technology. These are issues of justice, solidarity, protection of fundamental rights, non-discrimination and inclusiveness. The two pillars of the concept of Responsible Research and Innovation (RRI, European Commission 2013) are ethical acceptability and orientation towards societal needs.[65]

Not only do robotic products and applications have to comply with the fundamental human rights, but particular attention should also be given to those that respond to societal needs and contribute to achieve goals like equality of opportunities, justice, solidarity and to improve the quality of life of citizens, especially the more deprived and vulnerable ones. In other words: while the protection of humans from robots is in the focus of the debate on robot regulation, the other side of the coin, which could be termed the “right to robots”, must not be neglected.

5.6.6 Summary

As ethical problems can arise anytime in the lifecycle of robots, even in the prototype and experimentation stage, ethics of AAL robotics, both wider robot ethics and more specific machine ethics, must not be left as a special discipline to a handful of ethicists. Each researcher and developer in AAL robotics needs to be aware of the possible ethical issues that arise from design and experimentation in the field.

[65] http://www.rri-tools.eu/about-rri

5.7 Standardisation

Industrial robots have been part of industrial automation for a long time and are thus covered by several international standards such as ISO 10218. New standardisation efforts had to be launched for service robots in order to specify general safety requirements before serial products enter the market.

Three organizations are relevant for worldwide standardisation efforts in robotics: ISO, IEC and ITU.

ITU – International Telecommunication Union[66]

ITU is the United Nations specialised agency for information and communication technologies – ICTs. ITU allocates global radio spectrum and satellite orbits, develops the technical standards that ensure networks and technologies seamlessly interconnect, and strives to improve access to ICTs to underserved communities worldwide. ITU currently has a membership of 193 countries and almost 800 private-sector entities and academic institutions. ITU is headquartered in Geneva, Switzerland, and has twelve regional and area offices around the world.

IEC – International Electrotechnical Commission[67]

Founded in 1906, the IEC (International Electrotechnical Commission) is the world's leading organization for the preparation and publication of International Standards for all electrical, electronic and related technologies. These are known collectively as "electrotechnology". When appropriate, IEC cooperates with ISO (International Organization for Standardization) or ITU (International Telecommunication Union) to ensure that International Standards fit together seamlessly and complement each other. Joint committees ensure that International Standards combine all relevant knowledge of experts working in related areas. Some 174 TCs (Technical Committees) and SCs (Subcommittees), and about 700 Project Teams (PT) / Maintenance Teams (MT) carry out the standards work of the IEC. These working groups are composed of people from all around the world who are experts in electrotechnology. The great majority of them come from industry, while others from commerce, government, test laboratories, research laboratories, academia and consumer groups also contribute to the work.

IEC has currently two bodies that are relevant to AAL Robotics:

a) SyCAAL – System Committee on Active Assisted Living, founded in 2015. Its mission is to

- create a vision of Active Assisted Living that takes account of the evolution of the market
- enable accessibility of AAL Systems and user interfaces
- enable cross-vendor interoperability of AAL systems, products and components
- communicate the work of the SyC to IEC and the market to foster a strong community of stakeholders

b) ACART - Advisory Committe on Applications of Robot Technology

The tasks of ACART includes:

- coordinating common aspects of robotic technology such as vocabulary and symbols.
- preparing a guideline that outlines the critical aspects of preparing a standard for products that incorporate robotic technology.
- promoting collaboration between IEC and ISO as it relates to robotic technologies.
- resolving current overlaps and developing a process to prevent future overlaps, both within the IEC and between IEC and ISO.
- strong collaboration with the IEC CAB (Conformity Assessment Board)

The Austrian Member of IEC is OVE – Österr. Verband für Elektrotechnik[68]

ISO – International Organization for Standardization

ISO was founded in 1947, it is an independent, non-governmental membership organization and the world's largest developer of voluntary International Standards. ISO currently has members from 163 countries who are the national standards bodies. The central secretariat is based in Geneva. ISO has

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66 http://www.itu.int/en/about/Pages/default.aspx
67 http://www.iec.ch
68 https://www.ove.at/

nearly 300 technical committees that develop, review and maintain standards. Robotics is covered by TC 184 Automation systems and integration, and more specifically dealt with by its sub-committee 2 (ISO/TC 184/SC 2) [69]. Until 2006 only robotics standardisation projects in the industrial environment were included within the scope of ISO/TC184/SC2. In order to also include robot applications in the service robotics environment, a scope and title modification of SC2 and consequently also of ISO/TC 184 was decided. Nations that are currently actively participating in developing these standards are France, Germany, Japan, Korea, United Kingdom and the United States. Its secretariat is hosted by the Swedish Standards Institute (SIS) in Stockholm. Chair of the ISO Technical Committee is Gruvinder Virk (UK) who is also co-leader of the standardisation topic group within Eurobotics AISBL. TC 184/SC2 has set up several working groups, of which the following are particularly relevant for AAL Robotics:

TC 184/SC2 Modularity for service robots, WG 10

WG10 is a recently set up working group which comprises robot modularity experts from 9 countries (Austria, China, France, Italy, Korea, The Netherlands, Sweden, UK and USA). The WG is exploring different aspects of robot modularity and will develop international standards within SC2 by bringing forward proposals for new work items as appropriate. The aims of the group are to explore the standardization modularity needs for service robots covering software modularity, hardware modularity, with safety aspects, integrated design approach and interoperability. [euRobotics2015]

The current focus of the group is on the following areas:

- Hardware: classification of physical connectivity, functionality and inter-operability requirements, such as issues of attachment, communications, powering, control, actuation, motion, etc.
- Software: software architectures and unified component models for functionality and interoperability via software abstraction for hardware driving
- Robot components: identification of key robot components which are used most often in robot systems (e.g. power supply, smart actuator, localisation system, obstacle avoidance, arms, legs, etc.)

The area of modularity has wide implications for all robotics sectors. Although the current focus is on service robots, WG10 is exploring different grades of robot components, and also if safety requirements can be included in the modularity specifications. For example the notion of different grade components for industrial, domestic and medical sectors have been discussed and are likely to be explored further in the on-going work.

TC 184/SC2 Personal care robot safety WG 7

WG7 comprises 55 robot safety experts from 15 countries (Canada, China, Denmark, France, Germany, Hungary, Italy, Japan, Korea, The Netherlands, Romania, Spain, Switzerland, UK and USA). The WG deals with safety of service robots which are designed to perform actions contributing directly towards improvement in the quality of life of humans, excluding medical applications.

- Personal care robots involve close human-robot interaction, and human-robot contact is permitted to perform intended tasks. Personal care robots are classified into the following different classes:
- Mobile servant robot: capable of travelling to perform serving tasks in interaction with humans, such as handling objects or exchanging information.
- Physical assistant robot: to physically assist a user to perform required tasks by providing supplementation or augmentation of personal capabilities. These include restraint type (fastened to a human during use such as exoskeletons) or restraint-free robots that are not fastened to a human during use.
- Person carrier robot: for transporting humans to an intended destination.

WG7 is currently working on the following possible future work projects:

- Guidance to ISO 13482

[69]. SC 02 – Robots and robotic devices, http://www.sis.se/popup/iso/isotc184sc2/index.asp

- Safety related test methods for ISO 13482

TC 184/SC2 Service robots WG 8

Working group (WG) 8, Service robots, is investigating standardisation needs for service robots. Examples of applications could be transportation, healthcare, rehabilitation, entertainment or inspection. The group has recognized some applicable existing standards, and also identified gaps for which it recommends the creation of separate working groups developing new standards.The group is currently active in developing the performance standard for service robots, i.e. ISO 18646-1 Robots and robotic devices — Performance criteria and related test methods for service robots — Part 1: Locomotion for wheeled robots.

Table 6. Current state of ISO standards with relevance to AAL robotics

Standard	Title	Status
ISO 13482:2014	Robots and robotic devices -- Safety requirements for personal care robots	published
ISO/DIS 18646-1	Robots and robotic devices -- Performance criteria and related test methods for service robot -- Part 1: Locomotion for wheeled robots	under development
ISO/WD 18646-2	Robots and robotic devices -- Performance criteria and related test methods for service robot -- Part 2: Navigation	under development
IEC/NP 80601-2-78	Medical Electrical Equipment -- Part 2-78: Particular requirements for the basic safety and essential performance of medical robots for rehabilitation, compensation or alleviation of disease, injury or disability	under development

Experts to the ISO working groups are delegated by national standardisation authorities, hence, in Austria, by Austrian Standards[70]. It is also possible to be invited as an observer, without right of vote.

The EuRobotics topic group on standardisation was created in 2014. It deals with standardisation activities in ISO, IEC and other standardisation organisations. A focus lies on research activities to support standardisation, e.g. to provide experimental data which can be included in standards or can be used to validate the requirements in standards. The topic group publishes several newsletters per year to inform the robotics community of new developments in standardisation.[71] The Multi-Annual Roadmap [euRobotics2015] prepared by euRobotics now also contains a chapter on standardisation and benchmarking issues.

5.8 Summary

Key results:

Robots, even at current prices, have the *potential to compete* with products and services on the home care and assistive technologies market, on condition that their functionality fits closely with a) the needs of consumers in specific situations of age-related change of lifestyle and/or care and b) with the alternative products and services on the market. For product development, market segments have to be much more thoroughly defined and studied in order to design for the market.

***Ethics* of AAL robotics, both wider robot ethics and more specific machine ethics, raise important questions for design, evaluation, and use of robots which need to be discussed not**

[70] https://www.austrian-standards.at/

[71] http://www.eu-robotics.net/downloads/downloads/

only by ethicists, but by the field at large.

AAL Robotics should encourage the early debate on *legislative and regulatory issues*. A lack of regulation can lead to uncertainty in consumers, harm the market chances of AAL robots, and lead to delayed over-restrictive reactive regulation.

Work on *standards* in service robotics is ongoing on an international level. With the first published standard on safety of personal care robots, ISO has opened the way for the marketing of robots in the field of AAL. The recently begun work on standards for modularity and interoperability of service robots is expected to have a major impact on development and production costs and thus to bring down consumer prices considerably.

6 Outlook and recommendations

6.1 The future of AAL robotics

6.1.1 Mid- to long-term perspectives

Companions

"In relation to household robots, we see a huge gap between the high expectations concerning multifunctional, general-purpose robots that can completely take over housework, the actual performance of the currently available robots and robots that we expect in the coming years. In 1964, Meredith Wooldridge Thring [Thring1964] predicted that by around 1984 a robot would be developed that would take over most household tasks and that the vast majority of housewives would want to be entirely relieved of the daily work in the household, such as cleaning the bathroom, scrubbing floors, cleaning the oven, doing laundry, washing dishes, dusting and sweeping and making beds. Thring theorized that an investment of US$ 5 million would be sufficient for developing such a household robot within ten years. Despite a multitude of investments, the multifunctional home robot is still not within reach."[Royakkers2015]

It is important to understand that the multi-functional robotic companion will remain, for some time yet, a *vision of the future* that is used to drive research on various underlying issues such as technology development, ethical, legal and societal aspects but *not* a current goal of development and commercialization. Unfortunately this misconception is widely adopted even among researchers and funding bodies. Given the prematurity of companions it is clear that we cannot expect to market such multi-functional solutions any time soon. Nevertheless basic research on components, algorithms, societal, legal and ethical issues is necessary as – given it being an age-old dream and the strong current interest in this field – it seems clear that such robots will be an integral part of future technologies: "Such a vision is still far in the future and within the medium term research horizon it is important to establish the underlying elements that will be required to deliver and deploy such systems and to develop trials and platforms able to benchmark and establish performance baselines" [euRobotics2015]. Additionally, basic research on companion robots has the potential to produce spin-offs (materials, components, standards, abilities etc.) that can lead to simpler robotic solutions that enter the market much earlier.

Self-driving cars

Although not developed specifically for the elderly, self-driving cars and other autonomous means of transport will have a high impact on the mobility of the older generations by removing the need to be fit to drive [euRobotics2015].

Exoskeletons

Exoskeletons are still only emerging as products on the market. Orbis Market Research estimates the turnover of the sector to be at $ 16.5 million in 2014. Given today's exorbitant prices of exoskeletons – US$ 69,500 for Argo Medical Technologies' ReWalk[72] – the installed basis is still small, the customers being mainly health and rehabilitation institutions. The market is estimated to increase to US$ 2.1 billion in 2021[73], especially with the first products now being approved for home use in the USA, and starting to be marketed in Europe.[74]

If industry succeeds in developing and producing exoskeletons for private use at considerably lower prices, this technology has the potential to have, in the long term, an enormous impact on rehabilitation, mobility, manipulation abilities and hence for independent living of impaired persons and older people with mobility and manipulation deficiencies.

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[72] http://www.cbsnews.com/news/first-patient-takes-rewalk-robotic-exoskeleton-home/
[73] http://www.prnewswire.com/news-releases/global-exoskeletons-market-robot-worth-21-billion-by-2021-498794101.html
[74] and even in Austria, see http://www.re-mobility.at/

6.1.2 Short-term development

"The Robots are Coming" has been an often repeated headline recently.[75] There have been a multitude of news articles, broadcasts and debates about the displacement of human work by robots and the worries and fears this development causes in industrialised countries. We can safely assume that some of the journalists thus raising the alarm have a robot vacuum cleaner at home and use the assistive technologies which modern cars offer and which pave the way, step by step, toward self-driving vehicles: the robots have already arrived, through the backdoor.

To date, the common denominator of commercial robots for domestic use is that they do not replace humans, but other technologies and devices. Instead of an alarming robotic revolution, we are experiencing a gradual introduction of new appliances and functionalities in the form of machines that have no similarity to the deeply ingrained stereotype of the humanoid robot.

In the emerging field of AAL robots, the same phenomenon is likely to be observable. "Relevant analogies for care robots are not animals or humans but useful domestic appliances and personal technologies with attractive designs, engaging functionality and intuitive usability." [Blackman2013] These "invisible" or "embedded" robots are currently making their way to the market for health and care products. The commercial success of the vacuum cleaners and other household robots has initiated a cultural change that paves the way for other types of robots: they will hardly be perceived as robots at all, and the addition of robotic abilities to familiar technologies could soon become commonplace.

With rigorous reduction of on-board functionality and through interoperability with other (AAL-specific or general) technologies, even the socially assistive robot "for the supermarket shelf" [Blackman2013] need not remain a vision for the future much longer. The JIBO, with its clever avoidance of humanoid and zoomorphic associations, could break the ground for a generation of affordable low-level robots which, in conjunction with existing technologies that ensure most of their functionality, operate as social, easy-to-use and entertaining frontends to smart homes and telecare services. Interoperability and modularity will be the key requirement to make such robots both affordable and attractive, and upgradable to AAL-specific safety and health applications.

6.2 Recommendations

6.2.1 Recommendations for future research funding in Austria

- Acknowledge the premature state of companion robots and concentrate funding for this application field on basic research of robotic abilities (see chapter 4) in the short term.
- Applied research: For complex solutions such as mobile robots for primary users (fetch & carry, companions) longer project lifetimes are needed in order to allow for several cycles of user-centred design and hence generations of prototypes in order to reach the critical level of maturity needed for impact evaluation.
- Research should be focused on gaining evidence for impacts and cost-efficiency instead of mere acceptance. Therefore mature solutions that can be evaluated in real contexts over the long-term are needed.
- Focus research funding for applied research on proposals offering specific ideas with a specific application area and target group instead of multi-purpose robotic solutions.
- Basic research is needed in the fields of: methodologies for design & evaluation of AAL robots, integration of technical solutions into existing care management, and several technical domains such as robot perception (see also chapter 4.1).
- Initiate dissemination activities that raise the general public's awareness of AAL robots in order to raise willingness to use, and to counter misguided fears and expectations.
- Support the emergence of new and creative ideas in the field, e.g. by a youth award. Some research areas in AAL Robotics are under-developed, while efforts are duplicated in others.

[75] just one of many examples: http://www.huffingtonpost.com/robert-kuttner/the-robots-are-coming_b_7432126.html

6.2.2 Recommendations for research in the field of AAL robotics

- Applied research: As the field of AAL robots is wide, concentrate on one specific user group (e.g. older users with a certain disability, in a certain situation instead, of an age range) and a well defined, narrow application area.
- Concentrate more on less researched but promising application areas such as, for example, personal care aids; see also chapter 3.6.8.
- Concentrate on solutions targeting informal and formal caregivers instead of primary users and consider secondary users' needs; see also chapter 3.2.
- Consider the needs of other (tertiary) stakeholders, in particular the need for cost-efficiency.
- Collaborate with gerontologists, care practitioners, end users, etc. to better know your user group.
- Plan your projects so as to allow for thorough and possibly long-term evaluation and field trials; follow good scientific practice in the choice and application of evaluation methods, and make the results available to the community.

6.2.3 Recommendations for product development & marketing

- Know your market segment: the market for AAL robots with care and assistance functionalities is strongly segmented; the attempt to target too broad markets with more and unspecific functionalities risks to lead to over-engineering. Niche markets are better than none.
- Robots for the „lifestyle market" need to be useful, aesthetically appealing, affordable, and fully integrated into the socio-technical practices of users' lives. Be aware of the high risk involved in targeting this market.
- Do extensive market research before product development, in order to determine what consumers really need and want, and what they are ready to pay for it. "Much of the current development effort in this area is too focused on expensive machines, often aiming to mimic humans or pets, with little marketing research behind the work." [Blackman2013]
- Don't trust statistics: demographic data about objective needs of the target population are no indicator of the actual demand.
- Aim for incremental instead of disruptive innovation: the successful entry-level robot is hardly recognisable as such, but an improvement on existing technologies and devices.
- Do not duplicate functions that can be provided easier and cheaper by other technologies, but make your robot interoperable with them (e.g. smartphones, tablets, sensors).
- Know the alternatives: in any purchasing decision of potential users, AAL robots will be compared to other non-robotic assistive products and/or services. Robots should fit into the same scenarios of use and practices as the alternative solutions.
- Make it simple: concentrate on few functionalities, orienting development rigorously towards markets and core user needs.

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Annex:

Catalogue of AAL-Related Robots