Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Curriculum in Ingegneria Informatica, Gestionale e dell'Automazione

Design and virtualization of intelligent systems for the management of assistive environments

Ph.D. Dissertation of:
Paolo Sernani

Advisor:
Prof. Aldo Franco Dragoni

Curriculum Supervisor:
Prof. Claudia Diamantini

XIV edition - new series

Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Curriculum in Ingegneria Informatica, Gestionale e dell'Automazione

Design and virtualization of intelligent systems for the management of assistive environments

Ph.D. Dissertation of:
Paolo Sernani

Advisor:
Prof. Aldo Franco Dragoni

Curriculum Supervisor:
Prof. Claudia Diamantini

XIV edition - new series

Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Facoltà di Ingegneria
Via Brecce Bianche – 60131 Ancona (AN), Italy

Acknowledgments

The first thanks of this thesis is deserved by my advisor, Prof. Aldo Franco Dragoni: beyond advising and motivating me in this research with his knowledge and experience, he has been an example, every single day.

I would like to express my gratitude to Andrea, who preceded me in this path: he taught me what a Ph.D. really is, with good practices and precious tricks. Thanks to the members of the AIRTLab research group, Gianluca, Gianluigi, Luca and Paolo: without working with them it would not be possible to write this thesis. A special thanks is due to my colleague Davide: beyond being a coauthor, he has been an endless source of enthusiasm and starting points for our researches.

During my Ph.D., I have been so lucky to work in two labs: the TdB and the IntervieωLab; thanks to Emanuele, Gilberto, Gionata, Gioele, Laura, Leonardo, Mirco and Roberto for fruitful discussions, invaluable comments and all the Fridays spent together.

I am very grateful to Dr. Fabiano Dalpiaz and Prof. Sjaak Brinkkemper for hosting me in Utrecht for my visiting period: those months have been a great occasion of personal and professional growth.

I owe sincere thanks to all the bachelor and master students who helped me in carry out this research, with their thesis and projects. Thanks to all the colleagues and friend met during workshops, conferences and schools: their comments, hints and talks opened my mind.

I will never be able to reward my family for all their support: Alessia, Nadia and Renato demonstrated their unconditional love, during this Ph.D. and for my entire life. Moreover, I am extremely thankful to all my friends: being them “ministers”, “badgers”, “passatelli eaters” or “baskteball players”, they are always there to listen the complaints of a Ph.D. student and deal with his mood swings.

Finally I would like to thank all those I surely forgot: a Ph.D. is a long journey and everyone who spent a single word or gesture to make the travel pleasant deserves my sincere gratitude.

Ancona, January 2016

Paolo Sernani

Abstract

The global population ageing is posing unprecedented challenges. Ambient Assisted Living (AAL) aims at the extension of the time older adults can live in their preferred environment, by promoting the development of Information & Communications Technology to support active and healthy ageing. This thesis faces the issues raised by the scientific literature related to AAL: the need of interoperability between AAL services, the lack of a systematic design of AAL systems and an unsatisfactory acceptance of AAL technology.

The thesis proposes the use of Agent-Oriented Software Engineering and Agent-Oriented Programming as the ideal paradigms to cover all the development phases of intelligent systems to manage assistive environments, such as smart homes. The properties of agents and Multi-Agent Systems, as defined in Artificial Intelligence literature, allow to build modular and interoperable systems suitable for the management of networks of sensors and actuators in smart homes. In such context, one contribution of this thesis is the Virtual Carer, a Multi-Agent System based on the Belief-Desire-Intention paradigm for the management of a smart home and the health monitoring of an assisted person.

Moreover, the thesis advocates the use of serious games to increase end-users' awareness towards the enabling technologies for AAL. The thesis presents Smart Tales, an awareness game based on the virtualization of a smart home. Its goal is to promote the concept of AAL and its technologies to the general audience. In Smart Tales, the player covers the role of a smart home resident who is skeptical about the unobtrusiveness of the home, and tries to cheat sensors. While doing so, the player gets the informative content of the game and learns the basics on AAL and sensor technology. Beside the design of the game, this thesis presents the results of a formative evaluation with ten users, which shows promising results about the learning effectiveness and the usability of Smart Tales.

Contents

List of Figures

List of Tables

Chapter 1.

Introduction

The phenomenon known as global population ageing, i.e. the shifting towards older ages of the world population, is accelerating, and will be even faster over the coming decades [1]. Social and economical implications are involved: an older population means a rise of the number of chronic diseases and, thus, the increasing of health-related emergencies as well as the growing of the healthcare expenditure [2]. Ambient Assisted Living (AAL) addresses such themes and aims at extending the time that older adults can spend in their home environment: AAL promotes the use of Information and Communications Technology to assist older adults in the Activities of Daily Living and provide remote care services [3]. The attention towards the AAL field has grown over the years: national governments and international institutions are encouraging the industry, the academia and research organizations to contribute to the development of AAL, by means of specific programs. In Europe, the European Commission supports the "Active and Assisted Living Programme"[1], a funding initiative for projects in public-private partnership in the field of ICT for active and healthy ageing. According to the key objectives[2] of the AAL Programme, the concept of Ambient Assisted Living is understood as:

- Extending the time people can live in their preferred environment by increasing their autonomy, self-confidence and mobility;
- Supporting the preservation of health and functional capabilities of the elderly;
- Promoting a better and healthier lifestyle for individuals at risk;
- Enhancing security, preventing social isolation and supporting the preservation of the multifunctional network around the individual;
- Supporting carers, families and care organisations;

[1] http://www.aal-europe.eu—Between 2008 and 2013, the program was known as "Ambient Assisted Living Joint Programme".
[2] http://www.aal-europe.eu/about/objectives/

- Increasing the efficiency and productivity of used resources in the ageing societies.

This thesis has a double soul: on the one hand, it presents the contribution that techniques from Artificial Intelligence (AI) can give to the design and development of intelligent systems for the management of assistive environments; on the other hand, it proposes and supports the use of 3D virtual worlds for AAL, in order to provide a test environment for AAL systems and to increase end-users' acceptance of AAL technologies.

1.1. Motivation

According to World Health Organization estimates, the number of older adults will triple within 2050, due to the lengthening of life expectancy and the decreasing of fertility: from 524 million of people over 65 years old in 2010 (8% of the world population), we will reach 1.5 billion of over 65s in 2050 (16% of the world population) [4]. This means that the dependency ratio, i.e. the ratio between the number of people over 65 years old and those of working age, is increasing [5]: we need solutions to preserve the quality of life of older adults, since there will be, in proportion, fewer caregivers. Such solutions are developed by the industries, research centers and care organizations working in the AAL field. They build on the results of Ambient Intelligence (AmI): they develop networks of heterogeneous information appliances or smart artifacts based on miniaturized and low-cost hardware [6], in order to assist the end-users in their activities of daily living. In addition to the support to older adults and their closest carers (as their relatives), AAL services include e-health applications for health operators, general practitioners and medical specialists; in fact, the digitalization of information is pushing healthcare and telemedicine towards the "netmedicine": where possible, the medicine activities are carried out through the Internet [7].

An increasing number of AAL services has been proposed in recent years. However, despite the scientific literature recognized that "AmI systems need to be aware of the users preferences, intentions, and needs" [8], a lack of systematic design and development processes, tailored on end-users needs, affects the AAL field [9]. Moreover, despite the potential usefulness of AmI and AAL is well-recognized, the adoption of technological solutions by end-users is still unsatisfactory [10, 11]. Such challenges have been addressed in Chapter 3 and Chapter 4.

1.2. Objectives and thesis overview

This thesis aims at presenting the two distinct contributions to the AAL field. First, we propose the adoption of agent-based methodologies for all the phases that characterize the development of intelligent systems for the management of assistive environments. Such research led to the first artifact that we describe in this thesis: an agent-based model for a system able to manage a distributed sensor network, composed by ambient and biometric sensors; it acts as an interface layer between the network and the assisted person to provide assistance in her daily activities, such as closing a window or regulating the heating; it acts as an interface layer between the assisted person and her relatives, to provide a synthesis of the daily activities performed, the health status and, in general, the quality of life; finally, it acts as an interface layer between the assisted person and the medical staff, in order to provide a summary of relevant health conditions, report anomalies, and trigger alarms.

Then, we argue for the usefulness of 3D virtual environments in the AAL field. In particular, such research resulted in the second main artifact presented in this thesis: a computer serious game, named “Smart Tales”. Its main innovation lies in the use of elements from different game genres to raise end-users’ awareness towards AAL and its enabling technologies. To engage the user, the game is articulated in levels where the player impersonates a resident of a smart home who, at the beginning, is skeptical about the pervasive technology in the home; Smart Tales includes informative cards to drive the serious content to the player: as a game goal, he has to collect all the cards, in order to answer the quizzes at the end of each level.

In addition, the main chapters describe also other directions explored during author’s Ph.D.: we included all the research work pertinent to the two main contributions. The thesis structure is the following:

- Chapter 2 presents a brief description of the technological framework that characterizes the AAL. The aim of the chapter is to make the reader aware of the heterogeneous devices, techniques and architectures which allow to provide AAL services. For such reason, the chapter reports on a systematic literature review on a set of primary studies which describe AAL systems. The results highlight that the 77% of the technology described in the papers concerns network devices, communication protocols and sensing technology: remote services, such as monitoring, are the core of AAL. The literature review revealed also a substantial number of references to algorithms for Activity Recognition and Position Tracking and, in general, to AI-based algorithms: an increasing number of papers aims at designing and developing services to autonomously understand the scenario where the assisted persons live, as well as assess their conditions.

Finally, the review highlights a possible lack of a systematic design related to end-users' needs. Appendix A provides the list of reviewed papers.

- Chapter 3 proposes an agent-based system for the management of an assistive enrironment, such as a smart home, with the aim to assist an older adult in her Activities of Daily Living as well as monitoring her health conditions. The chapter goes through the development of the system: everything from the requirement analysis to the implementation is agent-based. This choice is motivated by the complex and dynamic nature of assistive environments, which are typically composed by heterogeneus devices: a smart home is "an ecosystem of smart objects that can individually or collectively provide services to inhabitants" [12]. By modeling a distributed sensor and actuator network as a Multi-Agent System (MAS), we aim at building a modular and interoperable system, where devices can be/added removed any time. The system, named "Virtual Carer", has a reasoning core based on the Belief-Desire-Intention (BDI) paradigm, in order to dynamically trigger alarms or execute actions (e.g. calling a relative/caregiver) when needed. The second part of the chapter explains the possible integration of the Virtual Carer within a national healthcare infrastructure, also modeled as a multi-agent environment: an agent-based architecture for Health Information Systems (HISs) allows to store health data in the healthcare facilities where data is generated. The proposed architecture is inspired by the administrative structure of the public healthcare in Italy, even if it is based on more general requirements, and thus can be generalized.

- Chapter 4 discusses innovative uses of virtual environments, based on game engines, for AAL. In the first part of the chapter, we propose to adapt a robotics 3D simulator to develop and test software systems for AAL. The main goals of the simulator are to speed up the development of systems to manage assistive environments and to provide a smooth migration to a real environment, in case the real devices are able to communicate over a network, as the virtual ones. The chapter includes a proof-of-concept with two use-cases: a mobile application and the Virtual Carer. The first use-case is inspired by the increasing importance of mobile devices and applications in the development and provision of AAL and pervasive healthcare services. The second use-case shows how the simulation environment can be used to generate testing scenarios for an intelligent system for AAL. The second part of the chapter proposes the use of virtual environments and game features in order to increase end-users' acceptance of ICT systems for AAL. The chapter systematically describes the design of our awareness game, Smart Tales: it is a computer game with the serious purpose to increase end-users' awareness towards ICT systems for AAL. The last part of the chapter includes a formative evaluation of Smart Tales, concerning the learning effectiveness and the user engagement; the tests involved ten real participants with individual game sessions of half an hour. The results on learning effectiveness are promising: 81% of the answers to the post-test questionnaires were correct; even the usability of the game, after a minor redesign, obtained positive scores. However, the user engagement needs improvements, and a partial redesign to avoid repetitiveness across the different levels of the game might be necessary.

- Chapter 5 draws the conclusions of the thesis, summarizes the main contributions, and suggests future directions.

1.3. List of refereed publications

In this section we present the list of refereed publications co-authored by the author of this thesis, during the three-years Ph.D. This thesis is based on a subset of such publications, cited in the introduction of each chapter.

International journals

- P. Sernani, A. Claudi, and A. Dragoni, "Combining artificial intelligence and netmedicine for ambient assisted living: A distributed BDI-based expert system," *International Journal of E-Health and Medical Communications*, vol. 6, no. 4, pp. 62-76, 2015.

- A. Claudi, P. Sernani, and A. Dragoni, "Towards multi-agent health information systems," *International Journal of E-Health and Medical Communications*, vol. 6, no. 4, pp. 20-38, 2015.

International conferences and workshops

- P. Sernani, F. Dalpiaz, A. F. Dragoni, and S. Brinkkemper, "Smart tales: An awareness game for ambient assisted living," in *Ambient Intelligence*, ser. Lecture Notes in Computer Science, B. De Ruyter, A. Kameas, P. Chatzimisios, and I. Mavrommati, Eds. Springer International Publishing, 2015, vol. 9425, pp. 187-204.

- C. Akasiadis, K. Panagidi, N. Panagiotou, P. Sernani, A. Morton, I. Vetsikas, L. Mavrouli, and K. Goutsias, "Incentives for rescheduling residential electricity consumption to promote renewable energy usage," in *SAI Intelligent Systems Conference (Intellisys 2015)*, 2015, pp. 328-337.

- P. Calvaresi, A. F. Dragoni, M. Pierdicca, D. Calvaresi, and P. Sernani, "Using a virtual environment to test a mobile app for the ambient assisted living," in *4th International Workshop on Artificial Intelligence and Assistive Medicine*, ser. CEUR Workshop Proceedings, vol. 1389, 2015, pp. 53-61.

- P. Calvaresi, D. Calvaresi, P. Sernani, M. Pierdicca, E. Morbidelli, D. Accattoli, and A. F. Dragoni, "A virtual caregiver for the AAL: Testing in a 3D simulator," in *Proceedings of the 1st Italian Workshop on Artificial Intelligence for Ambient Assisted Living, colocated with the 13th AI* IA Symposium on Artificial Intelligence*, 2014.

- A. Claudi, D. Accattoli, P. Sernani, P. Calvaresi, and A. Dragoni, "A noise-robust obstacle detection algorithm for mobile robots using active 3D sensors," in *ELMAR (ELMAR), 2014 56th International Symposium*, 2014, pp. 1-4.

- P. Sernani, A. Claudi, P. Calvaresi, D. Accattoli, R. Tofani, and A. F. Dragoni, "Using 3D simulators for the ambient assisted living," in *3rd International Workshop on Artificial Intelligence and Assistive Medicine*, ser. CEUR Workshop Proceedings, vol. 1213, 2014, pp. 16-20.

- D. Calvaresi, A. Claudi, A. Dragoni, E. Yu, D. Accattoli, and P. Sernani, "A goal-oriented requirements engineering approach for the ambient assisted living domain," in *Proceedings of the 7th ACM International Conference on Pervasive Technologies Related to Assistive Environments*, ser. ACM International Conference Proceeding Series, vol. 2014-May, 2014, pp. 20:1-20:4.

- P. Sernani, A. Claudi, L. Palazzo, G. Dolcini, and A. Dragoni, "Home care expert systems for ambient assisted living: A multi-agent approach," in *The Challenge of Ageing Society: Technological Roles and Opportunities for Artificial Intelligence*, ser. CEUR Workshop Proceedings, vol. 1122, 2013.

- L. Palazzo, M. Rossi, A. F. Dragoni, A. Claudi, G. Dolcini, and P. Sernani, "A multi-agent architecture for health information systems," in *Frontiers in Artificial Intelligence and Applications, Advanced Methods and Technologies for Agent and Multi-Agent Systems.* IOSPress, 2013, vol. 252, pp. 375-384.

- P. Sernani, A. Claudi, G. Dolcini, L. Palazzo, G. Biancucci, and A. Dragoni, "Subject-dependent degrees of reliability to solve a face recognition problem using multiple neural networks," in *ELMAR, 2013 55th International Symposium*, 2013, pp. 11-14.

Chapter 2.

The technological framework of AAL from 2004 to 2013: an analysis

Several reviews and surveys appeared in the scientific literature related to Ambient Assisted Living (AAL), with the aim to analyze the state of the art of particular AAL applications and technologies. For example, in [13] the authors present a survey on projects related to smart homes, highlighting advantages and disadvantages of such applications. A deeper review is presented in [14], where the authors provide a taxonomy of monitoring devices, communication protocols and algorithms used in smart homes. In addition to reviewing specific applications as smart homes, the scientific literature on AAL includes reviews on specific technologies, such as sensors: Brownsell et al. [15] present a review of technologies used for lifestyle monitoring, such as motion detection sensors, RFID, accelerometers and others; Ding et al. [16] analyze the sensor technology adopted in smart homes, distinguishing between binary sensors (such as motion detection sensors), video cameras, RFID and other sensors (such as temperature and light sensors).

In this chapter, we present a systematic literature review which do not focus on a specific application or technology: instead, our aim is to make the reader aware of the technological framework which constitutes the core of AAL. For this reason, we examined ten years of primary studies in the field of Information and Communication Technology (ICT) at the service of AAL, with the following research questions:

1. Which are the devices and protocols most used in AAL?

2. Which techniques enable to assess the conditions of the assisted persons, as well as of the environment where they live?

3. Which software architectures are applied (or could be applied) by the systems proposed in the scientific literature?

The objective of the first research question is to highlight the technological composition of AAL, to understand which different hardware devices, software artifacts and communication protocols are used to provide AAL services. The second question concerns those tasks, algorithms, activities and workflows which constitute the AAL services, as, for instance, Activity Recognition, Position Tracking, etc. Finally, the third question aims at shedding light on the architectural paradigms used for the design and development of AAL systems; since most of the papers does not mention any specific architecture, we broadened the definition of "service-based architecture" and "multi-agent architecture" to classify the systems proposed in the papers, according to whether they were based on services or on a series of autonomous components. Additional details are present in Section 2.2.

The review was based on 236 papers that we obtained by applying three inclusion criteria on the abstracts of 939 papers, downloaded from a set of bibliographic databases; full details on the collection process are described in Section 2.1, while the list of analyzed papers is provided in Appendix A. The remainder of this chapter is structured as follows:

- Section 2.1 describes the method we followed to include the primary studies in our review, and presents the queries that we executed to collect the papers as well as the inclusion criteria that we applied on papers' abstracts. In addition, the section explains the main threat to validity in our review.

- Section 2.2 highlights the results of the review and shows how the analyzed papers can be grouped in technological categories. Moreover, the section discusses the consequences and the limitations of AAL research, from a technological perspective;

- Section 2.3 draws the conclusions of our review, highlighting how a portion of our findings has been applied in the research described in the next chapters.

2.1. Method

For our analysis, we followed the protocol of a systematic literature review, as presented by Kitchenham et al. [17]. Thus, after the definition of the research questions, we defined also a set of keywords to collect the pertinent scientific literature by executing queries on bibliographic databases. The keywords are based on authors' background and knowledge related to the AAL domain. The keywords are the following:

AAL, Ambient Assisted Living, Caregiving, Multi-Agent System, Service Oriented Architecture, Healthcare, e-health, Computer Assisted Drugs, Computer Assisted Therapy, Monitoring, Ubiquitous Computing, Bed Occupancy, Night Time Care, Recognition, Medical Informatics, Awareness, Data Collection, Disability, Decision making, Machine Learning, Reasoning, Artificial Intelligence, Smart, Elderly, Surveillance, Impairments, Activities, Data Analysis, Ageing.

Since the analysis was focused on Ambient Assisted Living, the queries were executed by combining the keywords *AAL* and *Ambient Assisted Living* with the other keywords of the list, as in the following examples:

- AAL
- AAL + Healthcare
- ...
- Ambient Assisted Living
- Ambient Assisted Living + Healthcare
- Ambient Assisted Living + Multi-Agent System
- ...

We used the following bibliographic databases: "IEEEXplore"[1], "ScienceDirect"[2], "ACM Digital Library"[3], "CiteSeer"[4] and "PubMed"[5].

For each query, we decided to stop the search when a sequence of ten "incoherent" papers was found. We considered incoherent a paper with a title and an abstract not adherent with the performed query, according to our subjective view. The resulting number of papers was 1104. To reduce the number of papers, we included for the review only those with a publication date between 2004 and 2013: the upper bound was 2013 since the queries were executed in December 2013 and January 2014. Hence, we decided to apply a temporal window of ten years, excluding 165 papers[6]. In addition, to select the papers for the review among the resulting 939, we used three inclusion criteria based on

[1] http://ieeexplore.ieee.org
[2] http://www.sciencedirect.com/
[3] http://dl.acm.org
[4] http://citeseerx.ist.psu.edu
[5] http://www.ncbi.nlm.nih.gov/pubmed
[6] It is worth noting that the expression "Ambient Assisted Living" became widely recognized in 2007 with the activation of the "Ambient Assisted Living Joint Association" and the subsequent "Ambient Assisted Living Joint Programme": the queries resulted in only 246 papers published before 2007; the number of collected papers with a publication date between 2007 and 2013 is 858.

Table 2.1.: Inclusion criteria: the papers included in the review were those with the scenario, purpose or target users in these lists.

Criterion	**Value**
Scenario:	*Assistance at home, Caregiving, Patient Monitoring Patient Evaluation, Communication, Healthcare, Companionship, Theoretical Scenario, Hospital Lane*
Purpose:	*Improve Patient Life, Provide Support to Physicians, Improve Relatives Life, Improve Caregivers Life*
User:	*Physician, Patients, Relative, Caregivers, Developers*

the *scenario*, *purpose* and *user* of the studies: Table 2.1 shows the values that one of these three aspects (at least) should have in order to include a paper in the review. Three reviewers applied the inclusion criteria on the abstracts of the 939 papers contained in the temporal window[7]. To evaluate the inclusion criteria, the set of papers was split in three groups, with each group assigned to a different set of two reviewers: the papers were directly accepted or rejected for the review when both the reviewers expressed the same judgement[8]; in case one reviewer was for the inclusion of a paper and the second reviewer was for the exclusion, the third reviewer solved the conflict and, thus, allowed to take the final decision. After the application of the inclusion criteria, 236 papers were included in the review.

The main threat to validity is due to reviewers' previous knowledge and experience on AAL: the results and evaluations presented in Section 2.2 are actually based on the subjective view and the background of the reviewers; in particular, as the next chapters will highlight, the author of this thesis spent his Ph.D. on multi-agent systems and assistive monitoring environments, and thus a bias towards monitoring technology might be present. However, the aim of the review is to give an overview of the great heterogeneity of the AAL in terms of technologies, techniques and architectures: the possible bias can give a predominance to monitoring technology in the presented results, but cannot obscure such heterogeneity, which is present even if we limit the field of applications to monitoring.

[7]The author of this thesis was one of the three reviewers.

[8]Each reviewer assessed the abstracts of the papers for the inclusion or exclusion of the papers; the assessment was done independently by each reviewer, and the results were merged at the end of the process.

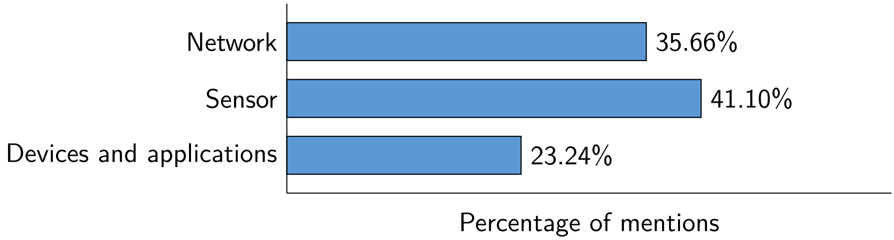


Figure 2.1.: The different kinds of technologies identified in the 236 reviewed papers. The bar chart shows the percentage of mentions related to technologies in the reviewed papers.

2.2. Results & discussion

The figures from 2.1 to 2.6 show the main results related to used technologies, applied techniques and software architectures in the systems proposed in the 236 papers included in this review.

Technologies. In order to understand the different enabling technologies which constitute the ground of AAL, we analyzed the technologies which are described in the reviewed papers, trying to group them in technological categories. Figure 2.1 shows the highest level categorization. We identified the 77% of the technology described in the papers as *Network* technology (36%) and *Sensor* technology (41%). In fact, these technologies are used to perform remote AAL services, such as monitoring. The figures from 2.2 to 2.4 show the composition of such groups.

Figure 2.2 includes the different groups of devices, protocols and software that we considered as *Network* technology. In such group, there is an high incidence of protocols and devices related to communication: half of the group is composed by wireless and Wi-Fi based technologies (18% of the *Network* technology), communication gateways (14%) Radio Frequency based technologies (12%), Bluetooth based technologies (11%), Zigbee based technologies (8%) and InfraRed based technology (7%). Almost the 27% of the *Network* technology includes generic boards and devices able to connect to a network through some sort of communication protocol: we called such category "Network Round". The results give an idea of the complexity of AAL in terms of heterogeneity of communication protocols used to provide remote services: there is not a predominant technology for network services. Thus, the main limitation is evident: the complexity lies on the integration of different network devices to jointly provide several AAL services.

Figure 2.3 depicts the composition of the *Sensor* group. It further confirms the predominance of monitoring services in AAL: the 34% of *Sensor* technology

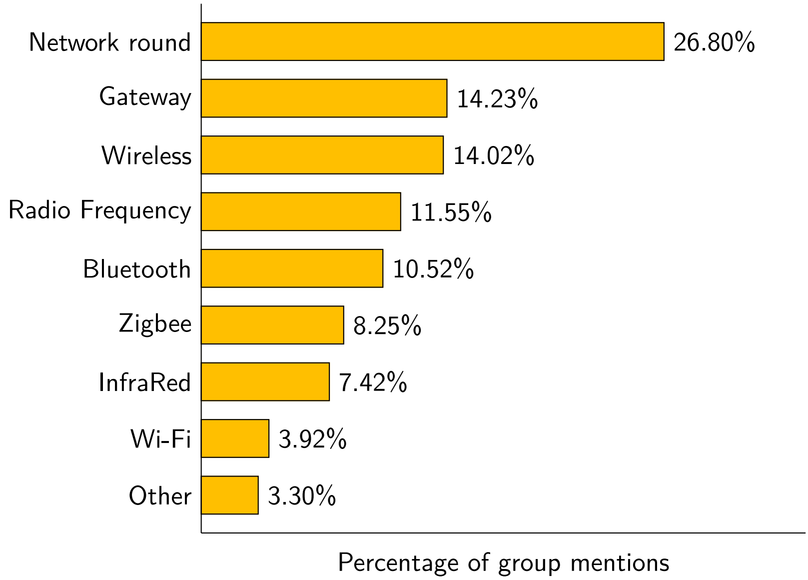


Figure 2.2.: Groups of identified *network* technologies: the 55.68% is composed by protocols and technologies for communications, such as RF, Bluetooth, Zigbee, IR and Wi-Fi.

is composed by ambient sensors, such as temperature sensors, humidity sensors, position detection sensors, etc.; the 28% of the group is composed by health sensors, such as blood pressure sensors, blood glucose analyzers, ECG sensors, etc. Inertial sensors, such as accelerometers, are also in the list (13%).

As highlighted in Figure 2.4, the *Devices and applications* group is led by mobile devices (32%[9]). Such predominance, in conjunction with the results on *Sensor* technology, confirms the trend toward the use of mobile devices in AAL: mobile devices and smartphone are considered promising tools to improve the quality of life of elderly people and are crucial to provide a more personalized care [18]. The *Devices and applications* group includes also devices such as cameras (22%), microphones (6%) and home appliances (7%), as well as back-end software technologies (5%), mainly to manage data. In fact, cameras are the 5% of all the technologies described in the papers, despite privacy concerns are one of the possible "show-stoppers" that could prevent the development of AAL and smart home services [12]. However, in our opinion, the incidence of computer vision technologies should increase in the next years, given the efforts to alleviate privacy concerns due to the use of cameras, for example with shape extraction [19]. The presence of papers dealing with microphones confirms the trend to use sound and speech processing AAL, in order to im-

[9] Mobile devices and applications are the 7.35% of all the identified technologies.

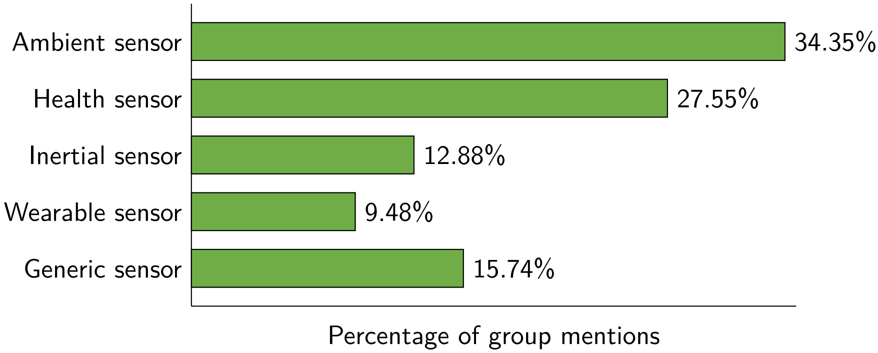


Figure 2.3.: Groups of identified *sensor* technologies: there were 34.35% of mentions for ambient sensors and 27.55% for health sensors.

prove comfort by means of voice commands and security by means of distress situations detection [20].

Techniques. To highlight the services supported by the technologies for AAL, we analyzed the main tasks and techniques described in the reviewed papers: we grouped such tasks and techniques by affinity, as shown in Figure 2.5. *Data Computing* and *Activity Recognition* represent the 50% of the used techniques and performed tasks. The *Data Computing* group (28.8%) includes data processing, data analysis, data fusion, sensor fusion, signal and image processing. The *Activity Recognition/Identification* group (21.1%) includes heterogeneous techniques with the common purpose of recognizing or identifying the Activities of Daily Living (ADLs) of the assisted persons: for example pattern recognition, automatic speech recognition, continuous and real-time monitoring can be all instances of the Activity Recognition group. In our opinion, these results are an evidence of the importance of techniques to automatically assess the scenario in an AAL environment (even if most of the analyzed papers do not provide explicit information about the impact on end-users' needs): the goal of the techniques in the *Data Computing* and *Activity Recognition* groups is to use sensor data, contextual information, data mining, computer vision, etc., to do scenario reconstruction; a scenario can be inside a home environment, addressing the need of detecting emergencies and potentials risks for the assisted persons; it can refer even to the reconstruction of the clinical status of the assisted persons. The importance of providing automatic AAL services is confirmed by the *AI-based* group of techniques, which sum up to the 21.8% of the total: it includes techniques such as neural networks, decision trees and machine learning in general, in order to develop decision support systems, reasoning engines and custom algorithms (e.g. for fall detection; path planning for robots; etc.). Given the portion of techniques related to *Position Tracking*

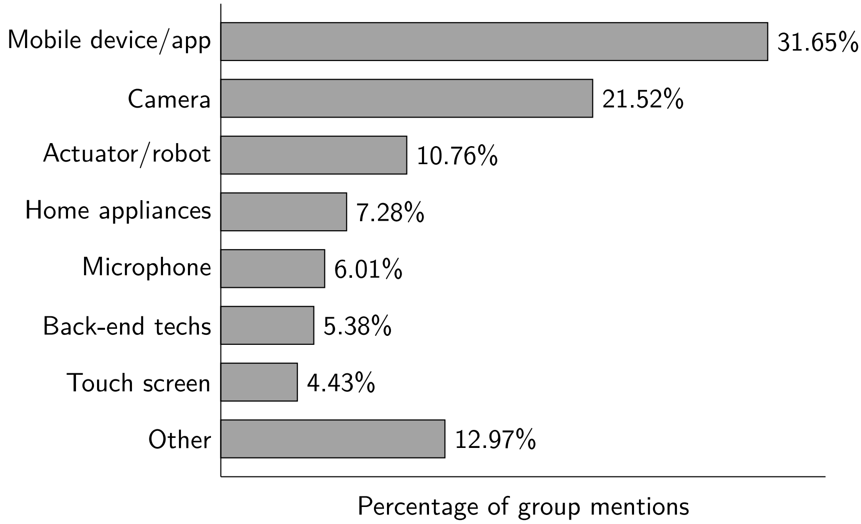


Figure 2.4.: Groups of other *devices and applications*: the 31.65% of mentions concerns mobile devices and applications.

(6.2%), we distinguished it from *Activity Recognition* and *Artificial Intelligence*. The *Network*-based group of techniques (9.9%) includes all the works done on data sharing, synchronization and connectivity at a software level. As for the technologies, this is evidence that AAL relies on remote services, performed over networks.

Architectures. Examined the technical and technological aspects of the AAL-related literature, we tried to understand if the proposed AAL services were similar, in terms of design and development, to multi-agent architectures or to service-based architectures. Hence, to classify the papers, we distinguished three categories: *ad-hoc* architectures, *service-based* architectures and *multi-agent* architectures. In the first we included all systems that are not ascribable to a single model, for two reasons: the authors does not explicity state to follow a model or the components of the proposed systems include aspects of more than one architecture. In *service-based* architectures we included systems and proposals that use services as fundamental elements to provide their functionalities, according to the definition of Service Oriented Computing (SOC) and Service Oriented Architecture (SOA) in [21]; however, we did not applied the definition strictly, by including only applications that are technologically neutral and loosely coupled: we included also more general client/server systems, where one or more server components offer some sort of elaboration services to a set of clients components. For the *multi-agent* architectures we started from Wooldridge and Jennings' definition of agent properties, i.e. autonomy, social

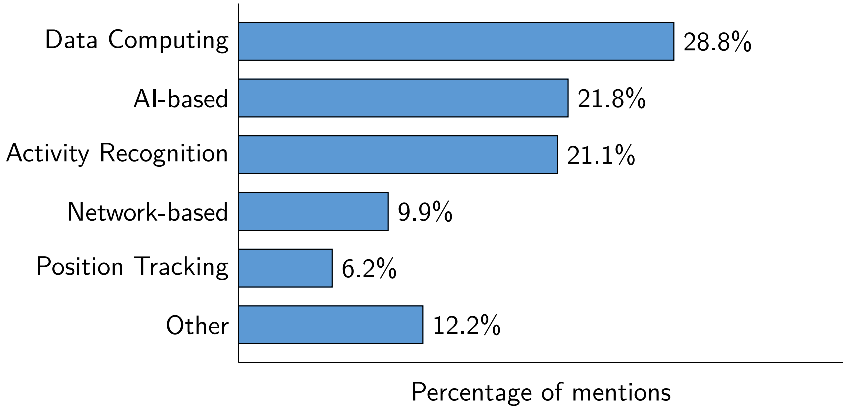


Figure 2.5.: The different kinds of techniques that we identified in the 236 reviewed papers. The bar chart shows the percentage of mentions of each group of techniques in the reviewed papers.

ability, reactivity and pro-activeness [22], and from the definition of multi-agent systems, as systems composed by multiple agents [23] which are entities which act on a common environment; even in this category, we did not applied the definitions strictly, but we included systems based on autonomous (self-contained) components that interact by means of asynchronous messages in a peer-to-peer configuration. Figure 2.6 shows the result of our classification: in 126 papers out of the included 236, the authors design, develop or implement an *ad-hoc* architecture to provide AAL services. Of the remaining papers, 48 are *service-based*, whilst we identified 45 architectures as *multi-agent*. There are also 17 papers for which an architecture cannot be identified: these are mainly position papers and do not report directly about an ICT system for the AAL.

Thus, the majority of the analyzed papers describes *ad-hoc* architectures; such results can be interpreted both positively and negatively: on the one hand, AAL systems should be tailored on end-users' needs and a high number of *ad-hoc* architectures might correspond to a high number of different addressed needs. On the other hand, a mixture of *ad-hoc* architectures can be the signal of a lack of a systematic requirements analysis: hence, it might be the case that architectures respond to what the designers perceive as end-users' needs instead of satisfying actual end-users' needs. In other words, there could be a lack of systematic attention to end-users' needs in the design of AAL systems, as highlighted in [9, 24]. Moreover, a limitation due to the significant portion of *ad-hoc* architectures is a low degree of interoperability among the diverse proposed solutions: AAL services based on custom (and different) architectures can hardly be merged, while in a wide field as the AAL, where many

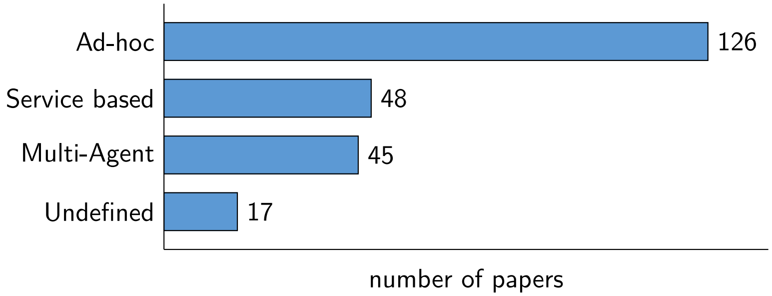


Figure 2.6.: The different kinds of architecture identified in the 236 reviewed papers. Most of the papers (126) are not ascribable to a single architectural model.

technologies are involved, interoperability is one of the main objectives[10].

2.3. Chapter conclusions

The papers examined in this review are ideal to show the wide heterogeneity that exists among the techniques and technologies that enable the provision of AAL services. The predominance of papers dealing with network technologies and sensor technologies (as well as the portion of papers reporting on Activity Recognition and AI-based techniques) highlights that the core of AAL is to provide remote services. However, the heterogeneity of the proposals makes hard the integration and interoperability of different services. On the one hand, it might be that many different ad-hoc architectures are necessary to address diverse end-users' needs; on the other hand, we recognized a lack of a systematic design of the proposed solutions to take into account end-users' needs. Of course, a portion of such lack may be explained with the need to use the limited number of pages acknowledged to authors to describe their systems: thus, authors might prefer describing the offered functionalities, and leaving the design methodologies to the dedicated literature. Finally, the analyzed papers confirmed the results of the "application-specific" reviews: as highlighted also in the work by Ding et al. [16], most of the studies demonstrates the feasibility of their technological solution. The evaluation of the proposed system is implicit in most of the cases rather than being explicitly reported on the papers.

In the next chapters we address the design and development of an AAL software systems for the AAL (Chapter 3) and the need of evaluating AAL systems (Chapter 4).

[10]The interoperability of AAL systems, and, in general, the technological transfer within the AAL field, are one of the missions of the "Active and Assisted Living Programme".—http://www.aal-europe.eu/support-to-projects/interoperability-standards/

Chapter 3.

Agent-based modeling of assistive environments

Artificial Intelligence plays a prominent role in several ICT-based applications for Ambient Assisted Living (AAL), Ambient Intelligence (AmI) and assistive devices: AI has the potential to supplement human caregiving [25] and, thus, to improve the quality of life of older adults as well as of the people taking care of them; AI can enable the creation of adaptive infrastructures to deliver evolutionary AAL services [26]; intelligent environments can provide support to individuals with cognitive or physical impairments by performing tasks such as activity recognition, detection of anomalies and reminders on diet, drugs and exercises [8].

As highlighted by the systematic literature review in Chapter 2, AI, both with its connectionist and symbolic souls, served and still serves AAL and AmI in their objectives with several contributions: applications include indoor positioning, movement and activity recognition [27, 28, 29], health monitoring and telemedicine [30, 31, 32], emergency detection and risk assessment [33, 34], intelligent and natural interfaces [20, 35].

Given the considerable heterogeneity of services and components for AAL systems, both in terms of software and hardware, in this chapter we argue for the great contribution to AAL and AmI that can be brought by two well-known AI paradigms, i.e. Agent-Oriented Software Engineering (AOSE) and Agent-Oriented Programming (AOP): we present a Multi-Agent BDI-based expert system, the “Virtual Carer”, as an answer to the need of highly modular and adaptive systems based on different devices and services to enhance the daily activities of smart home inhabitants.

The modeled architecture is intended to manage a distributed network composed by ambient and biometric sensors as well as simple actuators, such as automatic doors, windows, blinds, electrovalves and similar. The network should be modular to allow on-the-fly changes to the configuration, i.e. to add and remove devices at runtime. The name, Virtual Carer, is a metaphor that we use to define the services provided by the system: in fact, taking the inspiration from the actions and behaviours of a human caregiver, the Virtual Carer has the high-level goal to help the assisted person in her daily activities inside her home environment, simultaneously monitoring her health conditions and ensuring her security. Hence, the Virtual Carer need to be able to analyse data coming from the available sensors and, thanks to its symbolic representation of the current situation in its knowledge base, it has to infer new knowledge and to decide if detected values should be notified, possibly triggering an alarm, or if an action (such as opening the windows) should be performed. Moreover, the Virtual Carer has to act as an interface layer between the network, the assisted person, her relatives and the medical staff, providing to all those interested (and authorized) people a summary of the actions and facts concerning the assisted during a determined amount of time.

The rest of the chapter is organized as follows:

- Section 3.1 highlights the motivation behind the adoption of a Multi-Agent architecture; in fact, this choice derives from the features of these kinds of systems: distribution, modularity and robustness. The section gives also the necessary background on intelligent agents and related works;
- Section 3.2 describes the architecture of the Virtual Carer, highlighting its goals and how these can be achieved. The section includes the description of a proof-of-concept of the system;
- Section 3.3 sketches how the Virtual Carer could be integrated in a more general healthcare infrastructure, modeling it also with an agent-based approach.
- Section 3.4 concludes the chapter, summarizing the main conclusions that we can derive from the described research.

The research presented in this chapter is based on the results that we achieved in [36, 37, 38, 39].

3.1. Why an agent-based smart environment?

Smart environments are unobtrusive, interconnected, adaptable, dynamic, embedded, and intelligent [6]: thus, systems for AmI and AAL, as smart homes, includes a wide heterogeneity of devices, sensors, actuators and applications [13, 16, 40]. To face such heterogeneity, coordinate all the available services and provide a mechanism to include/exclude functionalities at runtime, we propose the adoption of agent-oriented paradigms in all the phases of the development of an intelligent system to manage a smart home, from the domain analysis to the implementation. Our objective is to satisfy the requirements for such a system by exploiting the basic properties of the notion of "agent", as given by Wooldridge and Jennings [22], i.e. autonomy, social ability, reactivity and pro-activeness. Autonomy indicates that software agents have the control over their actions and internal state and are capable to operate without (or with a limited) intervention by humans or other software; social ability refers to the capability of agents of interacting through standardized interaction protocols and, thus, exchanging information about the environment around agents; reactivity refers to the capability of responding to perceptions and to changes occurring in the world in which agents operate; pro-activeness indicates the ability of agents of acting following their goals to change the state of the world in which they operate.

In fact, agent-based software is widely considered suitable for open architectures that continuously evolve to include new components and meet new requirements [41]. Agents' properties allow to develop distributed and modular solutions, providing robust and scalable software systems that operate in dynamic and uncertain environments [42]:

- **Autonomy and Social Ability**. Being responsible for its own internal state, capable to communicate through an Agent Communication Language (ACL, [43]) and interact according to standard interaction protocols established by the Foundation for Intelligent Physical Agents (FIPA, [44]), each agent is the only entity who has to know the actual implementation of a sensor, providing services to other agents. Hence, devices can be added and removed in a transparent way, simply wrapping them with agents; each sensor can be associated with an agent, making the system robust to failures and disconnections; software agents can be natively distributed over one or more networks thanks to agent-oriented middlewares.

- **Reactivity**. Representing sensors as agents in an agent-based system simply means to wrap them with a software entity: the agent is the only one supposed to be aware of the actual implementation of the sensor and to control if the monitored parameter is in a security range. A relevant change in a parameter (i.e. an "out of range" value) corresponds to a message to the reasoning module of the system. Similarly agents responsible for actuators react to commands from the reasoning module.

- **Pro-activeness**. It makes an agent-based system capable of autonomously taking the initiative, guided by goals. In fact, the core of the system we propose is a reasoning module: the "*VirtualCarerAgent*", based on Belief-Desire-Intention (BDI, [45]) paradigm. It transforms data from sensors in logical predicates of its knowledge base, building a representation of the world in which the agent operates. Then, the *VirtualCarerAgent* can infer predicates and trigger plans to bring the world into desired states. In other words, the carer metaphor indicates that the system aims at modeling logical structures, reasoning and behaviours similar to those of a human caregiver. To perform actions on the monitored environment and interact with the assisted person, the *VirtualCarerAgent* uses FIPA standard messages to get values from agents that control sensors and to send commands to agents that control actuators.

Having advocated the suitableness of agent-oriented paradigms in the AAL field, in the following we give details about the notion of "intelligent agent" as presented in scientific literature as well as on related works concerning multi-agent applications for assistive environments.

3.1.1. Intelligent Agents

Despite the absence of a single agreed definition for the notion of "agent" in computer science literature, there are many common traits in the definitions of Ferber [46], Genesereth and Ketchpel [43], Jennings and Wooldridge [47], Maes [48], Russell and Norvig [49]: agents are entities that control their own decision making, perceive the complex and dynamic environment in which they are through sensors, act on it through effectors and are able to communicate through a common Agent Communication Language. Among the possible agent architectures, the Belief-Desire-Intention (BDI) model of agency, based on Bratman's human practical reasoning [50], is especially suited for dynamic and uncertain environments [51]; BDI agents are a natural solution for the development of systems with self-reconfiguring capabilities [52]. During its control loop, a BDI agent updates its beliefs, i.e. its knowledge about the environment, and its desires, i.e. the states representing the environment as desired; desires are states that, at some point (or under certain conditions), the agent might want to achieve; desires can be viewed as options for the agent [53]. The intersection between beliefs and desires generates agent's intentions, i.e. the set of desires that an agent is committed to achieve, through the execution of plans, i.e. sequences of actions that will bring the world in the desired states.

As the solution proposed in this chapter, an agent-based system usually consists of multiple agents [23] which constitute a Multi-Agent System (MAS): MASs are suitable to model complex systems, since they are based on decentralization and parallel execution of activities carried on by autonomous entities [54]. The Virtual Carer is composed by several agents which collect information about the home and the health status of the assisted person and execute actions on the environment, under the coordination of the BDI core of the system.

3.1.2. Related Works

The idea of software infrastructures based on agents to support tasks such as telemonitoring is rooted since many years in scientific literature. For example, in [55] a client-server architecture is extended with a set of software agents located in a home computer, to allow the exchange and elaboration of sensor data over a LAN (with a main server that manages the access to data by authorized client applications); the architecture is presented through UML diagrams. The work exploits the potentiality of asynchronous messaging through a common ACL, but, in more recent years, research works use agents' properties at a deeper level.

Indeed, MAS are recognized among the most interesting technologies for the development of healthcare applications and services [56]. The majority of the works in scientific literature is focused on demonstrating the viability of an agent approach on smart environments. Borowczyk et al. [57] describe a proof-of-concept of a BDI-based system, with the aim to show how goal deliberation can support patient monitoring. The proof-of-concept includes the adjustment of the home temperature via an "Air Conditioning Agent" and the evaluation of patient's heartbeat via an "Heartbeat Measure Agent" (triggering an alarm if necessary). The importance of pro-activeness in a dynamic, non-deterministic, complex environment is highlighted also by Reinisch and Kastner [58]: the authors propose a use case in which a small society of BDI agents copes with the energy efficiency of a smart home when different devices are available. In Nefti et al. [59] cognitive agents are applied to ambient monitoring. The authors adopt an approach slightly different from the previously presented, using fuzzy logic embodied in a "Risk Assessment Agent" to predict risk situations and send appropriate alarms; the agent's knowledge base consumes the information provided by agents responsible for various ambient sensors (such as a "Gas Detector Agent" or a "Temperature Analyzer Agent"). In [60] agents allow to adapt the behaviours of a smart home to users' goals: the authors propose the reasoning cycle (based on Prolog-like rules) and the planning workflows that an agent-based smart home environment should follow to adapt its actions to inhabitants' goals.

In this chapter we do not focus on a specific scenario: instead, we propose a comprehensive approach that relies on the use of agent-based paradigms since the domain analysis and the design phase, in addition to the implementation phase. Thus, we start from stakeholders' strategic goals to identify the capabilities of a system for the management of smart home and the health monitoring of an assisted person.

3.2. The Virtual Carer

The Virtual Carer is a system for AAL that models a distributed, reliable and modular sensor network composed by biometric and ambient sensors as well as actuators and characterized by the following fundamental purposes:

- To communicate with an assisted person;
- To monitor her health conditions;
- To control the environment around him.

To cope with a highly variable environment, the Virtual Carer models reasoning mechanisms and goal-oriented behaviours, following the BDI paradigm. The amount of information used by Virtual Carer is represented by logical predicates, forming its Knowledge Base (KB). The Virtual Carer chooses the right actions to perform on the environment with an inference engine applied on its KB. The Virtual Carer works as follows:

- It collects information generated by empowered sensors;
- It analyses data provided by sensors and updates its KB;
- When its KB is updated, it generates new knowledge using its inference engine;
- With backward reasoning rules applied on its KB, the Virtual Carer selects the main goal and chooses (through backtracking) the plan to satisfy it;
- It carries out the actions of chosen plan, collaborating with agents responsible for actuators, driving such small actuators in order to properly act within the environment;
- It maintains a private log-file (history) of all significant events.

The name “Virtual Carer” suggests, through a metaphor, that the system aims at modeling the behaviour of a human caregiver, enhancing the relationships between the assisted person and her own:

- Living body, recalling things to do, as to take medicines at a given time of the day, reading a book, monitoring health parameters (heartbeat, blood pressure, glucose, breath rate);
- Environment, controlling the opening and closing of doors and windows, flow of water and gas, giving commands to receive fast instructions and suggestions in daily activities such as cooking, hand washing, cleaning;

- Family and friends, answering the phone when the assisted sleeps, giving information to the caller about the health of the assisted and enabling them to access such information through a web-based/mobile interface;

- Health operators, enabling caregivers and medical personnel to obtain a summary of relevant information to quickly monitor the patient and the environment status.

In the following, Subsection 3.2.1 briefly describes the methodology we choose to model the Virtual Carer architecture. The details of all the development phases are given in Subsection 3.2.2, while a proof-of-concept implementation of the system is presented in Subsection 3.2.3.

3.2.1. Method

In order to represent the knowledge involved in the management of an assistive environment and, hence, to model the architecture of the Virtual Carer, we followed the phases of the Tropos software engineering methodology [41]. In the Early Requirements Analysis, we first modeled the knowledge handled by the main stakeholders who "act" within an assistive enviroment, in terms of their goals and plans to achieve such goals. Then, during the Late Requirements Analysis, we modeled the goals of the Virtual Carer and described why the actors involved in an assistive environment should use our system. Finally, during the Architectural Design and Detailed Design, we derived the agents (and their capabilities) which allow to retrieve values from ambient and health sensors, store the detected anomalies and execute plans to manage the home and to assist its users.

Figure 3.1 shows the graphical representation used in this chapter to represent the Tropos key-concepts, as defined in [41]: *actor*, *role* and *agent* to model the entities with intention within the assistive environment, both as the stakeholders that acts in the environment and the software or hardware agents operating in the system; *goals* which represent actors' intentions; *plans* which, through means-ends analysis, satisfy goals; the *dependencies* among the actors (of the environment and the system). For a comprehensive description of the Tropos methodology and its models and artifacts, see [61].

3.2.2. Virtual carer architecture

Following Tropos, we developed the architecture of the Virtual Carer applying Early Requirements Analysis, Late Requirements Analysis, Architectural Design and Detailed Design.

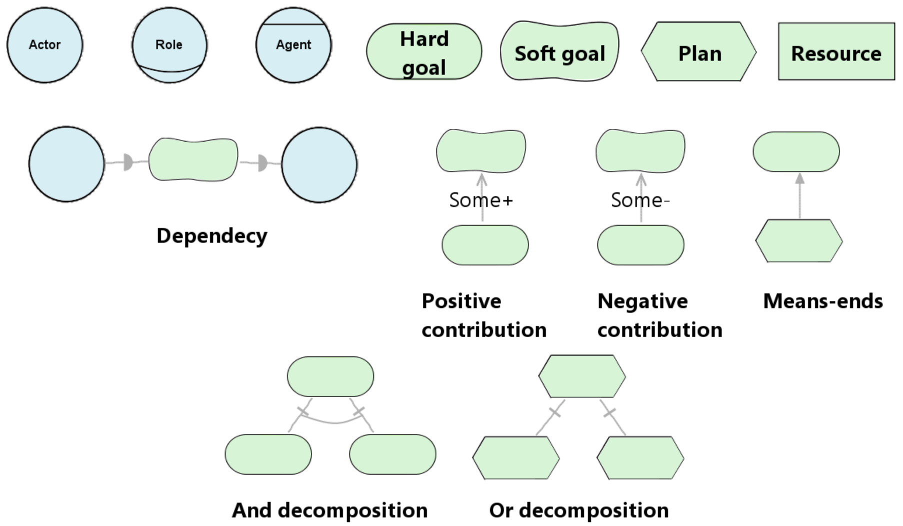


Figure 3.1.: Diagrams used to represent the Tropos concepts: actor, goal, plan, resource, dependency, contribution, means-ends, and-decomposition, or-decomposition.

Early requirements analysis

Figure 3.2 presents, at its highest level, the Strategic Dependency Model with the actors involved in the management of an assistive environment and the care of an assisted person. Everything is centered on the *Assisted Person* actor, with the goal to "maintain a good quality of life": an assisted person wants to live as long as possible in her preferred environment, at the highest possible degree of autonomy. As the age increases over the 65 years, she needs help to manage the home and the daily activities, and assistance to perform those daily checks to her health (as measuring the blood pressure) which are necessary to avoid risky situations. Such assistance is provided by one or more *Caregivers*, which we identified as a role, since, in the context of the home environment, it can be covered by health operators, informal carers or a close relative of the assisted person. Beyond being potential caregivers, (good) *Relatives* want to maintain a good relationship with the *Assisted*, who wants to stay in contact with her family and closest friends. There are various health problems that are more common in older than in younger people [62]: *Hospital* (intended as the health operators and the medical staff) is an actor who wants to ensure the health of patients; the *Assisted Person* depends on the healthcare infrastructure to get regular exams, and specialists need patient's anamnesis and data from past treatments to apply healthcare protocols.

A refined diagram, with a preliminary goal and plan analysis for the *Assisted*

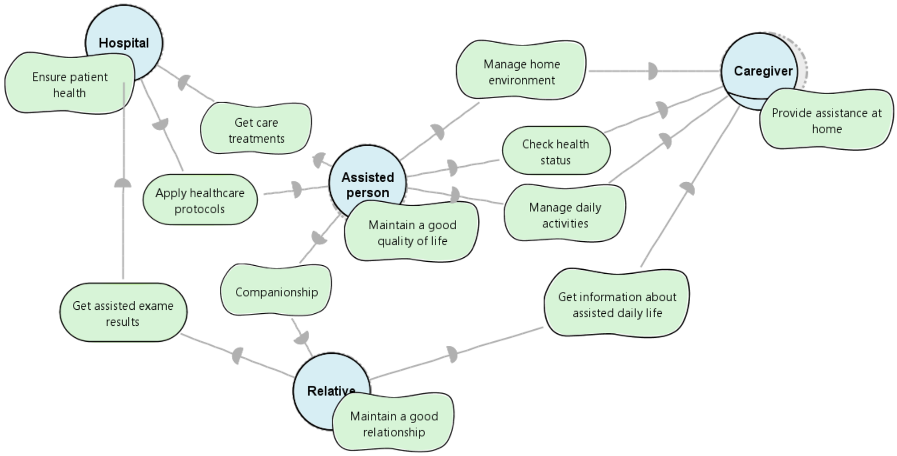


Figure 3.2.: Strategic Dependency Model with the actors involved in the management of an assistive environment and in the care of an assisted person.

Person, is shown in Figure 3.3. A good health, a comfortable environment and a pleasant life time are essential for the quality of life: this is reflected by the positive contributions received by the softgoal "maintain good quality of life". The goals and softgoal related to the *Assisted Person*'s health can be satisfied with plans that involve: nutrition, personal hygiene, the need to take medicines and to check regularly the health status. All this kind of tasks can be performed autonomously or with little assistance by a human *Caregiver* at home: for instance, the *Assisted Person* needs motivation to perform physical exercises or reminders to take pills. In case she is not completely autonomous, the *Assisted Person* needs help in carrying out regular health checks such as measuring the temperature or the blood pressure, and in preparing dishes for her nutrition. In fact, the diagram focuses on the dependencies between the *Assisted Person* and the *Caregiver*. This is even more evident with the plans that lead to the satisfaction of the goal "maintain environment comfortable": the *Caregiver* can provide assistance in all housekeeping activities. In addition, in case the *Assisted* needs "hospitalization" or "hospital visits", she has to provide documents with her clinical history and previous treatments.

Late requirements analysis

Figure 3.4 shows the goal diagram for the *Virtual Carer system* actor, within the actor model from Early requirements analysis: the main goal of the *Virtual Carer* is to "provide assistance" to all other actors. In order to support the *Caregiver* and the *Assisted Person*, the *Virtual Carer* has the objective to gen-

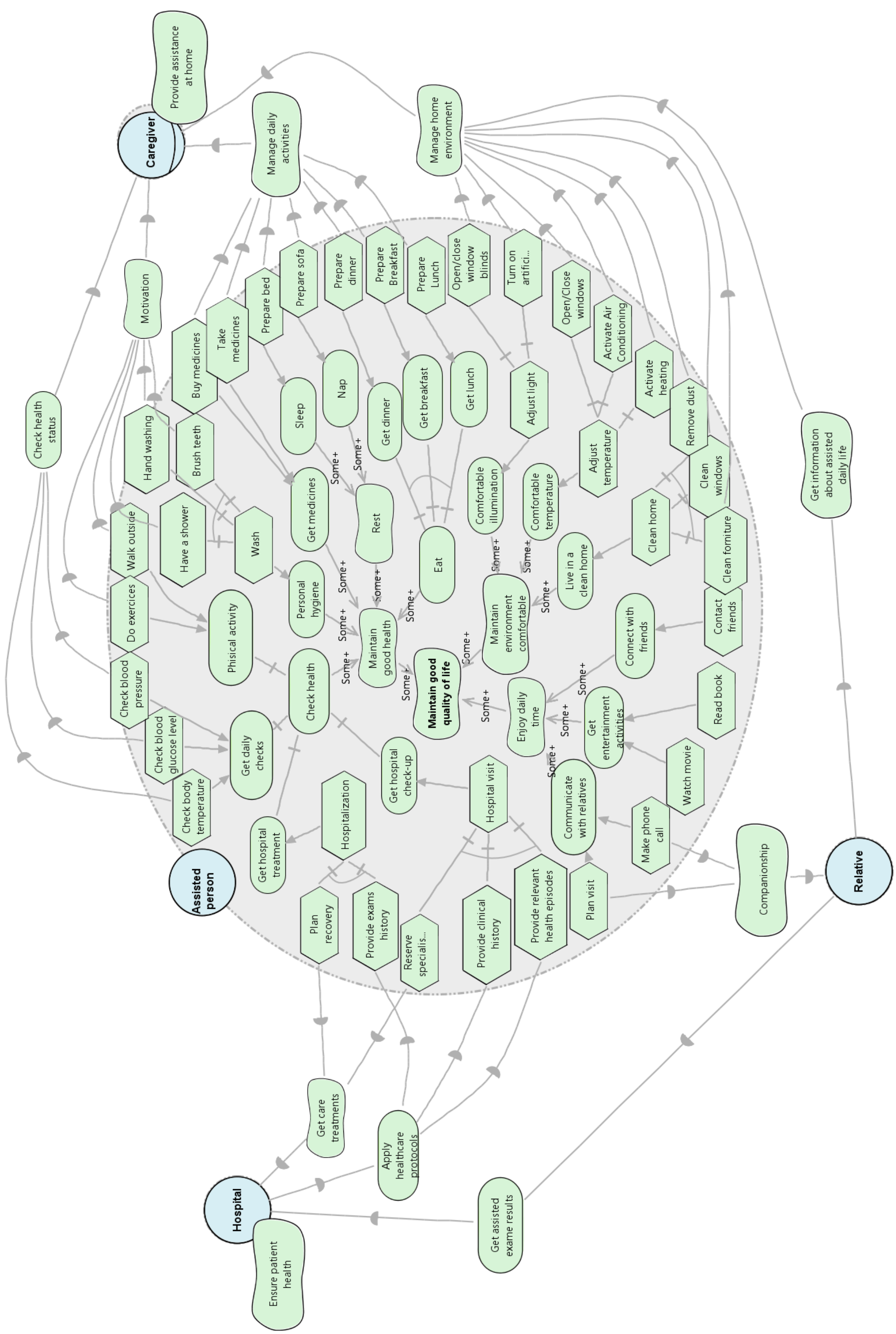


Figure 3.3.: Goal diagram for the actor *Assisted Person* and its dependencies with the other actors of an assistive environment.

erate an “assistance plan”, which is composed by various sub-goals: “ambient monitoring”, “health monitoring”, “device management” and “anomaly management”. “Ambient monitoring” and “health monitoring” can be satisfied by getting parameters from available sensors (and checking if the value is inside a security range). The management of devices relies on the possibility to check the status of available actuators and send commands to perform actions on the environment (e.g. turning on a TV or opening a door). The *Virtual Carer* has to face anomalies detected in carrying out “ambient” and “health monitoring”: such goal can be satisfied by sending commands to one or more actuators, as when a room is too warm or too cold; in other cases, e.g. when there is an anomaly in a health parameter, the system starts an emergency call. In fact, the satisfaction of “ambient monitoring”, “health monitoring”, and “device and anomaly management” gives a positive contribution to softgoals “manage home environment” and “manage daily activities”, as underlined by the dependencies of the *Assisted Person* and the *Caregiver* actors.

Figure 3.4 highlights also a reshaping of dependencies for the actors *Hospital* and *Relative*: in order to provide assistance the *Virtual Carer* has to maintain logs of all relevant events and anomalies that occurred in the assistive environment. Events such as daily activities, daily monitoring, parameters out of a security range and health checks, need to be registered in a event database and provided when necessary. The health operators of an *Hospital* can access to relevant health data through the interface provided by the *Virtual Carer*: they can rely on an additional tool to carry out the patient’s anamnesis. *Relatives* can use a similar interface in order to get news about the daily activities of the assisted: a *Relative* might be interested in knowing if her beloved did enough physical exercise or took her pills; if she spent to much time on bed or sofa; if she ate. Of course, the *Virtual Carer*, as all IT systems, should preserve its users’ privacy. As we will describe in Section 3.3, the system can be used to integrate results from procedures carried out in hospitals and clinics, making relatives (and even health operators in different healthcare facilities) able to consult medical reports.

Entertainment can be important for well-being and happiness of older adults, in addition to the maintenance of cognitive functions [63]. Hence, “entertainment” gives a positive contribution to the goal “provide assistance”: an IT system as the *Virtual Carer* can ease and automate tasks such as playing a movie, reading a book or connecting to social networks to stay in touch with friends.

Architectural Design

The goals of the Virtual Carer system are delegated to sub-actors as depicted in Figure 3.5. A *Virtual Carer Agent* is driven by the intention to provide

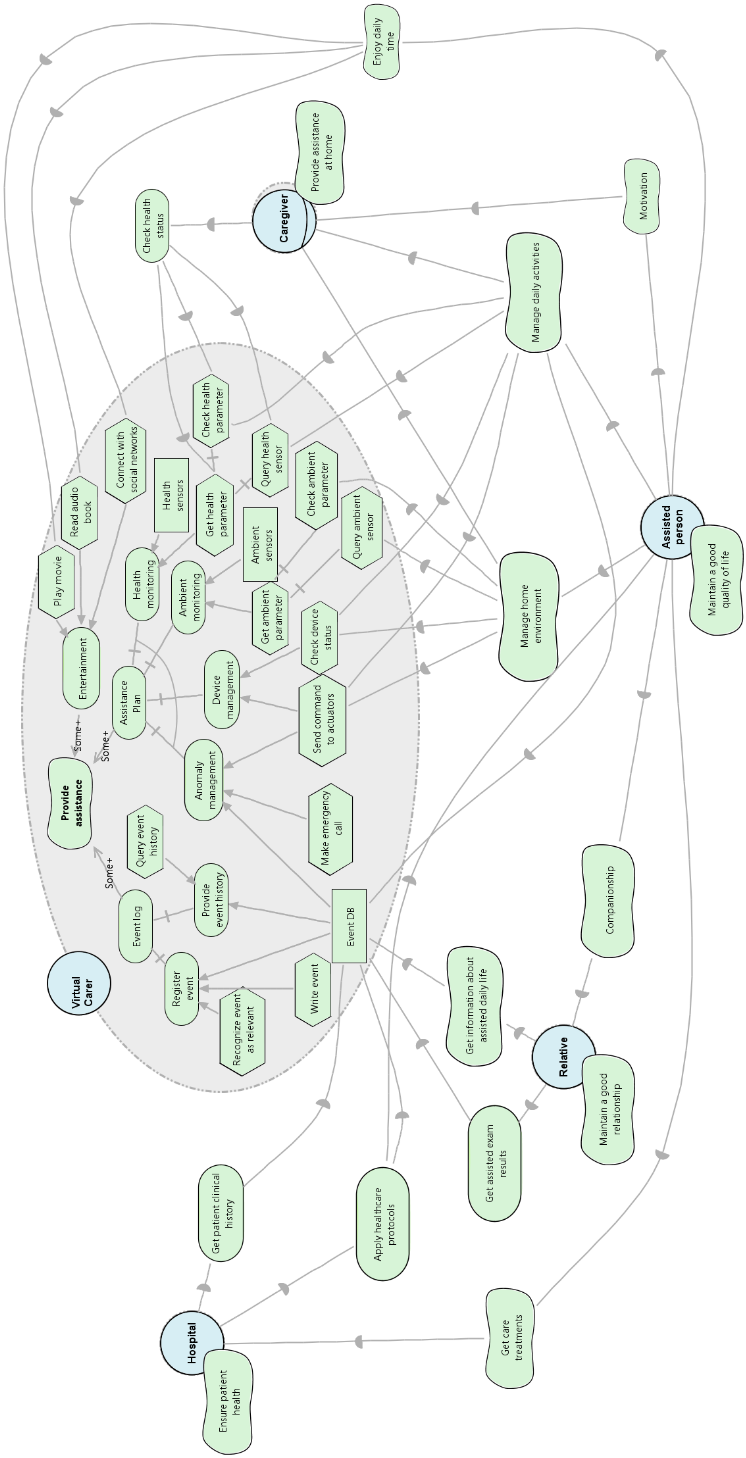


Figure 3.4.: Goal diagram for the *Virtual Carer system* and its dependencies with *Relative*, *Caregiver*, *Hospital* and *Assisted Person*.

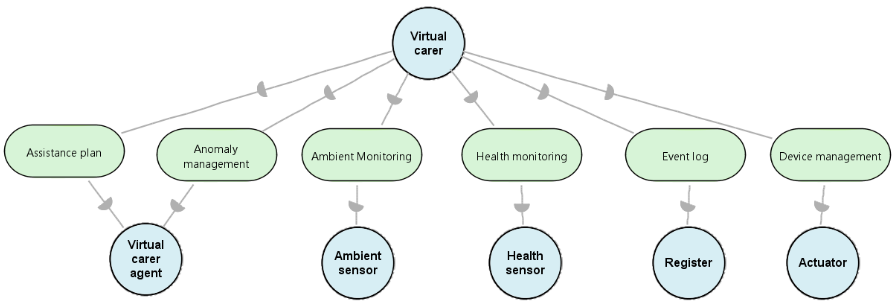


Figure 3.5.: Sub-actors to which the *Virtual Carer system* delegates its goals.

assistance plans, and includes the reasoning core of the system. Actors *Ambient Sensor* and *Health Sensor* perceive ambient parameters of the assistive environment, and health parameters of the *Assisted Person*. Actor *Actuator* is delegated to the management of devices present in the environment, such as speaker, monitors, motor-powered doors, windows, blinds, heating and air-conditioning. A *Register* is responsible for the storage of events, anomalies and actions planned by the *Virtual Carer Agent*.

The rationale of the *Virtual Carer Agent* is shown in Figure 3.6. The goal "assistance plan" can be decomposed in five sub-goals: "get sensor data", "anomaly identification", "manage anomaly", "provide data history on request" and "publish provided services". In fact, the *Virtual Carer Agent* is responsible for planning the actions to be executed in the environment, such as opening/closing windows, activating the air-conditioning or the heating, making an emergency call to relatives or health operators. The *Virtual Carer Agent* has to gather health data, to identify the health condition of the *Assisted Person*, and ambient data, to detect dangerous or anomalous parameters using available sensors: such data are used to update the belief base of the *Virtual Carer Agent* both on a regular basis and when required by the plan being executed. Sensor information, as the position of the *Assisted Person* inside the home, is used to identify anomalies and potential risks according to the rules in the knowledge base and to find actions to notify such risks or act on the environment. The *Virtual Carer Agent* is also responsible for queries on data representing past events about the *Assisted Person*. As shown in the dependency model in Figure 3.10, each actor depends on the others to accomplish its tasks. Considering that we choose an agent-oriented architecture (for the reasons that we explained in Section 3.1), we need to add another actor, a *Directory Facilitator*: it enables all the actors to publish the services that they offer and discover the services that they need to complete their tasks. Hence, actors can depend on each other services remaining loosely coupled. The *Virtual Carer Agent*, as all the other actors, has to register to the *Directory Facilitator* to publish its

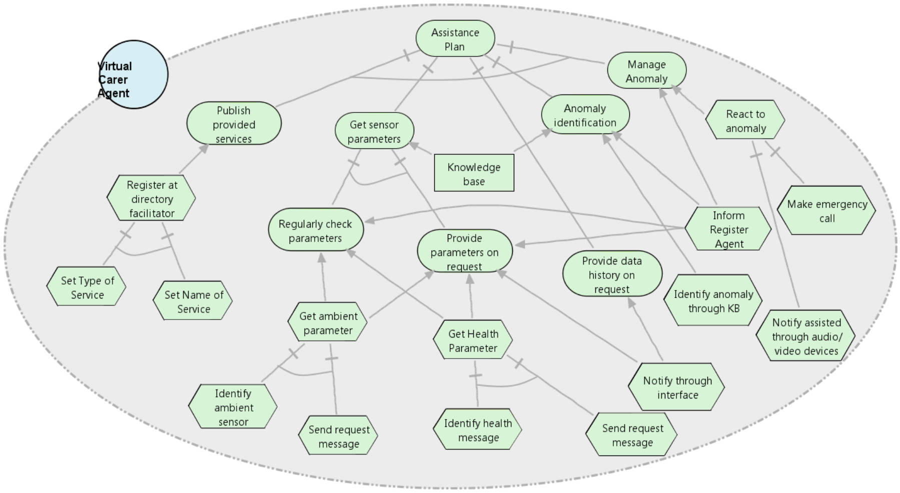


Figure 3.6.: Goal diagram for the *Virtual Carer Agent* actor.

services for other actors. In addition, it will use the *Directory Facilitator* to identify *Ambient* and *Health Sensors*, *Actuators* and the *Register*.

Sensor actors, that actually carry out monitoring, can be distinguished in two types: *Ambient Sensors* and *Health Sensors*. Figure 3.7 shows the rationale of the *Health Sensor* (*Ambient Sensor* has the same goals and can be represented with the same diagram). *Sensor* actors can receive messages with the request to read the monitored parameters; they are able to connect to the physical sensor and read the parameter values checking whether they are inside a predetermined security (or comfort) range. *Sensor* actors publish their services (i.e. reading one or more parameters) on the *Directory Facilitator*. *Ambient Sensor* actors read the value of ambient parameters, as the temperature of a specific room. Also binary sensors as presence sensors (such as Passive Infrared) are managed by the *Ambient Sensor* actors: they directly inform the *Virtual Carer Agent* and the *Register* about the presence of someone in the monitored room. Similarly, *Health Sensor* actors manage sensors which measure parameters related to the health conditions of the assisted person, such as the heartbeat, the blood pressure and the breath frequency.

Actuators (Figure 3.8) are responsible for the management of the various devices composing the system such as lights, shutters, speakers, monitors, doors, etc. They must be able to receive request messages (from the *Virtual Carer Agent* which actually plans to execute an action) in order to execute on/off commands on the devices. The *Register* actor (Figure 3.9) wraps and manages the system database and is responsible for the storage of monitored events, detected anomalies and the plans executed by the *Virtual Carer system.*

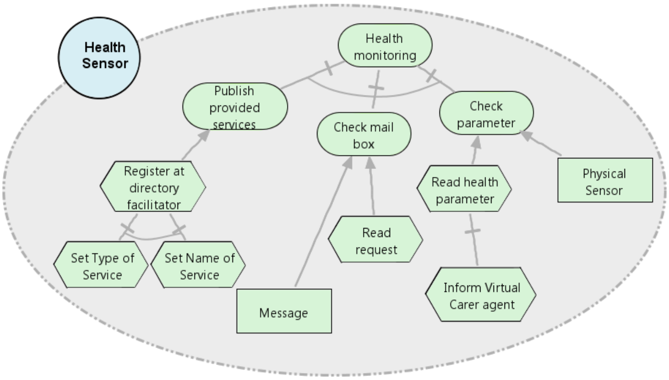


Figure 3.7.: Goal diagram for the *Sensor* actor.

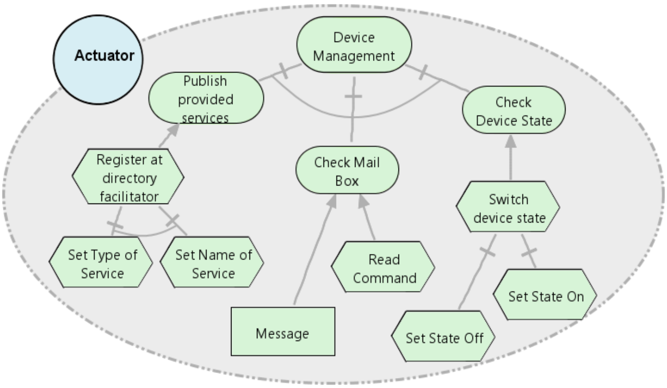


Figure 3.8.: Goal diagram for the *Actuator* actor.

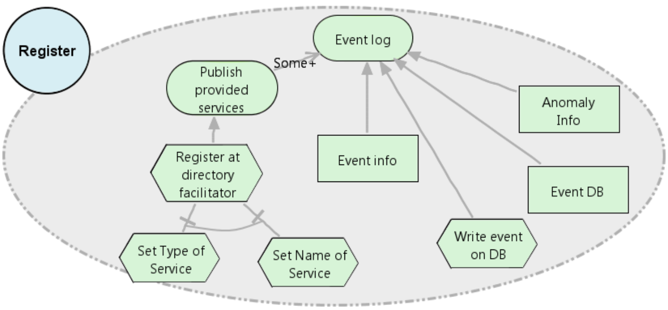


Figure 3.9.: Goal diagram for the *Register* actor.

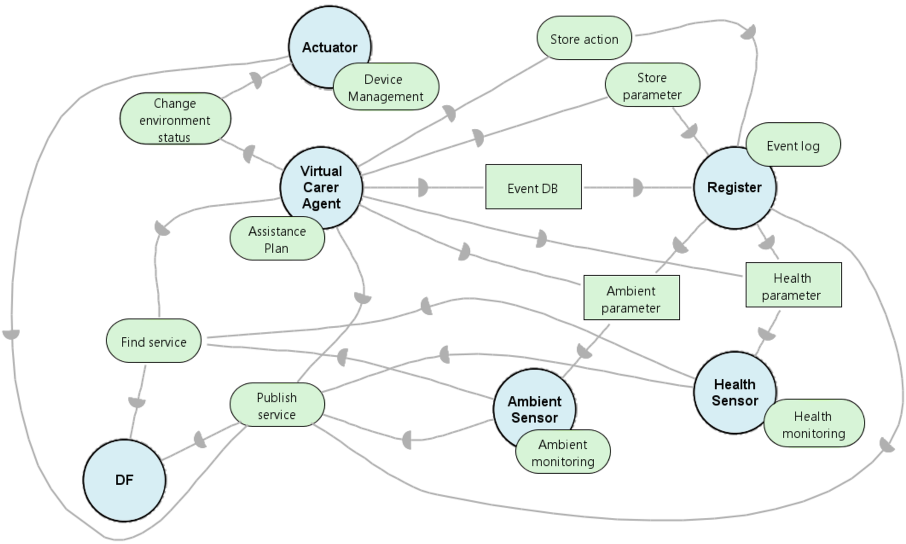


Figure 3.10.: Actor diagram for the *Virtual Carer system*.

The sub-actors of the *Virtual Carer system* depend on each other to satisfy their goal as depicted in Figure 3.10. The *Virtual Carer Agent* depends on the *Register* for the access to the system database both to store results of the reasoning process (sensed values, anomalies and executed actions) and to retrieve data when requested by external actors; it depends on *Ambient* and *Health Sensors* to get the values of ambient and health parameters from physical sensors during the reasoning process; it depends on *Actuators* in order to act on the environment and send audio or video notifications; it depends (as all the other actors) on the *Directory Facilitator* to publish its services and identify (i.e. find the addresses of) *Sensors*, *Actuators* and the *Register*. Being the actor responsible for the system database, the *Register* also depends on *Ambient* and *Health sensor* actors for the storage of values from physical sensors. *Sensors* can provide values on a request by the *Virtual Carer Agent*, or can pro-actively signal anomalies, and thus depend on the *Directory Facilitator* to find the *Virtual Carer Agent*. The capabilities of all the sub-actors of the *Virtual Carer system* are summarized in Table 3.1.

Detailed design

We mapped each system actor identified in the Late Requirements analysis into an agent which implements actor's capabilities: a *VirtualCarerAgent*, a *RegisterAgent*, a *Directory Facilitator* (DF) and a number of *ActuatorAgents* and *SensorAgents*, with the latter distinguished in *AmbientAgents* and *HealthA-*

Table 3.1.: Capabilities of the Virtual Carer actors.

Actor	**Capability**
Virtual Carer agent	find sensors find actuators publish virtual carer service get ambient (health) parameter send action request send storage request get event data
Ambient (Health) sensor	find Virtual Carer agent publish monitoring service
Actuator	switch device state publish action service
Register	store parameter store action provide event data get ambient (health) parameter publish register service
Directory Facilitator	store list of services store list of agent addresses provide list of services provide list of agent addresses

gents. The final system will include an *ActuatorAgent* for each different device in the assistive environment, such as a distinct *ActuatorAgent* for the lights in each room of the home. Each ambient sensor (e.g. a temperature sensor or a Passive Infrared sensor) is managed by an *AmbientAgent*; the same holds for *HealthAgents* managing health sensors.

The sequence diagram in Figure 3.11 shows a simplified version[1] of the interactions (in term of exchanged asynchronous messages) among the agents, after the detection of an anomaly by a *SensorAgent*, i.e. a value out of a predetermined range in its monitored parameter. Let's suppose that an *AmbientAgent*, responsible for a temperature sensor, detects 14° C in the living room, while the comfort temperature should be between 19° C and 22° C. The *AmbientAgent* queries the DF for the Agent Identifier (AID) of the *VirtualCarerAgent* in order to signal the anomaly. After receiving the value, the *VirtualCarerAgent* starts its reasoning cycle and verifies, in its belief base, that there is an open window in the living room; the first plan generated through the knowledge base includes an audio notification with the suggestion to close the window. Thus,

[1] In order to make the diagram readable, we omitted the FIPA Request Interaction protocol between the *VirtualCarerAgent* and the *ActuatorAgent* as well as between the *VirtualCarerAgent* and the *RegisterAgent*. However, the adoption of FIPA protocols is one of the main features of the approach, giving the possibility to add new agents to the system.

the *VirtualCarerAgent* searches on the DF the *ActuatorAgent* which manages the speaker in the bedroom where, according to the belief base, there is the assisted person. The *VirtualCarerAgent* sends a notification to the assisted person through the speaker, suggesting to close the window (or ask for the permission to close the window, in case it is motor-powered). The *VirtualCarerAgent* queries the DF also for the AID of the *RegisterAgent*, in order to store the detected anomaly and the executed action. As highlighted in the sequence diagram, an *ActuatorAgent* can fail in executing the received request: the *VirtualCarerAgent* stores this information thanks to the *RegisterAgent* and looks for another plan to face the anomaly. In the example, an alternative solution is to send the notification to the assisted person with another media, such as a monitor or the smartphone.

To this point, the presence of a *Directory Facilitator* might seem unnecessary. However, it enables agents to communicate without knowing, a-priori, the actual address of the other agents. One might argue that an agent should at least know the address of the DF, but, as we will explain in Subsection 3.2.3, the adoption of an agent-oriented middleware enables to manage the connection with the DF, abstracting its address. The DF might be considered a single point of failure, but, again, the choice of a suitable middleware allows to make persistent the data managed by the DF.

3.2.3. Proof-of-concept implementation

We will discuss in Chapter 4 the issues related to the evaluation of complex IT systems for AAL and how such an evaluation can be performed with virtual environments; in this Subsection, instead, we present the proof-of-concept implementation, based on a simulation scenario, of the Virtual Carer system. Our aim is to give some insights on the symbolic knowledge base of the *VirtualCarerAgent*, by means of simple examples of rules and plans. In addition, we will focus on the advantages of using agent-oriented middlewares for the implementation.

Figure 3.12 presents the fictional home map used in the simulation, with the arrangement of the available devices in the environment. There are four rooms: the bedroom (room 1), the hallway (room 2), the bathroom (room 3) and the living room (room 4). For each one, a temperature sensor (T1, T2, T3, T4), a Passive Infrared (PIR) sensor (PIR1, PIR2, PIR3, PIR4) and a device to turn on/off the light (AL1, AL2, AL3, AL4) are provided. In addition, there is a speaker (SP1, SP2, SP3) for each one of the first three rooms, and a monitor to visually communicate with the assisted person in room 4. Pressure sensors are supposed to be in each place where the person can sit or lie down (e.g. couch, bed, seats), and contact sensors are supposed to be placed on every

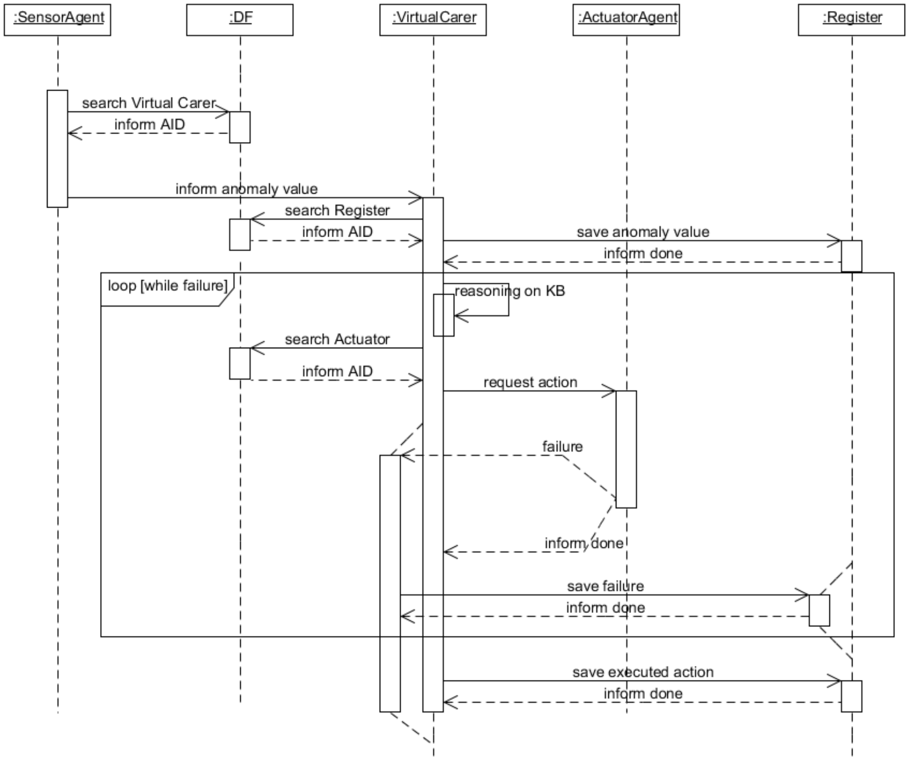


Figure 3.11.: Sequence diagram with the agent interactions that follow the detection of an anomaly (i.e. a value out of a predetermined security range) by a *SensorAgent* of the Virtual Carer system.

door and window, to monitor their open/close state. Body sensors are used to monitor the vital parameters (e.g. heartbeat, body temperature) of the assisted person. For each sensor and device in the scenario we created the appropriate *AmbientAgents*, *HealthAgents* and *ActuatorAgents*.

Agents with reactive or cyclic behaviours (*AmbientAgents*, *HealthAgents*, *ActuatorAgents* and the *Directory Facilitator*) are implemented using the JADE framework [23], while the BDI agent representing the *VirtualCarerAgent* and the *RegisterAgent* are implemented using Jason (based on the AgentSpeak language) [53]. JADE is fully compliant with FIPA specifications; it implements:

- The communication between agents with FIPA-ACL messages and FIPA standard interaction protocols, ensuring the modularity of the system. Different devices can be added any time simply integrating more agents;
- The basic FIPA components of an agent platform, i.e. an Agent Management System (AMS) and a Directory Facilitator (DF). In particular JADE implements primitives to register services in the DF and federate

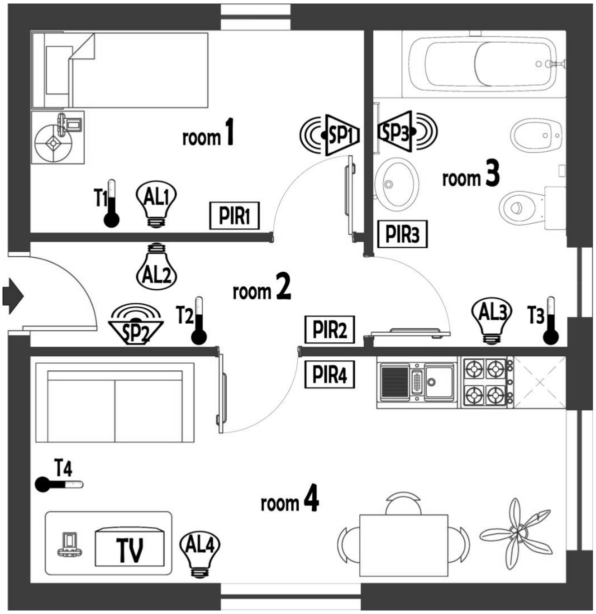


Figure 3.12.: Home map representing the implemented simulation scenario

any number of DF;

- Primitives for the migration of agents among different nodes of a network.

Jason is used for the *VirtualCarerAgent*, in order to apply the BDI paradigm, and for the Register Agent, allowing to store beliefs directly in the database. Moreover, Jason can be fully integrated with JADE: by using internal actions, a Jason agent can call JADE primitives, as those for the registration of services in the DF.

To run the simulations, we complemented the agency of the Virtual Carer with a BDI agent: the *ElderlyAgent*. It represents the behaviours of the assisted person and works by sending messages to other agents of the system: for example, to simulate the detection by a PIR sensor, it informs the *AmbientAgent* when it moves in the controlled room; moreover, it can send requests directly to the system in order to know the value of specific health parameters.

At the beginning of the simulations, the knowledge base of the *VirtualCarerAgent* includes beliefs representing the structure of the home environment, with available sensors and devices. The Listing 3.1 includes the beliefs that represent the rooms of the home in Figure 3.12 as well as some of the beliefs used to represent the composition (in terms of furniture and objects) of a room. The beliefs in Listing 3.2 are examples of the facts used to indicate the areas covered by the available devices. For instance, the speakers 1, 2 and 3 cover whole rooms; the tv, instead, is significant for the couch.

Listing 3.1: The beliefs representing the simulation scenario.

```
partOf(livingRoom,home).
partOf(bedroom,home).
partOf(hallway,home).
partOf(bathroom,home).
                  ⋮
partOf(couch,hallway).
partOf(bed,bedroom).
```

Listing 3.2: The beliefs representing areas covered by video and audio devices.

```
covers(tv,couch).
covers(speaker1,bed).
covers(speaker2,hallway).
covers(speaker3,bathroom).
```

In addition to the beliefs, the knowledge base of the *VirtualCarerAgent* includes also rules to infer new knowledge and, thus, trigger plans. The rules allow the *VirtualCarerAgent* to localize the elderly in a specific room, establish which actuator acts in that room and decide if the actuator has to be activated for an emergency plan. Some examples of these rules are shown in Listing 3.3. The rules with "admissible(D)" in the head of the clause indicate that a device D is considered admissible for a plan, if the assisted is inside the room A, and the device D "covers" the room A. Similarly, if a device D covers the area $R2$ and the area $R1$ is part of the area $R2$, the device D covers also $R1$.

We run simulation scenarios by triggering several plans of the *ElderlyAgent*. In a first simulation scenario, started with the *ElderlyAgent*'s plan in Listing 3.4, we modeled the situation in which the assisted person goes to bed and measures its body temperature. The simulation works as follows. At first, the

Listing 3.3: An example of the rules in the *VirtualCarerAgent* knowledge base.

```
                  ⋮
admissible(D):- inside(A) & videoDevice(D) & covers(D,A).
admissible(D):- inside(A) & audioDevice(D) & covers(D,A).
                  ⋮
covers(D,R1):- partOf(R1,R2) & covers(D,R2).
                  ⋮
```

Listing 3.4: A plan of the *ElderlyAgent*: it starts the simulation moving to room 1 and then queries the *VirtualCarerAgent* for the body temperature.

```
+-simulation1 : true <-
        .send(carer,tell,init(hallway));
        .wait(10000);
        .send(pir1,tell,at);
        .send(carer,achieve,queryP(bodyTemp)).
```

Listing 3.5: When the *VirtualCarerAgent* has a new belief "enter" sent by a PIR sensor it updates its belief base with the new position of the assisted person and activates the plan "powerOn". The plan includes also some debug messages written on the standard output with the ".print" internal action.

```
@ent[atomic]
+enter[source(A)] : true <-
        ?inside(M);
        ?spir(A,R);
        M \== R;
        -+inside(R);
        !powerOn(R,M);
        .print("light on in ");
        .print(R);
        .print("light off in ");
        .print(M);
        -enter[source(A)].
```

ElderlyAgent sends the information about its initial position to the *VirtualCarerAgent*[2], initializing the simulation; then, after 10 seconds (i.e. the time necessary to get to bedroom), it informs the *AmbientAgent* responsible for the PIR sensor about its presence in the final position (this simulates the detection of the elderly by the PIR sensor). The *AmbientAgent* notifies the *VirtualCarerAgent* about the presence of a person in the bedroom; thus, the *VirtualCarerAgent* has a new belief (i.e. the presence of the assisted person in room 1), and activates the plan (shown in Listing 3.5, with the debug strings sent to the standard output with the internal action ".print") to turn on the light in the bedroom and to turn off the light in the hallway. Finally, the *ElderlyAgent* sends a message to the *VirtualCarerAgent* to know its body temperature value. The *VirtualCarerAgent* activates a plan that includes all the actions necessary to require the data from the proper *HealthAgent* and to communicate it to the *ElderlyAgent*.

Beside plans similar to the one just described, we simulated plans without

[2] At runtime there is always a sensor that detects the position of the assisted person; the message is sent only to initialize the simulation.

Listing 3.6: Anomaly plan for room temperature.

```
+temp_anomaly(V)[source(A)] : true <-
        .print("Room temperature out of range");
        .print("from sensor ", A);
        .print("value ", V);
        .time(H,M,S);
        .send(register,tell,anomaly(A,V,H,M,S));
        .print("Information sent to Register Agent");
        ?em1(N);
        New = N + 1;
        -+em1(New);
        !notify.
```

an explicit request by the *ElderlyAgent*, in which the Virtual Carer system had to infer the right actions. For example, when a window remains open in the bedroom and the assisted person is taking a nap, the decreasing of room temperature should activate the plan with the suggestion to the assisted person to close the window. In this scenario, the *VirtualCarerAgent* has a belief corresponding to the window state "open": the *AmbientAgent* associated to the bedroom window informed the *VirtualCarerAgent* that the window was open. At a later stage, the *AmbientAgent* responsible for $T1$ sensor communicates to the *VirtualCarerAgent* that the detected value is out of the predetermined range, triggering the *VirtualCarerAgent*'s plan in Listing 3.6. The *VirtualCarerAgent* updates its knowledge base with these new beliefs, sends the anomaly to the *RegisterAgent* (with the internal action ".send") and activates the goal "notify", to send an audio message to the assisted person, suggesting to close the window.

To fully validate the proposed approach, some tests should be carried out in a real home environment, equipped with existing sensors and devices. However, the implemented simulations are suitable to underline the advantages of the application of MAS and BDI paradigm to AAL. The frameworks we used for implementation, JADE and Jason, provide fault tolerant techniques to implement agent platforms, such as the Main Container Replication Service (MCRS) and the *Directory Facilitator* Persistence: the first prevents that the agent creation and management can be single points of failure, the latter allows the traceability of agent services. Moreover, they provide primitives for the management of agent lifecycle and for the registration of agent services. More in general, an approach based on Multi-Agent systems ensures the distribution of agents over a network; the adoption of FIPA standards guarantees modularity to the system: devices can be added without specific efforts. Furthermore agents, by using FIPA-ACL messages for communication, can provide information over the internet, being able to publish services for the authorized clients. The BDI paradigm allows to quickly respond to changes in a dynamic environment: new data from sensors results in the updating of the belief base, allowing the *VirtualCarerAgent* to infer new beliefs; thus, goals are established and plans to achieve them scheduled, using the knowledge base rules and backtracking mechanisms to select the best plan for the current state resulting from the belief base.

3.3. Integrating assistive environments with e-health services

The Virtual Carer system is mainly designed for the task of managing an assistive home environment; however, the agent properties explained in section 3.1 have the potential to enhance the (e-)health infrastructure with the possibility:

- For the health professionals, to access data of daily living of their patient, enrich the contents of Electronic Health Records and exchange clinical documents and health reports with other specialists;
- For the patients, to access reports and clinical results regarding their treatments through a pervasive e-health infrastructure.

In this section, thus, we argue for such potential of agent-oriented paradigms and MAS, by proposing the architecture for an agent-based Health Information System (HIS) capable to access geographically distributed data to allow health professionals to retrieve/update any patient's health record efficiently and reliably. The architecture is based on the properties introduced in Section 3.1, especially agent control over their own state and agent communication through asynchronous messages based on FIPA-ACL. In fact, HISs have been recognized crucial for tracking patients' medical histories, surgeries, medical examinations and lab test results, easing the work of physicians and medical staffs [64]. With our agent-based architecture for HISs we aim at ease the interoperability for HISs and healthcare infrastructures, in order to support the improvements in the management of medical institutions and the reduction of healthcare costs [65, 66].

The architecture is tailored on the case of the Italian public health infrastructure which divides the public health management in administrative districts. However, as highlighted in Subsection 3.3.1, the architecture is based on general requirements and principles that are valid for all health infrastructures. Subsection 3.3.2 deeply describes the architecture of the proposed system, focusing on how it is structured in software agents rather than describing how we reach such configuration (we applied the Tropos methodology as with the Virtual Carer system). Subsection 3.3.3 describes the interactions among the agents composing the architecture in a typical application scenario.

3.3.1. Features of an agent-based Health Information System

HISs and, in general, IT systems for e-health should respect basic requirements to address interoperability and protect the investments made by facilities and institutions. Such requirements are well represented by the directives promoted by the Italian Ministry for Innovation and Technologies in 2006 [67] that we took as a reference in developing the architecture:

- *Localization and availability of health records.* Patients' clinical information should be available 24 hours a day and 7 days a week, wherever data are stored.
- *Federated architecture.* Healthcare facilities and services are distributed and federated by nature, and clinical data should be maintained in the facility where they are produced, ensuring that information will be updated when necessary.
- *Security and privacy.* Due to the importance and the strictly personal nature of clinical data, information should be processed by means of secure architectures, addressing privacy laws.
- *Scalability, modularity and reliability.* The infrastructure should be modular, to avoid a quick obsolescence, and scalable, to support the growing number of medical records; a HIS should be designed to achieve a safety critical degree of reliability.
- *Integration with legacy systems.* HIS architecture should integrate with existing systems in order to preserve past investments and to make its adoption practicable for local facilities.
- *Use of open standards.* It is, in fact, a mandatory requirement for those systems, as HISs, addressing interoperability issues.

The proposed architecture exploits the features of agent-based systems to meet the interoperability requirements among different health facilities and, at the same time, integrate with existing legacy systems (including local databases), being a new software layer on top of existing ones; the main advantages of such architecture are:

- *Distribution.* A key concept of agent technology is flexibility: the complex issues of interoperability and integration with existing systems are broken down to minor tasks assigned to individual agents: single agents will be responsible for the translation of local data into a common form. Retrieving data is possible from any point in the territory just through communication of distributed agents, and expensive infrastructures are not required.

- *High modularity.* Thanks to the standardization activities made by FIPA for agent communication and interactions, simply adding new agents in the architecture (registering their services and sharing the same ontology) is enough in order to extend the capabilities of the system.

- *Integration with existing systems.* With the aid of wrapper agents, each one designed for a particular instance of legacy information systems, the architecture represents a higher fully interoperable software layer. Communication at this level can be based on well established standard ontologies for messaging and definition of clinical documents (such as HL7[3]-CDA[4]) and healthcare terminologies (such as SNOMED CT[5]).

3.3.2. System architecture

The agent oriented architecture is expressed by three levels of abstraction: local platform, district platform and client platform. The discriminating factor between the first two layers is of administrative nature: there is a local platform for each healthcare facility in the territory (e.g. a hospital); facilities belong to administrative districts, which constitute the second layer of the architecture; finally, the client level is represented by any software agent which needs to login to the infrastructure to retrieve documents or insert/update a patient's health record. Each level has a precise role inside the architecture: local platforms are responsible for documents and procedures locally in a healthcare facility; district platforms allow authorized clients to access data and documents of different local and district platforms. Figure 3.13 shows the logical structure of the proposed architecture: as we explain in the following, client applications connect to a district platform to retrieve data from the local platforms of their district and, if necessary, of other districts.

Local Platform

There is a local platform for each healthcare facility. It has the role to interface with any information system, currently present in the structure, committed to the management (create, edit, search, access) of clinical documents and the scheduling of different departments in the facility. Every local platform needs to know the address of its referring district platform in order to have access

[3] Health Level Seven — HL7 — is a non-for-profit organization for the definition of standards for the exchange, integration, sharing, and retrieval of electronic health information. — http://www.hl7.org

[4] Clinical Document Architecture.

[5] SNOMED CT is the health terminology provided by the The International Health Terminology Standards Development Organisation (IHTSDO). — http://www.ihtsdo.org/snomed-ct

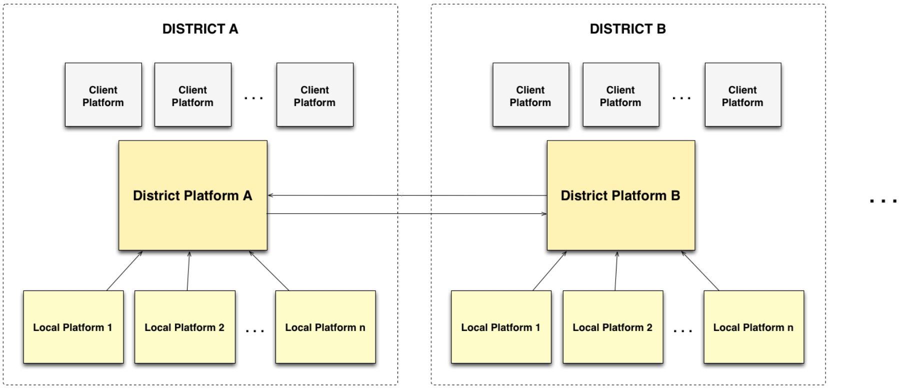


Figure 3.13.: The three levels of the architecture.

to the entire agent infrastructure. The agents inside a local platform are: *LocalDBWrappers*, *DocumentHandlers*, *Service Agents*. Each local platform is a distinct agent platform: as such, there are also an *Agent Management System* (AMS), which manages the operations inside an agent platform (i.e. agent creation, deletion and migration), and a *Directory Facilitator* (DF), which allows the agents inside a local platform to register and find services locally.

LocalDBWrappers provide an interface to the databases of a certain local healthcare institution. The advantages in the use of wrapping agents are the following:

- All the legacy systems would not be modified or replaced, but actually encapsulated within such agents. In this way, any external agent, which needs to access to data contained by a local database, will be able to obtain them simply by communicating with the *LocalDBWrapper* agent, thus avoiding direct interaction with legacy systems.

- The actual data representation can be abstracted from the representation of the different information systems available in the various facilities. With this solution, issues like homonymy, synonymy and data schema inconsistencies do not need to be addressed by burdensome techniques of renaming, restructuring or even system redesign; it is sufficient to design a wrapping agent for each different legacy system able to translate the internal data representation in the ontology shared by all the agents in the infrastructure.

- Data can be kept in the local facilities where the medical records are generated, differently from outsourced cloud solutions that store data in remote servers and have to deal with privacy concerns [68].

The *LocalDBWrappers* must register to the *DF_Intra-district* agent of their district platform, in order to make the local information available for distributed and remote agents (and client applications) which need to retrieve data contained by the local structure.

DocumentHandlers are able to access the content of a specific clinical document produced within the facility, such as clinical reports, laboratory tests, prescriptions, etc. A *DocumentHandler* is contacted by a client agent to get the health records managed by it: the *DocumentHandler* agent locates the requested document through its unique identifier, obtains it from the clinical repository and translates the information in an outgoing message towards the requesting client agent.

Service Agents are designed for the management of different departments in a healthcare facility (e.g. radiology, cardiology, analysis laboratory, etc.). *Service Agents* are responsible for the scheduling of healthcare services and activities and for the access to departmental documents, and make use of established healthcare standards and ontologies. Further details on the agentification of departmental activities can be found in [38] where a use-case with the IHE Radiology Scheduled Workflow[6] is provided.

District Platform

A district platform encapsulates all the local platforms that administratively belong to it. Basically, the district platforms represent the logic layer which composes the final architecture and allows to achieve the interoperability goal of our distributed system: the district platforms, therefore, must know each other their address. Several agents compose a district platform: *DistrictDBWrappers*, *DocumentHandlers*, *Gateway*, *Init*, *DF_Intra-district*, *DF_Inter-district*, *LoginServer*.

DistrictDBWrappers have similar functions with local wrappers: they manage data within district databases and keep track of the reference to document of a patients produced in other districts. The *Gateway* agent contacts wrappers in order to store or retrieve any reference to a patient's clinical records, which have been produced by every local platform in the territory or by general practitioners.

DocumentHandlers manage documents which are of administrative competence of a district, such as Electronic Health Record and Patient Summary. They may refer to health records which are distributed in different local platforms: the *Gateway* agent gathers this information.

[6] The Radiology Scheduled Workflow defines the flow of information for ordering, scheduling, imaging acquisition, storage and viewing activities associated with radiology exams; it is provided by the "Integrating the Healthcare Enterprise" — IHE — the initiative for the standardization of computer systems in healthcare —http://www.ihe.net/.

The *Gateway* agent catches the client requests and makes queries to local and district wrappers to retrieve data about any distributed health record of a citizen. It returns the addresses of *DocumentHandler* agents which the client must contact to get the required documents. To accomplish this task, the *Gateway* performs two basic activities:

- When it retrieves the distributed data required to fulfil a client request, it must integrate them into a data structure, so that the client can handle a single dataset.
- When a clinical record is produced within a district for a patient belonging to another district, the former *Gateway* must inform the latter one to make its referring *DistrictDBWrapper* agent register such event in its own district database.

The *Init* agent performs its task during the starting phase of the district platform. It registers the *Gateway* in its platform to all the active *DF_Inter-district* agents of the remote district platforms in the territory.

Two kinds of *Directory Facilitator* inhabit district platforms. The *DF_Inter-district* is the *Directory Facilitator* in which all the remote *Gateways* are registered. This allows a single *Gateway* to communicate with any other distributed gateway in the entire infrastructure. The *DF_Intra-district* contains all the *LocalDBWrapper* agents registrations of the local platforms belonging to the same district.

The *LoginServer* is the agent responsible of establishing and maintaining a secure connection with the client application that wants to access to the infrastructure to retrieve data in a specified district platform. Figure 3.14 summarizes all the agents in local and district platforms.

Client Platform

It includes client applications (which may be any agent oriented software) that access data through the connection (managed by the *LoginServer*) with a *Gateway* agent of a certain district platform. Examples of client applications could be: software to access the EHR, both by medical staff and citizens, mobile applications to retrieve the Patient Summary for emergency situations, software to update health records by general practitioners, etc. In general, this layer can contain web services able to communicate with the HIS using the FIPA standard and shared ontologies.

3.3.3. Document and data retrieving

After the login phase managed by the *LoginServer*, a *Client Agent* can ask for a citizen's health records by typing her tax code. Figure 3.15 shows the typical in-

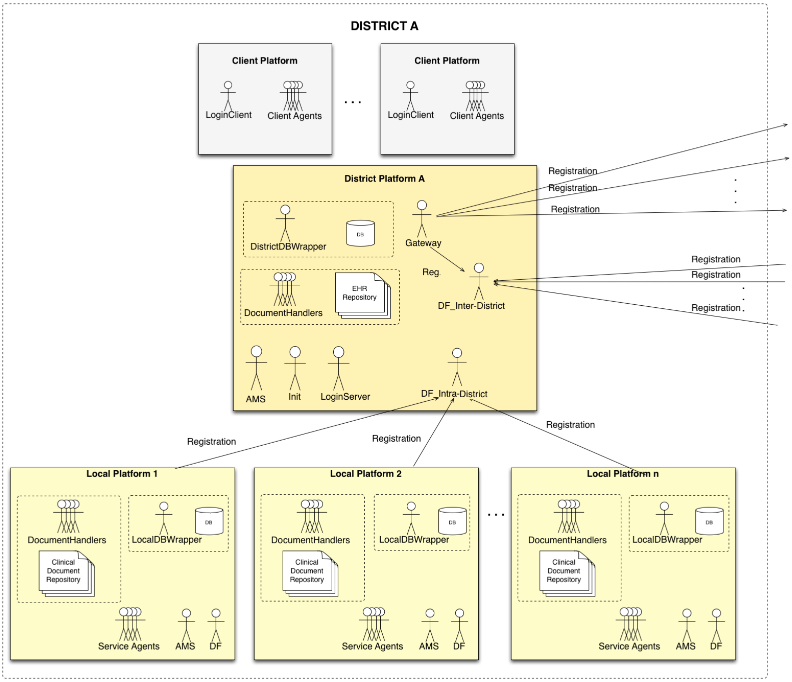


Figure 3.14.: The agents composing the architecture.

teractions in such scenario. The *Gateway* agent queries the *DistrictDBWrapper* to know which districts store the requested data (the citizen might have received treatments in other districts). In this example, all requested data are in district *A* and, thus, the *Gateway* queries the *DF_Intra-district* of district *A* to retrieve *LocalDBWrappers* with relevant data. *LocalDBWrappers* send to the *Gateway* the references to *DocumentHandlers* managing requested health records. The *Gateway* informs the *Client Agent* about the location of health records. After this phase, it is directly the client application that gathers this data from the *DocumentHandler* agents of the platforms which hold the patient's records. In addition to the daily use of clinical documents, the architecture may have an impact on emergency scenarios: first-aid doctors can exploit authorized mobile applications to know patient history before the first-aid intervention (as in the scenario described in [37]).

The Virtual Carer system presented in Section 3.2 is, by design, fully interoperable with the presented agent-oriented HIS. In fact, it could act as a client application to interact with the healthcare infrastructure: the *VirtualCarerAgent* would act as a *Client Agent* to ask for exam results and health records to the *Gateway* of the district to which the assisted person administratively belongs. Moreover, the Virtual Carer system could be seen as a local plat-

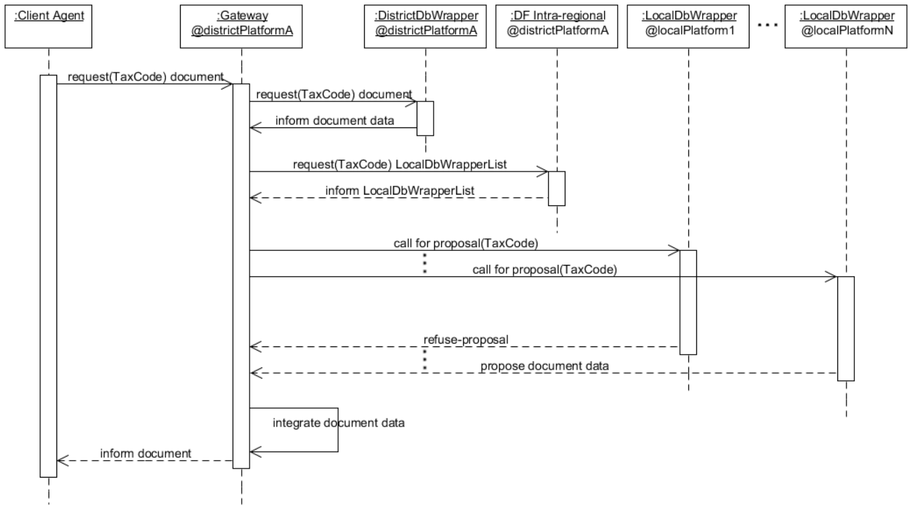


Figure 3.15.: The client agent queries the infrastructure for a citizen's health records.

form by the district of the assisted person, with the *RegisterAgent* acting as a *LocalDbWrapper* and the *VirtualCarerAgent* as a *DocumentHandler*, providing data about the assisted person directly from the assistive environment.

3.4. Chapter conclusions

In this chapter we proposed the adoption of agent-oriented paradigms in Ambient Assisted Living (AAL), Ambient Intelligence (AmI) and healthcare. Our aim was to show how two well-established AI paradigms — Agent-Oriented Software Engineering (AOSE) and Agent-Oriented Programming (AOP) — are ideal to develop smart solutions in AAL and healthcare, especially to face environments with a broad heterogeneity of devices and services. Autonomy, social ability, reactivity and pro-activeness are agent properties that can be exploited to face dynamic environments, provide a common communication language to software entities, and ensure the interoperability of all the components.

At first, we presented a Multi-Agent System (MAS) approach to AAL to face a dynamic environment, monitoring the health conditions of an elderly or disable person in an assistive context. We developed a BDI-based expert system which consists of several agents to manage a smart home. We implemented a prototype of the system, i.e. the Virtual Carer, in order to highlight the benefits of the proposed architecture. The reasoning core of the system is a BDI agent: the *VirtualCarerAgent*. It collaborates with other agents controlling various sensors and devices (*ActuatorAgents*) to facilitate the daily activities of the assisted person and to trigger alarms when an anomaly is detected by the *SensorAgents* among the parameters regarding the patient's health conditions or the status of the environment. We used software simulations in a fictional scenario to show the feasibility of the approach. The assisted person was represented by another BDI agent, the EldelryAgent, with several plans modelling different actions (such as movements in the home environment, direct requests of health parameters). We implemented *ActuatorAgents*, *SensorAgents* and the *Directory Facilitator* (DF) with the JADE agent framework, while we used the Jason framework for BDI agents (the *VirtualCarerAgent*, the *RegisterAgent* and the *ElderlyAgent*). The adoption of agent-oriented frameworks, as those we used, natively provides services addressed to fault-tolerance: in JADE, the Main Container Replication Service and the DF persistence make the agent-based architecture resilient to single point of failures for the agent management and for the traceability of agents' services.

Then, we described how MASs can support Health Information Systems (HISs) to face the challenges in providing a more coordinated healthcare, with interoperable software systems and documents, reducing, at the same time, the healthcare costs. In order to meet requirements related to access to data, security and the use of open standards, we proposed a MAS approach to model an interoperable HIS. Interoperability with legacy systems can be obtained simply using wrapper agents, sharing an ontology with the other agents of the system. MASs are distributed by nature and, while cloud computing solutions propose to centralize information and services in the cloud (with privacy problems and the potential of a dangerous vendor lock-in), the proposed architecture ensures that clinical information is stored in the same place where it is produced. Thus, Multi-Agent HISs maintain the distributed and federated nature of healthcare services.

Both the Virtual Carer system and the agent-based HIS highlight that system flexibility can be enhanced by the adoption of FIPA standards for agent communication and interaction: new devices, services and components can be added simply integrating agents in the proposed architectures, making the systems ready for the inclusion of new technologies. As future work more insightful tests have to be conducted: a real AAL scenario, i.e. a daily-used home environment equipped with devices and sensors, where an assisted person can live, is beyond our possibilities, but is the only way to fully validate the proposed approach. The same holds for the testing of the Multi-Agent HIS. In Chapter 4 we will describe how virtual environments, as those provided by game engines, can be used to partially satisfy the need of deep tests for AAL and healthcare systems.

The future direction for the research described in this chapter is a full integration between HISs and the Virtual Carer, i.e. between the professional care of the patients by the medical staff and the need to live at home as long as possible. The result of such integration will be a Virtual Nurse, i.e. a virtual hospital ward at the patient's home environment. Such a system should be tailored on the diseases of the assisted person and, in addition to perform health and ambient monitoring, should provide the medical staff with a synthesis of the same information available in a real hospital ward: the result could be an earlier dehospitalization for the patient, following the need of having hospital wards available for emergencies and trying to provide an economically sustainable healthcare.

Chapter 4.

Virtual environments for the Ambient Assisted Living

In this chapter, we propose the use of virtual environments for two issues related to the adoption of Information & Communications Technology (ICT) systems for Ambient Assisted Living (AAL) and Ambient Intelligence (AmI): the need of testing AAL systems and the low degree of acceptance towards the enabling technologies of AAL and AmI.

Indeed, IT systems for the AAL, and smart homes in particular, are "complex ecosystems involving the occupants, physical and operational components of the home, external and internal context, and dependencies between these" [69]. Being dwelling equipped with technology to monitor its inhabitants and to ensure their independence and good health [13], smart homes should ease daily life, by increasing user comfort, and constitutes healthcare facilities to generate health reports and to guarantee emergency support [14]. Thus, the evaluation of systems that aim at the interaction with the assisted person to help her and ensure her security should include several perspectives, as described in [70]: at least the points of view of end users (elderly people and their relatives), physicians, medical caregivers and developers (software and systems engineers) are essential to assess the quality and the effectiveness of such systems. Moreover, the ideal tests for AAL systems which interact with the end-users should include participatory evaluations [71]. In order to completely satisfy such conditions, the development and the following testing of smart homes for the AAL in a real environment[1] require enormous resources in terms of work, time and money. Assessing technologies for the AAL during their development, in real world scenarios, with real participants, is a huge challenge because the trials should be conducted extensively:

- With real human inhabitants with different kinds of impairments;
- In different environmental situations;

[1] With "real environment" we mean a daily-used home environment equipped with devices and sensors, where an assisted person can actually live.

- Taking into account diverse economical conditions.

Such trials will be also extremely expensive, especially for the development of software prototypes that would require the hardware for a great number of tests; furthermore the result of this effort could be the need to modify or redesign some components (and thus to repeat tests). Additional challenges have to be faced to gather data in the real world to test and validate algorithms, technologies and whole frameworks. Collecting data can be done in two ways [72]:

- By building an ad-hoc home environment and convice volunteers to live there for a certain amount of time;
- By re-furnishing the homes of the monitored patients.

To collect data, the designer should follow the patients in their daily life at home, living with them or recording their activities: in both the cases the normal flow of actions is influenced. Hence, generating test data and establishing a ground truth are slow and cumbersome tasks [73].

Thus, in Section 4.2 of this chapter, we propose the use of a 3D virtual environment that simulates a real smart home, with avatars for humans and robots, with interfaces to sensors and actuators: such simulator can be an effective tool to develop, simulate and test intelligent systems for the AAL, such as the Virtual Carer. Using virtual environments to accurately reproduce AAL contexts would allow a partial decoupling of the software development from the hardware development, enabling to:

- Speed up the development of software systems; real tests can result in the need to modify or even redesign a component. With the simulator this process is faster and real tests can be carried out in more advanced phases;
- Easily migrate software systems from the simulator to the real world. This can be an advantage for both the development of a system and its maintenance (as the migration can be also in the opposite direction);
- Execute tests in an economically sustainable way.

In addition to their use in simulators for AAL, in this chapter we argue for the use of virtual environments to support the acceptance of AAL technologies. In fact, despite its promises of increasing older adults' autonomy, self-confidence and mobility [3], the acceptance of AAL and its technology is still unsatisfactory, and studies have shown a rather low intention of prospective users to adopt AAL techniques [10, 11]. The reasons for low acceptance are many [74], and include technological concerns about the trustworthiness of AAL solutions [75] (in terms of functionality, reliability, usability) as well as ethical considerations such as the potential loss of privacy [10, 76], dignity [77] and autonomy [78]. Our diagnosis is that low acceptance is often caused by the lack of awareness of the purpose of AAL and its enabling technologies. Although this is not the only cause, we hypothesize that raising awareness could positively contribute to acceptance by avoiding misconceptions and by mitigating unjustified fears.

Hence, we propose the use of *awareness games* as a tool to deliver knowledge on the objectives and working principles of AAL. Awareness games are serious games [79] that aim at increasing awareness in a certain target audience about a given domain, in addition to providing engagement as regular (computer) games. Awareness games have been proposed for several domains, including environmental issues [80], security engineering [81], and flooding policies [82]. In Section 4.3, we present our developed awareness game: *Smart Tales*. In the fictional context of the game, the player impersonates an assisted patient living in a smart home, and gets to learn about AAL and its technologies while trying to cheat the sensors that are placed in the house. While doing so, the player collects informative cards concerning AAL, which are necessary to answer the knowledge quizzes at the end of each level so as to unlock further levels. We developed Smart Tales to give the opportunity to learn about the devices of a smart home to those people potentially interested to equip their home with smart technology.

The rest of the chapter is structured as follows:

- Section 4.1 presents the “state of art” use of virtual environments for AAL, ranging from the need to gather test data for AI algorithms, to the use of serious games for rehabilitation therapies.
- Section 4.2 highlights our AAL simulator, based on a robotics simulator, as a platform to test intelligent software for AAL; the section includes the description of a mobile application to manage a smart home that is a use-case for the simulator, in conjunction with the Virtual Carer system.
- Section 4.3 describes Smart Tales, our game to raise awareness towards AAL; the section presents the systematic description of the design of Smart Tales, as well as a formative evaluation about the learning process and the engagement of the game.
- Section 4.4 highlights the results of the two main contributions of this chapter: the adoption of virtual environments in the testing of systems for AAL, and the importance of serious games to increase the acceptance of AAL technologies.

The content of this chapter is based on the research we published in [83, 84, 85, 86].

4.1. Current uses of virtual environments in AAL

The studies in AAL scientific literature point out the need of ways to test and validate AAL technologies before their adoption in a daily-used environment, as well as the difficulties of carrying out such tests in a real scenario. Bowling et al. [87] list the most important features required for analysis and simulation tools for AAL: the analysis tools, which are based on performance measures and do not require a simulation, need to model the coverage of available sensor and the kinematic and dynamic performances of available robots; the simulation tools need collision and physics engines as well as the emulation of the software systems to manage the sensor networks and/or the robots (with a coherent simulation time). Focusing on simulation, Godsey and Skubic [73] propose the simulation of a sensor network by using game engine elements, with the aim to reproduce data about the movements of a patient in a home environment. By exploiting the collision mechanism of the physics engine, the authors simulate passive infrared (PIR) sensors and test the correspondence of such a simulation with a real case. A more advanced framework to collect data about patient's behaviours is presented in [72]: the authors define three distinct models for the human, the environment and the motion sensor network; by defining complex actions for the human (as well as a mechanisms to schedule such actions), several days can be simulated; the simulation generates textual logs about different variables (e.g. bed pressure, unwashed dishes in the sink, etc.) to train and test activity recognition algorithms. Obtaining long-term data about human behaviours is the objective of SIMDOMO, a simulator of sensorized domestic environments proposed in [88].

The AAL simulator proposed in Section 4.2 differs from those just listed: rather than generating data to test AI algorithms, it should exploit a physics engine to represent the behaviours of a dwelling, for an AAL intelligent system. We aim at providing a virtual environment where software for AAL can communicate with virtualized sensors and actuators as it would do with real devices, to support a transparent migration. Thus, the proposed simulator supports also development phases. In fact, the scientific literature includes example of virtual environments used in the design of AAL platforms: Van't Klooster et al. [89] propose the use of Interactive Scenario Visualization to clarify system functionalities and gain stakeholders' feedbacks, by means of 3D models. The computer-aided tool presented in [90] allows usability engineers to define the workflow of a simulation and to visualize the simulation in a 3D environment, in order to validate AAL systems.

However, the majority of the current applications of virtual worlds in the AAL is addressed to motor and cognitive rehabilitation [91] and to improve social inclusion [92]. In particular serious gaming has been widely adopted in rehabilitation. Indeed, typical game features (as providing challenges and goals, stimulating curiosity, cooperation, competition [93]) enhance user engagement and intrinsic motivation, motivating users in following therapies. In general, serious games support users in developing their skills, in learning and in experiencing situations that are impossible (e.g. for economical reasons) in the real world [79, 94]. For these reasons, virtual reality and serious games are also used in therapies for pain management [95].

The innovation of our game presented in Section 4.3, Smart Tales, is the use of computer serious games to increase end-users' awareness towards ICT solutions for AAL. Smart Tales makes a step forward in the promising research direction of serious gaming to foster acceptance of smart homes, trying to break the learning barriers in the field [96].

4.2. 3D virtual environments as a testbed for AAL applications

The use of 3D virtual environments to develop intelligent software systems to manage virtual homes is inspired by the robotics field, where a relevant number of 3D software simulators is available (see, as examples, Gazebo [97], or Morse [98]). Following what already exists in robotics, we propose to use a 3D simulator that exposes the interfaces to sensors and actuators (through suitable libraries) available in the market and that allows to create a virtual home environment: in such simulator, intelligent software systems for AAL could be tested to evaluate their behaviours, even when facing unexpected events. Ideally, the intelligent systems tested in the simulator should be migrated transparently in a real environment with the sensors and actuators previously simulated.

To this point, one might argue that there is no need to use the 3D for AAL simulations. Nevertheless, the 3D feature gives not only the involvement typical of graphical effects, but should provide to system developers the possibility to interact directly with the simulations, for example moving objects on the fly. With a reliable physics engine (as those typical of computer games), developers can simulate unexpected events and thus understand if the system behaves correctly.

To show the potential of the adoption of a 3D simulator for the AAL, we implemented a proof-of-concept. Actually, in addition to take the inspiration from robotics simulators, we adapted an existing robotics simulator, exploiting its public APIs for our experiments. We used Morse[2] (presented in [98]), the Modular Robots Open Simulation Engine. It is an open-source robotics simulator

[2] http://www.openrobots.org/wiki/morse/

based on the Blender game engine. The architecture is based on components able to simulate sensors, actuators and robots; its structure is modular since components (as sensors and actuators) can be added with a scripting mechanism. To model the home environment for the simulations, we used Sweet Home 3D[3], an open-source interior design application to draw the plan of a house and to arrange the furniture in a 3D model. It allows to easily create and export in Blender[4] models of domestic environments, in which the different sensors and actuators can be placed.

Hence, after developing a fictional 3D home map (Figure 4.1), we implemented virtual sensors and actuators as in the scenarios already described in Chapter 3. Thanks to the public APIs of Morse, we simulated a set of ambient sensors: temperature sensors, motion sensor and RFID sensor. The possibility to adjust the ambient temperature is essential in order to ensure the maximum comfort within the house. The simulated temperature sensor emulates a thermometer, measuring the temperature with respect to the distance from heat sources. It defines a default temperature throughout the scenario, which is affected by local heat sources. The temperature rises exponentially when the distance between the sensor and the heat source decreases. Its equation is given by:

$$temperature = DefaulTemperature + \sum_{s} HeatTemperature(s) \cdot e^{(-\alpha \cdot distance(s))}$$

In the experiments that we will describe in Subsections 4.2.1 and 4.2.2, we modeled the assisted person sitting on a wheelchair; thus, we placed one temperature sensor exactly on the wheelchair: this choice reflects the possibility, for the assisted person, to control the perceived temperature at any given point.

Beyond complex applications for activity detection and recognition, motion sensors are essential even in simple tasks, such as turning on lights only when it is actually needed; similar checks can be applied also to the climate system. Since in Morse there are no motion sensors as those described, we simulated it using a *SICK* sensor, made available by the software, in order to reproduce a Passive Infrared sensor. The SICK sensor is a laser scanner which works by generating a series of rays in predefined directions, and by using the collision system of the physics engine to detect whether any active object is found within a certain distance from the origin of the sensor. We used the simulated motion sensors to localize the assisted person inside the home. We placed them in strategic points of the house to get the maximum possible coverage.

We simulated *RFID* sensors by using the proximity sensors offered by Morse, positioning them near the doors. These sensors can be used to determine which

[3] http://www.sweethome3d.com
[4] http://www.blender.org/

Figure 4.1.: The fictional home map developed for the simulations in Morse.

objects are within a fixed radius from the sensor itself. The type of tracked objects can be specified using the *Track* property. A simulated RFID tag has been applied to the avatar representing the assisted person: for example, whenever the avatar approaches one of the two doors, the tag transmits the information to the receiver; data are then sent to the home automation system allowing the identification of the subject and to open the door automatically. In fact, we simulated also actuators, representing motor-powered doors and windows, as well as gas and water electrovalves.

Thanks to the scripting mechanism available, we simulated other sensors not included in Morse, for the management of dangerous situations: gas detector sensors, flowmeter sensors, a heart rate sensor and an apnea detector sensor. The first detects leaks of gas in the apartment; the flowmeter detects possible flooding; the heart rate sensor measures patient's heart rate in real time; the apnea detector verifies assisted person's apneas arisen during sleeping time.

Figure 4.2 summarizes the concept of our simulator: software systems for AAL can interact with the simulated home in Morse through network sockets. Each sensor (and each actuator) in the simulated environment is associated to a thread where software can retrieve values (and send commands). Thus, with a communication based on the TCP/IP protocol, the tested software can be easily migrated in real environments, if virtual sensors provide the same

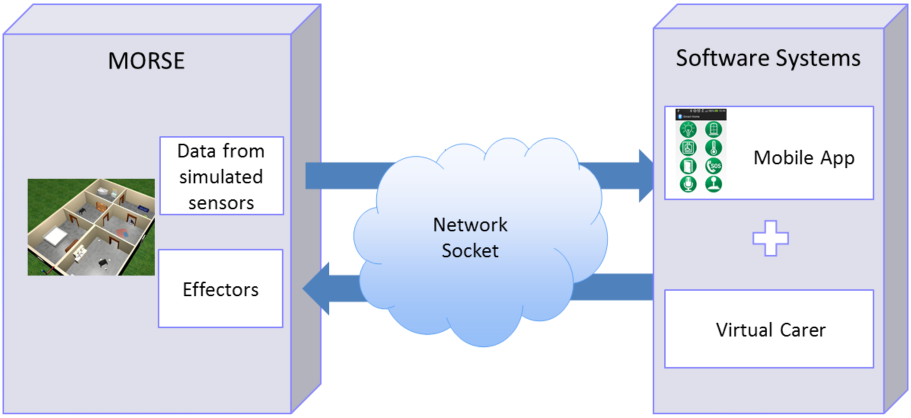


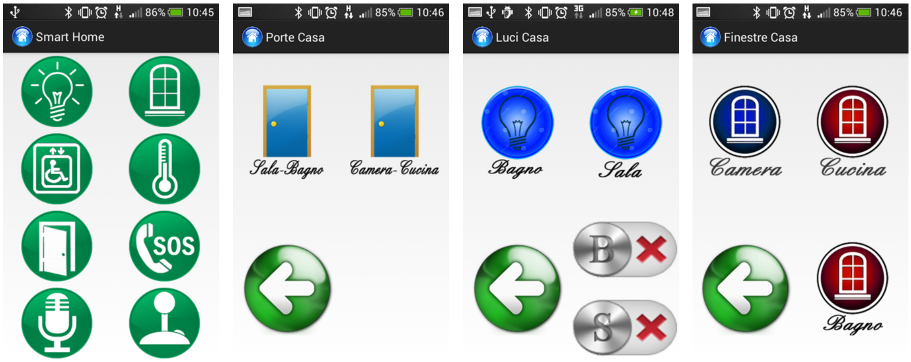
Figure 4.2.: Real applications interact with the virtual environment through network sockets.

interface as off-the-shelf sensors capable of communicating over a network. As highlighted in the figure, we used our proof-of-concept Morse-based simulator with two use cases: a real mobile application and the Virtual Carer described in the previous chapter. Subsection 4.2.1 includes a description of the mobile application and its interaction with the virtual environment, while Subsection 4.2.2 describes the emergency scenarios implemented for the interaction with the Virtual Carer. Finally, Subsection 4.2.3 explains the challenges faced to simulate basic human behaviours inside the simulator.

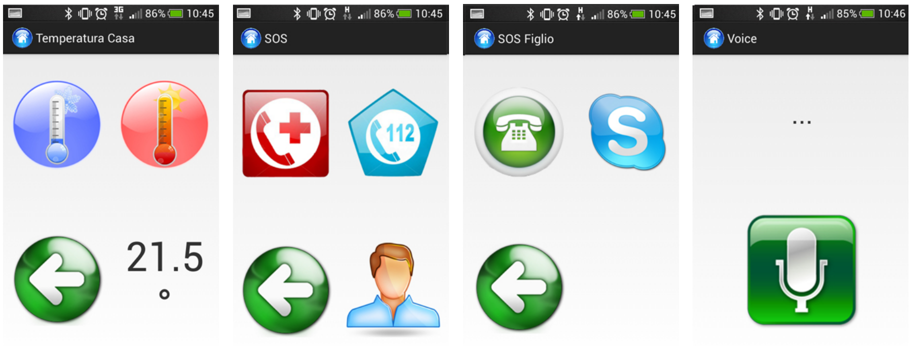
4.2.1. A simulator use case: a mobile application for the AAL

The first use case for our simulator is a mobile application that we developed for the management of a smart home. As highlighted in Chapter 2, mobile devices and smartphone are considered promising tools to improve the quality of life of elderly people. Thus, many applications are sprouting in healthcare and AAL: examples are remote monitoring by general practitioners [99], remote monitoring of patients affected by chronic diseases [100], and assessment of the quality of life through activity recognition [101]. The testing of a mobile application is then a significant example of a software system for AAL.

Figure 4.3 shows the main components of the mobile application. The smartphone becomes a real remote control that interacts with the home environment of the assisted person: through the smartphone interface, the assisted person can manually control lights, doors, windows, temperature and more. Figure 4.3a is the application main page: it provides the access to all the pages for the interaction with the devices in the smart home. The stylized light bulb controls the lights of the environment (Figure 4.3c). Figure 4.4 shows an ex-



(a) Home page (b) Door control (c) Light control (d) Window control



(e) Thermostat (f) Emergency calls (g) Safe number call (h) Voice commands

Figure 4.3.: Different pages of the mobile application.

ample of interaction: one can turn the light on in a room by touching the icon that corresponds to that room. The interface provides an immediate feedback of the status of the lights in the home: a yellow background of the icon of a light indicates that it is turned on. Automatic doors and windows can be controlled through the respective stylized icons (Figures 4.3b–4.3d). Even in this case, there is an immediate feedback of the status of the home: for example, in Figure 4.3d, if the background of an icon is blue the correspondent window is open. Through the thermometer icon, the assisted person can set the desired temperature inside the home: intuitively, the blue and red icons decrease and increase the preferred value (Figure 4.3e). In the SOS page (Figure 4.3f), the patient can quickly send emergency or familiar calls; in the second case (Figure 4.3g) either a normal call or a skype call can be selected. One of the most important features is represented by the icon with the stylized microphone (Figure 4.3h): it allows to use the smartphone speech recognition system to send voice commands to the home. In facts, we mapped all the commands available in the interface, adding also the possibility to open/close all the windows or

Figure 4.4.: Example of an interaction between the mobile application and the simulator.

turn on/off the light with a single command.

Thus, the virtual domestic environment can be manually controlled by a user through the mobile application: the communication between the simulation in Morse and the mobile application on a real smartphone uses IP sockets. This allows to simulate a real world scenario where the domestic Wi-Fi network can be used to take advantage, anywhere in the environment, of all the services offered by the application and the smart home. The smartphone adds real sensors to the simulation: ambient light sensor, accelerometer, gyroscope, GPS and microphone are available to interact with the simulator. The ambient light sensor is able to detect changes in light: hence, we used it to automatically activate the lights in the room, inside the virtual environment, where the avatar of the assisted person is located; in case of emergencies such as a blackout, it can activate the flashlight of the camera. The accelerometer, gyroscope and GPS can be used for indoor and outdoor localization of the patient's wheelchair and fall detection. Finally, through the use of the microphone we tested voice commands on the virtual environment. In fact, all the described functionalities have been tested in the simulator, and a video is publicly available[5].

4.2.2. A simulator use case: the Virtual Carer

The second use case is based on the testing of the system presented in Chapter 3, the Virtual Carer. The agents composing the Virtual Carer interact with the

[5]The link to the video is the following: https://www.youtube.com/watch?v=zXEpShRNGuo

simulated environment using the IP sockets exposed: each agent uses a socket channel to retrieve values from sensors and send commands to actuators. In addition to the transparent migration of entire systems, this is an advantage also when the Virtual Carer (or another agent-based system) is running in a real smart home: new agents can be implemented in virtual environments and added to the real one; moreover existing ones can be migrated in the virtual environment for maintenance.

As for the mobile application, there is a public video that shows the tests with the Virtual Carer[6]. The video includes some simple actions based on the simulated motion and RFID sensors: the lifting of the platform at the entrance of the home; the opening of doors and windows for air circulation; the temperature control. The simulations include also critical conditions, as danger of flooding and gas leaks. As shown in the video, the danger of flooding may occur when the assisted person tries to fill the bathtub, changes room for some reason and forgets the tap open. The simulated flowmeter located in the tube of the tap continuously measures the water flow rate (expressed in litres per minute) that flows from it. This value is taken as input by the Virtual Carer which has, in its knowledge base, the maximum capacity of the bathtub (in our case 160 litres) and binds it to the event “closed cap” 4.5. When the flow of water out of the tap is about to exceed the maximum capacity of the bathtub, the Virtual Carer decides to shut the water tap just before the outflow of water from the bathtub, thus avoiding the danger of flooding. The scenario with a gas leakage is similar: let’s suppose that the assisted person approaches to the stove to cook and forgets the gas valve open. The percentage of gas in the air will increase up to a limit value (10%) detected by the sensor; at this point the Virtual Carer notifies the assisted person using an audio message, closes the valve of the gas tap and opens the windows for the gas leakage. Finally, once the situation is normal, a further notice will be issued to reassure the assisted person.

4.2.3. Representing human behaviours

In a complete 3D simulator for the AAL, also human behaviours should be represented: the involved research topics are similar to those concerning the inclusion of human reasoning mechanism in computer (and serious) games [102]:

- The selection of the AI approach to model and imitate human behaviours especially taking into account the need of human like responsiveness and communication;

[6] The link to the video is the following: https://www.youtube.com/watch?v=IBuYZFoKmy8

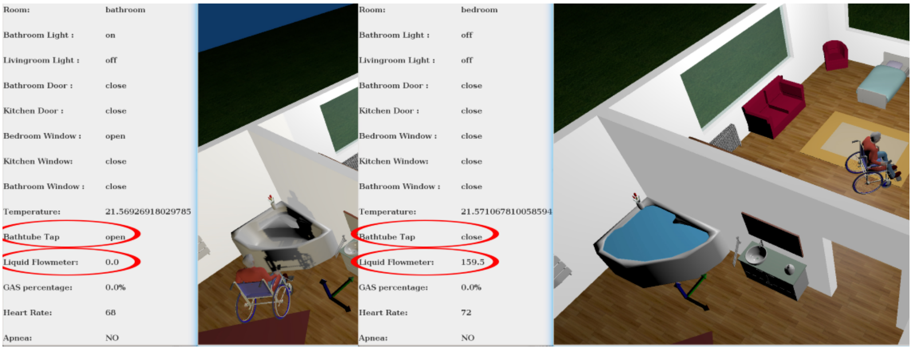


Figure 4.5.: Simulation of a flooding emergency situation.

- The influence of the adoption of strong AI techniques to imitate human reasoning on the simulator design, since a well identified problem in computer game design is the introduction of the AI in the last phases.
- The definition of behaviour goals to test intelligent software systems for the AAL.

A promising direction is the design and implementation of virtual characters as BDI agents (see, for instance, [103] for the development of BDI based Non-Player Characters in computer games). Although this approach is ideal to implement virtual characters capable of carrying out long-term autonomous actions, it leads in several sub-problems: balancing between proactive and reactive behaviours, scheduling properly goals on the basis of the application domain, representing the environment in a symbolic manner and translating this representation during the interaction with the simulator engine.

Hence, we extended Morse also to include a human avatar that represents the behaviours of the assisted person: at the current stage the implementation is separated from the previous scenarios. We based our model on the same mechanism that authors in [72] used to generate data about human daily activities: the modeled human behaviours are based on the temporal evolution of simulated trends of human parameters (representing the human status), which will generate specific needs (i.e. thirst, hunger, boredom, sleepiness). As desires in a BDI model, these needs trigger intents, implemented as high level activities composed by several lower level atomic actions, that are executed in a sequence, as in a plan. As described in Kormányos and Pataki's paper, each scheduled activity is influenced by both the human state and one or more scheduled activities.

Since our simulations run in a 3D environment, we added to the previous model the visual perception of the avatar: the motion of the virtual avatar does not use pre-determined coordinates or a simulated GPS; the spacial awareness is based on a motion and exploration algorithm depending on visual references caught by a sensor (the *semantic camera* sensor provided by Morse). Each intent is composed by a movement action to reach a certain object in the virtual world to achieve the scheduled intent and a following interaction phase with that object. For this purpose, there are two kinds of movement actions implemented into the simulator:

- *Exploration*, used if the desired object's location is not known;
- *Motion*, used if the character already knows where the desired object is located;

At the beginning of the simulation, the avatar will not have any initial knowledge about the surrounding environment: so the avatar will have to explore it if needed. The motion algorithm is based on the notion of *Place*, intended as a set of visible objects perceived using the semantic camera sensor. All the gained information is saved on a SQLite database and used to build an explorable graph where it is possible to use traditional pathfinding algorithms to elaborate movements. We implemented the avatar's intents, actions and movements using Java: thus a Java program controls the simulation, interacting with the virtual representation of the person and the environment in Morse through IP sockets.

4.3. Virtual environments in an awareness game for AAL: Smart Tales

Smart Tales is a serious game that aims to raise awareness about the potential of ICT solutions for AAL. Being a serious game, the main goal of Smart Tales goes beyond pure entertainment [104]: the purpose of the game is to give the opportunity to end-users to learn about sensors that can be placed in a smart home, showing their capabilities as well as their weaknesses. The player is the inhabitant of a smart home that is equipped with a number of sensors to detect the presence of the player's avatar, and to determine the room where the player is located.

The version of the game presented and evaluated in this section is focused on motion detection and indoor positioning, and is composed by three levels of increasing difficulty. Three kinds of sensors are present in the virtual world: passive infrared (PIR) sensors for motion detection; active infrared sensors for passage detection; smart tiles for both motion and presence detection [40]. The implementation relies on the Unity 3D 4.6 game engine[7]; we developed the 3D

[7] www.unity3d.com/

model of the smart home with SweetHome3D and Blender, as in the simulator described in the previous section.

Since Smart Tales is intended as a driver to achieve wider awareness and acceptance of ICT solutions for AAL by end-users, engagement and effectiveness of learning are the key determinants to assess the success of the game. Thus, during the design and development of Smart Tales we needed to take into account multiple, partially conflicting requirements:

- Both technical and non-technical people need to be able to play the game. Hence, the controls should be easy to remember, minimal and intuitive.
- Information about AAL shall be delivered within the game mechanics in order to make the learning process lighter, using typical game features to enhance user engagement and intrinsic motivation [93].
- The player shall be motivated to keep playing through all the levels, avoiding to overwhelm him with excessive information. Moreover, in line with the theory of flow [105], the game difficulty has to gradually increase, increasing the challenge but not the frustration, in order to reward the player for his progress and his learning.

To engage the player and satisfy the listed requirements, Smart Tales includes elements from different game genres: third/first person shooters, puzzle games and arcade games. The virtual environment of the game is in 3D (inside a dwelling) and the player controls an avatar through the arrow keys. The goals are to avoid being detected by the sensors in order to score points, and to progress to the next levels while gathering information about AAL and sensors. The player's goal is to provide evidence that some of the sensors are misplaced. In other words, the player is supposed to *cheat* the home, scoring points as much as he can. The game consists of levels: upon completing a level, the following level is unlocked.

In Subsection 4.3.1 we present a systematic description of the design of Smart Tales; then, in Subsection 4.3.2, we show the results of a formative evaluation of the game, based on a playtesting session on the three game levels with real participants.

4.3.1. Game design

To describe the design of Smart Tales in a systematic manner we use the Serious Game Design Assessment (SGDA) framework, proposed by Mitgutsch and Alvarado [106]. This framework enables studying a serious game design in relation to the game purposes and intention: it allows to analyze a serious game investigating the cohesiveness of its *content and information*, *mechanics*,

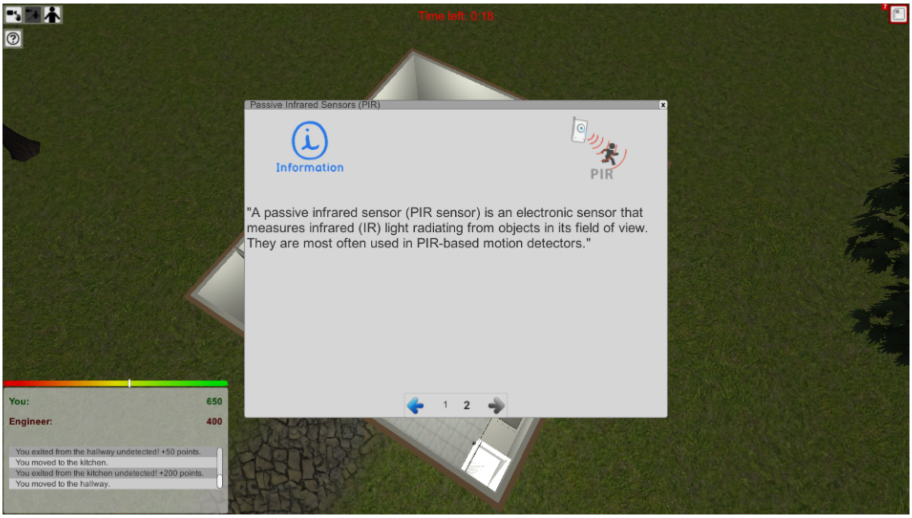


Figure 4.6.: Delivering awareness through informative badges: the definition of the sensor "PIR".

fiction and narrative, *aesthetics and graphics* and *framing*, and their coherence in relation to the game purpose: to raise awareness about AAL and its enabling technologies.

Content & Information

In the SDGA framework, this aspect refers to the information and data provided during the game. We can distinguish between:

- The serious content that provides information about AAL and the sensors present in the virtual home;
- The information related to the game status.

The serious content relates to the core purpose of Smart Tales: in the game, the player has to collect informative cards (badges) about Ambient Assisted Living and the sensors present in the game levels. The player can read the collected badges in any moment of the game except while he is answering the quizzes at the end of each level, since the provided information is needed to correctly answer to the questions.

Figure 4.6 shows the information in one of the badges, that defines the notion of a "PIR sensor". The provided information is both textual and visual. The textual information describes the content of the badge, while the visual information facilitates the recognition of the badge. The top-left "information logo" on the badge clarifies that the included information is useful to answer

Figure 4.7.: In-game notifications to the player: by exiting the kitchen undetected for the first time in that level, the player scores 100 points plus 100 points of bonus.

to the questions at the end of the level; the top-right logo identifies the main topic of the badge: there are different logos for badges on general information about AAL, PIR sensors, active infrared sensors and smart tiles.

In order to keep the player engaged in the game, to not overwhelm him with too extensive information and to make the learning process more effective, the information is split in nine cards. Furthermore, to ease the reading process, the content of the badges with longer content is presented in multiple pages.

During the game, the player can visualize data about the game status, including the time left to play the level, the earned points (and the points of his opponent, the engineer who configured the smart home, covered by the CPU) and the number of unread badges in the player's inventory. As depicted in Figure 4.7, the player gets notified whenever he scores points. Such elements allow to keep the player focused on his goals in the game, pushing him to beat the home engineer, collect and read more badges, in order to foster engagement as a key factor in the learning process.

Game Mechanics

Mechanics are the various actions, behaviors and control mechanisms afforded to the player within a game context [107]. In the SGDA framework, the game mechanics involve the in-game goal of the game, the reward system, and the main playful obstacles/challenges. In Smart Tales the player has to achieve three goals to advance to the next level:

- Score more points than the home engineer;
- Collect all the badges within the level;
- Answer correctly to all the questions presented at the end of a level.

The first goal gives a challenge to the player: he needs to beat the engineer who configured the home. The difficulty increases with the levels, and the player has to carefully plan an effective path for his avatar to follow. To do so, the player can choose in which room he wants to place his avatar; some choices are better than others, and the right positioning can be crucial to pass the level. Thus, challenge and planning are instrumental to keep the player focused and engaged. The second goal pushes the player to collect all the badges with information about AAL. Finally, to unlock the next level, and thus to continue the challenge, the player needs to answer to three questions at the end of each level. The content in the badges is essential to answer correctly. In case wrong answers are given, the player does not unlock the next level.

To score points, the player needs to exit from the rooms of the smart home without being detected. When a sensor detects the presence of a player inside a room, the home engineer scores points. Consecutive actions give extra-bonus points, using a multiplier, as in arcade games, either to the player for having cheated the house, or to the CPU engineer for having kept track of the player. The basic action that the player can perform is to move his avatar in the 3D smart home, using the arrow keys, in order to avoid the placed sensors. The player is able to see the sensors' coverage before placing the avatar in the home; while playing, he can see the devices on the walls and doors, but not their sensing area. Moreover, the player gets bonus points by reading the informative badges: this mechanism gives an extra in-game incentive to read the AAL-related content. Another game mechanic is the time limit to play a level, since the player has one minute to complete the level and to achieve the first two objectives: to score more than the engineer and to collect all the badges. On the one hand, the time limit makes the level more challenging; on the other hand, keeping it low allows the player to not waste time waiting the quiz at the end of the level, in case he achieves the first two goals.

Fiction & Narrative

The fictional context of Smart Tales has the following logline: *an engineer equipped an assistive "unobtrusive" environment (a smart home), but the skeptical inhabitant does not consider the home that unobtrusive.* The player lives in the home and has to prove that the engineer has misplaced the sensors. The game takes place in a dwelling: the player has to place his avatar in a room and then he has to start moving, collecting badges and avoiding sensors.

The fictional context reflects the target environment of AAL: the home of an assisted person. The narrative introduces the player to the game challenges that will engage him in his learning process: the inhabitant does not consider the home unobtrusive, and his aim is to mislead sensors to proof they are misplaced.

Aesthetics & Graphics

To support the game purpose, Smart Tales uses basic 3D graphics to represent the smart home and the players avatar. A 3D environment gives additional opportunities to the player to avoid the sensors: in addition to moving inside the home, the avatar can walk crouched, jump and do small steps. To support the game mechanics, the main elements are highlighted in the user interface: the time is shown in red color on the top-center of the screen; the scores are on the bottom left of the screen (the player points are in green, the engineer points are in red). In addition, as per Figure 4.7, a status bar shows whether the player is currently defeating the engineer, by positioning a cursor within a red-to-green scale (red = engineer is leading, green = player is leading). A green notification on the left side of the screen appears when the player scores points; a similar red-colored notification appears when the home engineer scores points on the right side of the screen. Finally, a set of icons allows the player to change the game camera (top-left of the screen) and to access the inventory of the collected badges (top right of the screen).

Framing

This element of the SGDA framework refers to the target group of a serious game. Since the purpose of Smart Tales is to increase the awareness of ICT solutions for AAL, the target group is composed by people potentially interested in equipping a home with smart technology, such as the relatives of older adults who live alone. Hence, Smart Tales is mainly targeted to non-technical people and non-gamers. The complexity of the levels gradually increases in order to not overwhelm the player. In the first level, a few PIR sensors are available, and the badges are easy to collect. In the third and last level, both passive and active infrared sensors as well as smart tiles are present, and the player has to properly plan beforehand on how to collect the badges, bearing in mind that he should score more points than the home engineer.

The controls of the game are easy to allow non-technical people to play: the avatar can be moved with the arrow keys (or the "WASD" keys) and the buttons on the screen are mouse-clickable. The default game camera is automatic and follows the avatars' movements, from a third person perspective. However, more skilled players can choose a manual camera that can be rotated with the mouse and can even use the “CTRL” key to make the avatar crouch, the “Q” key to do just a small step and the “space bar” to jump. A detailed tutorial explains all the controls of the game. As a reminder of the game controls, the player can always press the “question mark” button on the top-left of the screen: it shows the game controls and summarizes the level’s goals.

4.3.2. Evaluation

We carried out a preliminary evaluation to assess user engagement and learning effectiveness. Engagement is crucial to keep the player motivated to play: the player should experience the entire (or at least most of the) gameplay. This is important because the serious purpose of the game—raising awareness on AAL—is delivered through the gameplay by collecting badges and answering to questions.

Evaluation method

The evaluation is based on user tests with ten people having different backgrounds, selected because of their inexperience in AAL. All the participants were from the same geographical area: the Netherlands. Eight participants were male and two were female. Nine of them had university level education in various fields of expertise including Mathematics, Psychology, Linguistics, Human/Economic Geography, Anthropology, Social Studies, Film Sciences, History and Electrical Engineering. One had secondary school education level. The age ranged from 21 to 30 years old. All but one finished the game and completed all the three levels of the tested version of Smart Tales.

We based the tests on the quasi-experimental research design model of Mayer et al. [108], and our study was conducted by three M.Sc. students. After an explanation of the game goals and of the evaluation’s objectives, the participants filled in a short questionnaire to determine their prior knowledge on AAL and the sensors that Smart Tales features. Then, the participants were asked to play the three levels of the game, without imposing time limits. In the pre-game questionnaire, the users had to give yes/no answers to the following five questions:

1. Do you know what is ambient assisted living?
2. Do you know what is a smart home?
3. Do you know what is a passive infrared sensor?
4. Do you know what is an active infrared sensor?
5. Do you know what is a smart tile?

As a double check, the questionnaire included five open questions that asked the participant an informal definition of the concepts of the previous five questions. Seven participants answered negatively to all of the questions; however, when asked to define AAL using their own words, they associated it to the concept of a "home technologically equipped to assist in some task and/or perform monitoring". One participant (with a background in Electrical Engineering) answered positively to the first four question, although he gave a wrong definition of infrared sensors. The last two participants knew what is a smart home; one of them answered "yes" on the last two questions, but actually gave a wrong definition of active infrared sensor and smart tile.

After the gameplay session, the participants had to fill in two questionnaires: the former measured user engagement, and was based on the User Engagement Scale (UES) proposed by Wiebe et al. [109] to assess engagement in video game-based environments; the latter focused on the assimilated knowledge by asking the same questions that were in the game, and was delivered thirty minutes after the end of the game session. The choice of relying on the same questions poses threats to the validity of the results, while it minimizes the chance of asking knowledge that the game did not deliver.

The tests were carried out in two sessions, at different stages of game development. Six participants tested an early version of the game, while four participants tested a revised version, including different textual and visual information. The early version displayed information on the badges without visual logos. Moreover, a clearer description of the in-game goals was added before the first level as well as in the game help. We performed this redesign after collecting feedback from the first six participants, in order to improve usability and limit confusion.

Learning effectiveness

In Smart Tales, the player has to answer three questions at the end of each level, in order to advance to the next one. The questions concern the serious information content that is contained in the badges collected in the level that was just played. The choice of including knowledge into artifacts is inspired by the *reified knowledge* game design pattern [110], in order to introduce knowledge into a game without disrupting the flow.

Figure 4.8 shows the questions at the end of the first level. These questions check the acquired knowledge on the concept of AAL and on the definition of PIR sensor; such topics are covered by the badges placed in the first level. While answering the in-game questions, the player is actually performing a self-assessment of his first-order learning. Visual feedback informs the player about the correctness of his answers: those highlighted in green are correct, while those in red are wrong (see Figure 4.9). If wrong answers are given, the

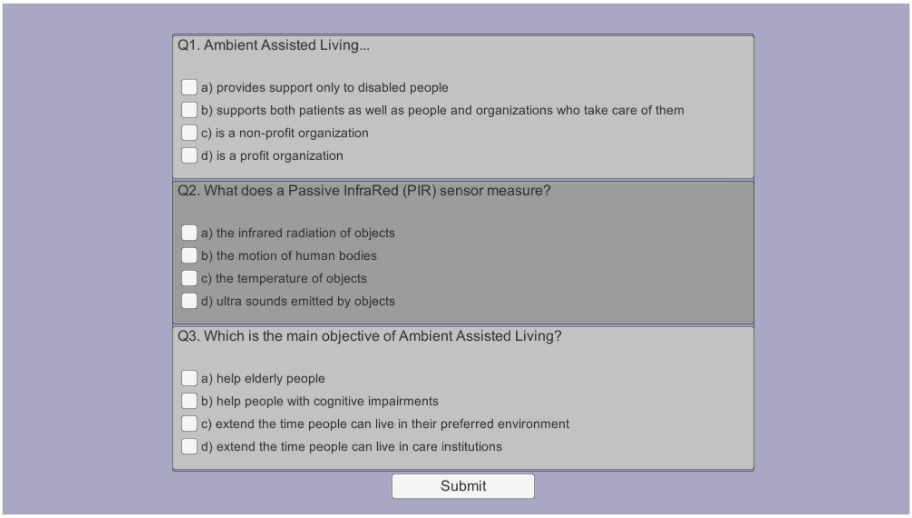


Figure 4.8.: The questions the player is confronted with at the end of the first level to unlock level two.

player has to replay the level and re-answer the questions, in order to unlock the next level. This is an incentive for learning the content in the badges.

During the users tests, we evaluated first-order learning: according to Mayer et al. [108], it is direct influence of playing the game on the individual, small group attitudes, knowledge, skills or behaviour. We reused the nine questions that the player has to answer while playing Smart Tales (three per level): the questions were provided to the users as a questionnaire, thirty minutes after playing the game, in order to assess the effectiveness of the learning process. Figure 4.10 shows the number of correct answers per player in the post-game questionnaire. Globally, 81% of the answers given by the participants was correct: one player answered all the questions correctly, while five players gave just one wrong answer. However, one player was able to give only four correct answers. In fact, such player was not able to complete the second level, and gave up after five attempts; this means that he did not read all the badges and he did not learn enough to answer to more questions.

The approach that we employed in our preliminary evaluation of learning effectiveness does inevitably suffer from threats to validity:

- To adequately assess the learned knowledge, the time between the end of the game session and the post-questionnaire should be longer than thirty minutes. Further tests with an improved research protocol are essential;
- A comparison with traditional learning methods (for example reading books or papers) should be performed, in order to clearly evaluate whether

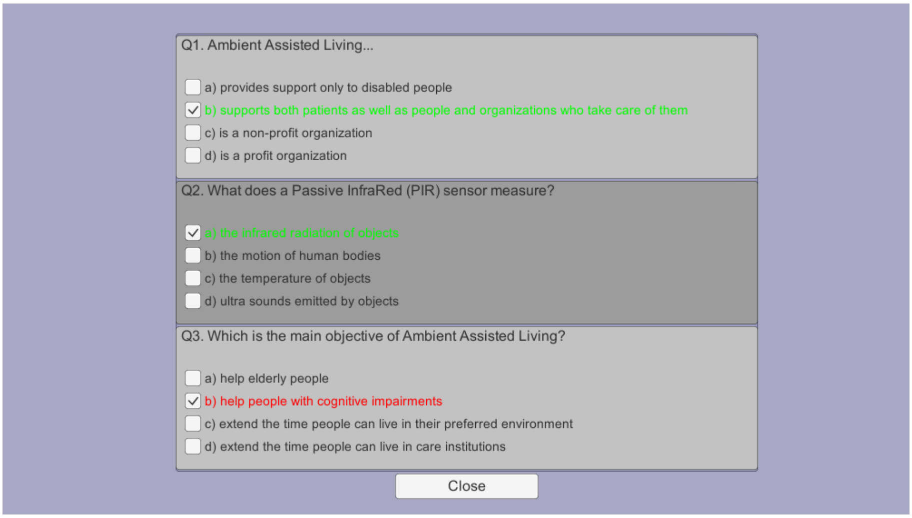


Figure 4.9.: The answers given by the player: the game provides a visual feedback on the correct answers (green) and on the wrong ones (red).

our awareness game is suitable for teaching the basics of AAL and its enabling technologies. This should involve a different research method where participants are allocated to either a treatment group (playing the serious game) or a control group (relying on other instructional techniques) [111].

- The post-questionnaire should be slightly different from the in-game questions, in order to be sure that the tester does not memorize the correct answer, but instead learns the information provided by the badges.

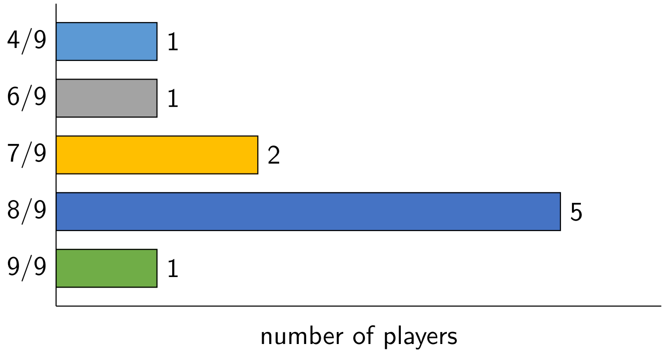


Figure 4.10.: Correct answers per player in the post-game questionnaire: 5 participants gave 8 correct answers out of 9 questions.

Engagement

To evaluate user engagement in Smart Tales, we used the User Engagement Scale (UES) proposed by Wiebe et al. [109] as a validated measure that is tailored for video games. According to the UES, engagement is composed by four factors:

- *Focused attention*, based on the theory of flow [105], to evaluate the concentration, the temporal dissociation and the absorption of the player;
- *Perceived usability*, to evaluate affective (challenge/frustration) and cognitive (effortful) aspects of playing the game;
- *Aesthetics*, to evaluate the visual appearance of the game;
- *Satisfaction*, to evaluate the interest the game evoked, the fun of the gaming experience and the willingness to play it again (and to recommend the game to others).

For each factor, we posed statements that the users could agree or disagree with using a 5-point Likert scale, where 1 corresponds to strong disagreement and 5 to strong agreement with the statement. In order to compute a score for each factor, we used the average of statements that related with that factor.

Table 4.1 shows the UES scores obtained by computing the mean of scores given by the participants, before and after the redesign phase. The score for focused attention was 2.42 before the redesign phase and 2.53 after the redesign (1 = low ability to focus on the game, 5 = high ability to focus). The perceived usability scored 3.4 before and 1.91 after (1 = high sense of usability, 5 = low sense of usability); the aesthetics scored 2.8 before and 2.9 after (1 = low appealing game, 5 = high appealing game); the satisfaction scored 2.64 before and 2.04 after (1 = low satisfaction, 5 = high satisfaction). The data highlights a significant improvement in the perceived usability, and a slight improvement in the focused attention and in the aesthetics, and thus a more engaging game. Nevertheless, user satisfaction was lower after the redesign: this can be due to the fact that the three in-game goals were explicitly listed at the beginning of the level, instead of being present just in the tutorial; hence, the player might

Table 4.1.: UES results for Smart Tales, before and after the minor redesign.

UES factor	Before	After
Focused Attention	2.42	2.53
Perceived Usability	3.40	1.91
Aesthetics	2.80	2.90
Satisfaction	2.64	2.04

feel overwhelmed by the game goals. The small number of subjects, however, does not allow to draw any statistically significant conclusion.

In the following, we describe the detailed results on each factor, by means of diverging stacked bar charts. The bars (see, for example, Figure 4.11) shows the distribution between strong disagreement and strong agreement of all the players who tested Smart Tales, using different colors; the number on each bar indicates how many players gave that precise score to one statement.

Focused Attention. Figure 4.11 lists the statements associated with the factor "Focused Attention", as well as the distribution of players on the Likert scale. Before the performed redesign, all the statements but one has been scored "strongly disagree" by, at least, one player. The statements with the lowest score are those about the perception of time: the statement *I was so involved in my gaming task that I lost track of time* received negative scores by 5 player (2 "strongly disagree", 3 "weakly disagree"). The statements about absorption and concentration got a score a little closer to neutrality, but scores are still unbalanced towards disagreement: 3 players weakly disagreed with the statement *I was really drawn into my gaming task*; the other 3 players were "neutral" to that statement. While players need to concentrate to achieve the game goals, they seem not to lose awareness of the fact that they are performing a learning task. While there are no significant improvements for the perception of time, the redesign seems to have an impact on player absorption: the state-

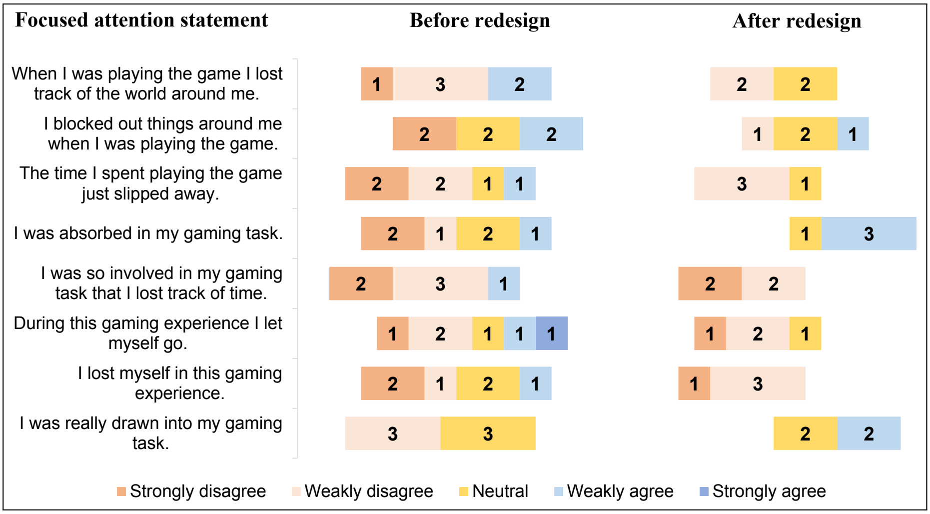


Figure 4.11.: Focused attention scores: before the redesign, 3 players out of 6 weakly disagreed with the statement *I was really drawn into my gaming task* while the other 3 players were "neutral".

ment *I was really drawn into my gaming task* got “weakly agree” by 2 players and “neutral” by the others; *I was absorbed in my gaming task* improved even, with 3 “weakly agree”.

Perceived Usability. The bar chart in Figure 4.12 includes the statements related to the factor “Perceived Usability”. The results of the tests before the redesign clearly indicate the need to improve usability of the game. In particular, the participants felt frustrated: all the players but one weakly agreed with the sentence *I felt frustrated while playing the game.*

Follow-up interviews with the users revealed that the main reason was that players did not really know what to do due to ambiguous or missing feedback and a lack of instructions. The tutorial of Smart Tales includes written instructions given to the player using pop-ups. Most of the players found such instruction boring, and skipped the pop-ups before reading the content. Thus, a redesign might be needed, and tests with different techniques to give instructions should be carried out (for example we can consider to give audio instructions and to use subtitles).

However, the results on perceived usability after the redesign are encouraging: each statement gets a better score, and perceived usability globally scores 1.91. The sense of frustration was lower, and all the 4 participants to the tests after the redesign strongly agreed that they were able to do the things they needed to do in the game.

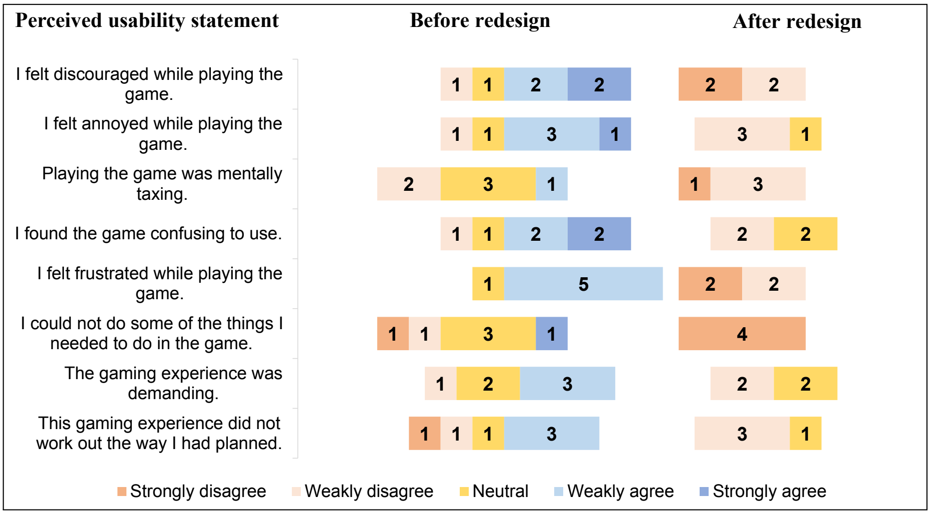


Figure 4.12.: Perceived usability scores: after the redesign, all the 4 players were able to accomplish their tasks in the game.

Aesthetics. Figure 4.13 shows the scores of the statements related to the factor "Aesthetics". Users gave a positive score to the statements on layout and graphics, which indicates that the basic graphics chosen for Smart Tales are appropriate for the purpose of the game. In fact, both before and after the redesign, 3 players agreed with the statement *I liked the graphics and images used in the game.* Nevertheless, the users did not define the game as very attractive since the graphics reminds third person shooter games, which typically have high-quality visual effects. This expectation can have a negative impact on global engagement: the statement *the game was aesthetically appealing* was scored without any significant difference before and after the redesign; most of the participants (6 out of 10) weakly disagreed with the sentence, three were neutral and one agreed.

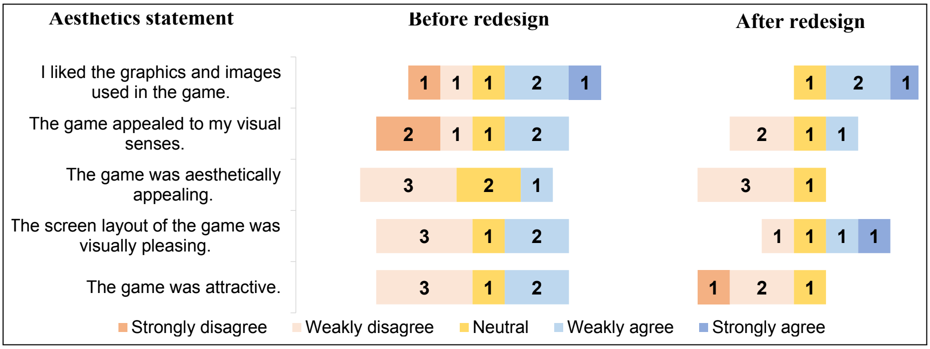


Figure 4.13.: Aesthetics scores: the players did not define the game attractive, probably because the graphics remind third person shooter games.

Satisfaction. Figure 4.14 includes the scores of the statements about factor "Satisfaction". Both before and after the redesign phase, the players indicated a low willingness to continue playing and to suggest the game to other people. In addition, all the participants involved in the tests after the redesign weakly disagreed with the sentence *Playing the game was worthwhile.* One reason for these issues is that the same home and sensors are present in all the three levels; thus, some players might find the game repetitive. Hence, a redesign might be needed, by adding levels with different home maps and more sensor types. The new redesign should address also players' curiosity and interest, since the participants negatively scored the statement *I would continue to play this game out of curiosity* (5 players out of 10 expressed strong disagreement with the statement, 2 before the redesign, 3 after).

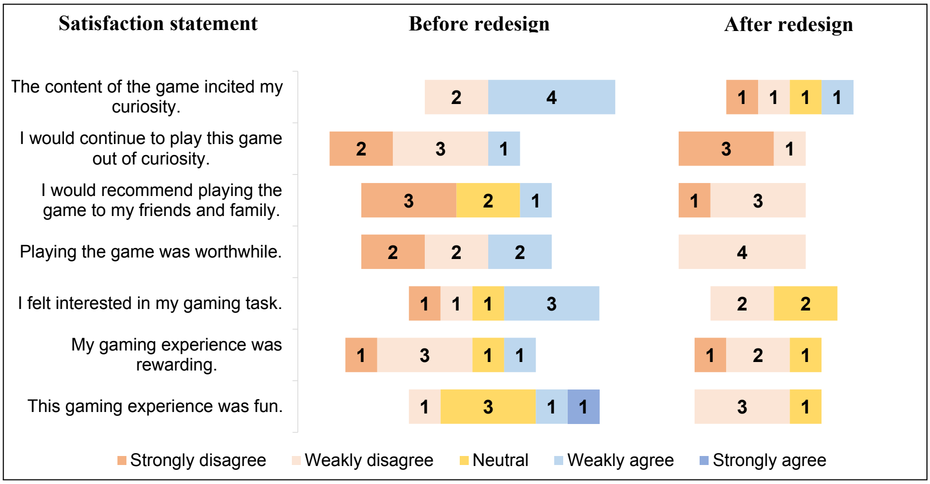


Figure 4.14.: Satisfaction scores: the players showed low willingness to replay the game, even if, according to the scores, the content (but not the gameplay) seems to stimulate curiosity.

4.4. Chapter conclusions

We discussed about innovative uses of virtual environments for AAL and AmI. In the first part of the chapter, we presented a robotics simulator extended to test and validate AAL applications. To show the interactions between the simulator and AAL systems, we described two use cases, as examples of software that could be developed and tested with the 3D virtual environment:

- A smartphone application for the management of a smart home;
- The Virtual Carer (as presented in the previous chapter).

In addition of a decoupling of the software from the hardware, using a simulator can improve the economical sustainability of the development of software to control smart homes: even if such an approach cannot completely replace user trials before the everyday use, it can speed up the development of prototypes and allow the use of real environments only for release candidate versions. The interactions between simulated sensors (and actuators) and AAL systems are based on network sockets: the software systems tested in the simulator should be easily migrated in real environments, if virtual sensors provide the same interface as off-the-shelf sensors (the only requirement is their capability to operate in a TCP/IP network).

Of course, more qualitative and quantitative tests on the simulator are needed. In our vision, an AAL simulator could be an ideal platform to combine the efforts of the AAL research community for the development of assistive technologies; as future work, instead of extending a robotics simulator, as in our simple proof-of-concepts, the possibility of developing a dedicated AAL simulator (with a physics engine) should be evaluated, in order to adhere to specific AAL needs. Moreover, the implementation of human behaviours needs improvements: the simulator has to take into account that smart homes are socio-technical systems [112], being characterized by the interplay between the human factor and the technical aspects of AAL. The simulation of human behaviours does not involve only the assisted persons: the simulations should include avatars representing all the people interacting with the assisted persons (such as relatives, a caregiver, a mailman, a repairman, health operators, etc.); thus, even the mechanism for the goal scheduling of the patient is complicated by the possible interactions. The BDI paradigm, in particular, could allow to reproduce human-like cognitive processes which can seriously enhance the credibility of avatars' behaviours, an essential aspect for simulators and virtual environments [103].

In the second part of the chapter, we argued for the importance of virtual environments to increase the acceptance of AAL. Thus, we presented the Smart Tales game that raises awareness on concept, objectives, working principles and enabling technologies of AAL.

Currently, the game has three levels as well as a tutorial for the user to learn about the game controls and objectives. The player covers the role of an inhabitant of a smart home, and his objective is to cheat the deployed sensors. The player has also to collect informative cards about AAL and its technology, gaining the necessary knowledge to answer the quizzes at the end of each level, and advance to the next one.

We conducted a preliminary formative evaluation of the game with ten participants. Six participants played the game in its early stage, while the other four played an improved version, where we performed a minor redesign of some graphics of the game (mainly on the informative cards). The post-test questionnaires answered by the participants to assess learning process show promising results: 81% of the answers were correct. Hence, the results encourage the use of serious game to increase the knowledge about AAL technologies. The tests on user engagement show clear room for improvement. On the one hand, the redesigned version obtained a perceived usability score of 1.91 in a scale from 1 to 5 (where 1 represents a high sense of usability and 5 a low sense of usability). On the other hand, focused attention, aesthetics and satisfaction obtained an average score at the middle of the scale: the repetitiveness of the levels needs to be reduced (e.g., by creating levels with different home maps and adding new sensors), to increase the players' curiosity and sense of fun; improving the graphics could lead to higher immersion and, thus, enhance the sense of flow.

As future work, more extensive tests need to conducted: a comparison with a control group relying on traditional learning techniques can better validate the usefulness and effectiveness of serious games to increase awareness about AAL. Another direction concerns replacing the CPU-as-an-engineer gameplay with an additional role for the players, i.e., that of an engineer that has to properly configure a smart home.

Finally, in our vision, the fictional context of Smart Tales should evolve towards an entire story, where the skeptical inhabitant becomes, at the end of the game, confident in the potential of concepts and enabling technologies of AAL.

Chapter 5.

Conclusions

Most of the scientific literature about Ambient Assisted Living (AAL) deals with the technological aspects of ICT systems to respond to end-users' needs. Three aspects emerge:

- A wide heterogeneity of technologies and techniques to provide AAL services, and thus the difficulties in the integration and interoperability of different services;
- A lack of systematic design of the proposed solutions for AAL;
- The low acceptance of AAL technologies.

5.1. Thesis contributions

The main contributions of this thesis address such aspects. We presented a BDI-based expert system, the Virtual Carer: it is a Multi-Agent System for the management of an assistive environment, such as a smart home, which monitors also the health condition of the assisted persons. The core of the system is a BDI agent, the VirtualCarerAgent, which analyzes data coming from the SensorAgents and infers plans to act on the environment, as regulating the heating, or trigger alarms, by sending commands to ActuatorAgents. Finally, a RegisterAgent is responsible for the management of the databases storing the occured events. The agent-based approach is not limited to the implementation phase, but the entire development is based on agent-oriented paradigms: we systematically designed the Virtual Carer, starting from stakeholders' strategic goals and following the Tropos methodology. In addition, we highlighted the contribution of Multi-Agent Systems as a key to achieve interoperability in healthcare and the integration with AAL services. In particular, the interoperability with the legacy systems of local healthcare facilities can be achieved by using wrapper agents with the responsibility to translate clinical documents in international standards (such as HL7-CDA). The adoption of FIPA standards for agent communication and interactions allows to achieve system modularity, making the systems ready for the inclusion of new technologies. Moreover, the agent-based architecture for Health Information Systems proposed in Chapter 3 ensures that the clinical data is stored in the facilities where it is produced, avoiding to centralize personal health information in cloud services (with potential privacy issues).

Then, we proposed the use of 3D virtual environments in AAL. First, we argued for the adoption of a simulation environment to speed up the development and test of intelligent software for AAL. We adapted a robotics simulator, MORSE, to simulate a smart home that can be managed by software applications for AAL, as a testbed. The communication between the real systems to be tested and the simulator is based on IP sockets. To highlight the interactions between the simulator and the software systems to be tested, we used two use-cases: a real mobile application and the Virtual Carer. The first use-case was representative of the trend in AAL and pervasive healthcare towards the use of mobile devices and applications. The second use-case highlighted the use of the simulator as a testbed for intelligent systems for AAL. However, the main contribution of this thesis on virtual environments for AAL is the use of games to increase end-users' awareness towards the AAL and its enabling technologies: we developed an awareness game, Smart Tales, which is driven by such serious purpose. The player impersonates a resident of a smart home, skeptical about the unobtrusiveness of the AAL technology. Such fictional context engages the user, in conjunction with elements from different game genres: Smart Tales has a scoring mechanism to engage the users as in arcade games; it includes different levels and the goal to collect "badges" as platform and puzzle games; it features first person and third person cameras, as shooting games, to enhance the sense of immersion of the user. The serious content, which should make the user more aware on AAL, is delivered by informative badges, that the user has to collect to answer to in-game quizzes, at the end of each level. A formative evaluation with ten people highlighted promising results on the learning effectiveness of Smart Tales (the 81% of the answers was correct) as well as a good usability. Nevertheless, users' immersion and willingness to play again the game need improvements: a partial redesign to avoid the repetitiveness of the levels is necessary.

5.2. Future works

The main limitation of the research presented in this thesis is the lack of tests in home environments, equipped with sensors and devices, with real residents. As explained in Chapter 4 it would require an effort beyond our possibilities. Nevertheless, we described a proof-of-concept implementation of the proposed multi-agent architecture, which is one of the main artifacts produced in this research.

In addition to more insightful test on the Virtual Carer, an expansion of Smart Tales is necessary. The current version features three levels, based on motion detection and indoor positioning: in the future, it should include more AAL services (e.g. health monitoring), and evolve towards a complete story, where the skeptical inhabitant becomes confident in the potential of AAL.

Our vision for the future of the research reported in this thesis includes a deeper work on the interface between the Virtual Carer and the assisted persons. In fact, the interaction should be natural and intuitive, and, in our opinion, vocal. With the integration with Health Information Systems and healthcare infrastructures, as proposed in Chapter 3, the Virtual Carer should evolve towards a virtual hospital ward at the patient's home environment. The objective would be to improve the level of remote health monitoring, bringing a hospital ward in the home environment of the patient, allowing an early dehospitalization, when possible. Such system should "inherit" the features of the Virtual Carer, being capable of:

- Vocal interaction to receive commands and to give information and suggestions in Activities of Daily Living (ADLs) such as cooking, hand washing, cleaning;
- Management of routine activities such as remote command to open/close doors and windows, switching on/off lights and domestic devices;
- Entertainment (e.g. book reading);
- Interfacing with family and health operators;
- Browsing a summary of relevant information to quickly monitor the patient and the environment status; this information recap, made accessible over the internet by means of suitable security protocols, is particularly useful when a human carer cannot be in the environment where the patient lives.

Appendix A.

Studies included in the systematic literature review

This appendix includes details about the studies analyzed in the literature review presented in Chapter 2. In Section A.1 we highlight the temporal distribution of papers according to the publication date; in Section A.2 we list all the studies that satisfied the inclusion criteria and, thus, were analyzed.

A.1. Temporal distribution of analyzed papers

Table A.1 shows the temporal distribution of the papers included in the review presented in Chapter 2, according to the publication date.

It is worth noting that the "Ambient Assisted Living Joint Association" was founded in 2007 and that the "Ambient Assisted Living Joint Programme" started in 2008: we can identify 2007 and 2008 as the years when the locution *Ambient Assisted Living* became widely recognized. In fact, before those years, there are only 14 papers that satisfied at least one inclusion criterion. While the review includes 51 studies published in 2011 and 48 in 2012, there are only 32 papers published in 2013. This is due to the fact that we performed the collection process between December 2013 and January 2014: thus, many papers of 2013 were not appeared yet in bibliographic databases.

Table A.1.: The number of papers included in the review for year of publication.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
# of papers	4	4	6	10	18	28	35	51	48	32

A.2. List of papers included in the review

[1] J. Abascal, "Ambient Intelligence for people with disabilities and elderly people," in *Workshop on Ambient Intelligence for Scientific Discovery (AISD) Workshop*, 2004.

[2] L. Coetzee and E. Barnard, "Pattern recognition in service of people with disabilities," in *15th Annual Symposium of the Pattern Recognition Association of South Africa (PRASA 2004)*, 2004.

[3] E. M. Tapia, S. S. Intille, and K. Larson, "Activity recognition in the home using simple and ubiquitous sensors," in *Pervasive Computing*, ser. LNCS. Springer Berlin Heidelberg, 2004, vol. 3001, pp. 158–175.

[4] N. Zouba, F. Bremond, M. Thonnat, A. Anfosso, É. Pascual, P. Mallea, V. Mailland, O. Guerin, I. Sophia-antipolis, S. A. Cedex, and C. S. Antipolis, "Assessing computer systems for monitoring elderly people living at home," in *Proceedings of the 19th IAGG World Congress of Gerontology and Geri-atrics, IAGG. 2009.*, 2004.

[5] G. de Haan, O. B. Henkemans, and A. Aluwalia, "Personal assistants for healthcare treatment at home," in *Proceedings of the 2005 Annual Conference on European Association of Cognitive Ergonomics*, ser. EACE '05, 2005, pp. 225–231.

[6] J. Eklund, T. Hansen, J. Sprinkle, and S. Sastry, "Information technology for assisted living at home: building a wireless infrastructure for assisted living," in *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the*, 2005, pp. 3931–3934.

[7] R. Hill, S. Polovina, and M. Beer, "Managing healthcare workflows in a multi-agent system environment managing healthcare workflows in a multi-agent system environment," in *Proceedings of the Agents Applied in Healthcare Workshop, Nineteenth International Joint Conference on Artificial Intelligence (IJCAI)*, 2005.

[8] M. E. Pollack, "Intelligent technology for an aging population the use of ai to assist elders with cognitive impairment," *AI Magazine*, vol. 26, no. 2, pp. 9–24, 2005.

[9] J. C. Augusto and P. Mccullagh, "Enhanced healthcare provision through assisted decision-making in a smart home environment," in *2nd Workshop on Artificial Inteligence Techniques for Ambient Inteligence*, 2006.

[10] B. O'Flynn and P. Angove, "Wireless biomonitor for ambient assisted living," in *International Conference on Signals and Electronic Systems - ICSES'06*, 2006, pp. 257–260.

[11] A. Milenković, C. Otto, and E. Jovanov, "Wireless sensor networks for personal health monitoring: Issues and an implementation," *Computer Communications*, vol. 29, no. 13Ű14, pp. 2521 – 2533, 2006.

[12] H. Sun, V. De Florio, and C. Blondia, "A design tool to reason about ambient assisted living systems," in *Intelligent Systems Design and Applications, 2006. ISDA '06. Sixth International Conference on*, vol. 2, 2006, pp. 1136–1144.

[13] V. Tiponu, A. Gacsádi, T. Laviniu, C. Lar, and I. Gavrilu, "Integrated environment for assisted movement of visually impaired," in *Proceedings of the 15th International Workshop on Robotics in Alpe-Adria-Danube Region (RAAD 2006)*, 2006.

[14] G. Virone, A. Wood, L. Selavo, Q. Cao, L. Fang, T. Doan, Z. He, R. Stoleru, S. Lin, and J. Stankovic, "An assisted living oriented information system based on a residential wireless sensor network," in *Distributed Diagnosis and Home Healthcare, 2006. D2H2. 1st Transdisciplinary Conference on*, 2006, pp. 95–100.

[15] H. Aghajan, J. C. Augusto, C. Wu, P. McCullagh, and J.-A. Walkden, "Distributed vision-based accident management for assisted living," in *Pervasive Computing for Quality of Life Enhancement*, ser. Lecture Notes in Computer Science. Springer Berlin Heidelberg, 2007, vol. 4541, pp. 196–205.

[16] P. Gray, T. McBryan, N. Hine, C. J. Martin, N. Gil, M. Wolters, N. Mayo, K. J. Turner, L. S. Docherty, F. Wang, and M. Kolberg, "A scalable home care system infrastructure supporting domiciliary care," Department of Computing Science and Mathematics, University of Stirling, Tech. Rep. CSM-173, 2007.

[17] J. Hoey, A. V. Bertoldi, P. Poupart, and A. Mihailidis, "Assisting persons with dementia during handwashing using a partially observable markov decision process," in *Proceedings of the International Confeference on Vision Systems.*, 2007.

[18] J. Hou, Q. Wang, B. AlShebli, L. Ball, S. Birge, M. Caccamo, C.-F. Cheah, E. Gilbert, C. Gunter, E. Gunter, C.-G. Lee, K. Karahalios, M.-Y. Nam, N. Nitya, C. Rohit, L. Sha, W. Shin, S. Yu, Y. Yu, and Z. Zeng, "PAS: A wireless-enabled, sensor-integrated personal assistance system for independent and assisted living," in *High Confidence Medical Devices, Software, and Systems and Medical Device Plug-and-Play Interoperability, 2007. HCMDSS-MDPnP. Joint Workshop on*, 2007, pp. 64–75.

[19] A. F. Harris III, R. Kooper, R. Kravets, G. Maselli, and C. Petrioli, "Meditrina: Addressing the system-level challenges to ambient assisted living," in *Proceedings of the 1st ACM SIGMOBILE International Workshop on Systems and Networking Support for Healthcare and Assisted Living Environments*, ser. HealthNet '07, 2007, pp. 79–82.

[20] J. Koch, M. Anastasopoulos, and K. Berns, "Using the modular controller architecture (mca) in ambient assisted living," in *Intelligent Environments, 2007. IE 07. 3rd IET International Conference on*, 2007, pp. 411–415.

[21] L. Litz and M. Gross, "Covering assisted living key areas based on home automation sensors," in *Networking, Sensing and Control, 2007 IEEE International Conference on*, 2007, pp. 639–643.

[22] D. Lymberopoulos, T. Teixeira, and A. Savvides, "Detecting patterns for assisted living using sensor networks: A case study," in *Sensor Technologies and Applications, 2007. SensorComm 2007. International Conference on*, 2007, pp. 590–596.

[23] A. Petrakou, "Exploring cooperation through a binder: A context for it tools in elderly care at home," in *ECSCW 2007*. Springer London, 2007, pp. 271–290.

[24] H. Sun, V. De Florio, N. Gui, and C. Blondia, "Participant: A new concept for optimally assisting the elder people," in *Computer-Based Medical Systems, 2007. CBMS '07. Twentieth IEEE International Symposium on*, 2007, pp. 295–300.

[25] L. Atallah, B. Lo, G.-Z. Yang, and F. Siegemund, "Wirelessly accessible sensor populations (wasp) for elderly care monitoring," in *Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on*, 2008, pp. 2–7.

[26] A. Bamis, D. Lymberopoulos, T. Teixeira, and A. Savvides, "Towards precision monitoring of elders for providing assistive services," in *Proceedings of the 1st International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '08, 2008, pp. 49:1–49:8.

[27] M. Betke, "Camera-based interfaces and assistive software for people with severe motion impairments," Department of Computer Science, Boston University, Tech. Rep. BU-CS-2008-025, 2008.

[28] A. Borowczyk, M. Gawinecki, and M. Paprzycki, "BDI agents in a patient monitoring scenario," in *Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on*, 2008, pp. 82–85.

[29] A. Hristova, A. Bernardos, and J. Casar, "Context-aware services for ambient assisted living: A case-study," in *Applied Sciences on Biomedical and Communication Technologies, 2008. ISABEL '08. First International Symposium on*, 2008, pp. 1–5.

[30] B. Kröse, T. Van Kasteren, C. Gibson, and T. Van den Dool, "CARE: Context awareness in residences for elderly," in *Proceedings of the 6th International Conference of the International Society for Gerontechnology, ISG 2008*, 2008, pp. 101–105.

[31] V. Mylonakis, J. Soldatos, A. Pnevmatikakis, L. Polymenakos, A. Sorin, and H. Aronowitz, "Using robust audio and video processing technologies to alleviate the elderly cognitive decline," in *Proceedings of the 1st International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '08, 2008, pp. 28:1–28:8.

[32] D. Schneider and M. Becker, "Runtime models for self-adaptation in the ambient assisted living domain," Lancaster University, Tech. Rep. COMP-005-2008, 2008.

[33] C. J. Su, "Mobile multi-agent based, distributed information platform (madip) for wide-area e-health monitoring," *Computers in Industry*, vol. 59, no. 1, pp. 55 – 68, 2008.

[34] T. H. Teo, W. Tiong, P. K. Gopalakrishnan, and V. K. H. Phay, "Wireless healthcare monitoring system for home," in *Proceedings of World Academy of Science: Engineering & Technology*, 2008.

[35] M. H. Vastenburg, T. Visser, M. Vermaas, and D. V. Keyson, "Designing acceptable assisted living services for elderly users," in *Ambient Intelligence*, ser. LNCS. Springer Berlin Heidelberg, 2008, vol. 5355, pp. 1–12.

[36] R. Velentzas, A. Marsh, and G. Min, "Wireless connected home with integrated secure healthcare services for elderly people," in *Proceedings of the 1st International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '08, 2008, pp. 77:1–77:4.

[37] D. Vergados, C. Kavvadias, O. Bigalke, A. Eppler, B. Jerabek, A. Alevizos, M. Caragiozidis, C. Biniaris, and E. Robert, "An intelligent interactive healthcare services environment for assisted living at home," in *Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on*, 2008, pp. 329–329.

[38] D. Vergados, A. Alevizos, A. Mariolis, and M. Caragiozidis, "Intelligent services for assisting independent living of elderly people at home," in *Proceedings of the 1st International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '08, 2008, pp. 79:1–79:4.

[39] Y. Verginadis, P. Gouvas, T. Bouras, and G. Mentzas, "Conceptual modeling of service-oriented programmable smart assistive environments," in *Proceedings of the 1st International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '08, 2008, pp. 11:1–11:8.

[40] M. Wojciechowski and J. Xiong, "On context modeling in ambient assisted living," in *International Workshop on Modelling and Reasoning in context (MRC), International Conference on Human Centred Processes (HCP)*, 2008, pp. 13–24.

[41] P. Wolf, A. Schmidt, and M. Klein, "Soprano — an extensible, open aal platform for elderly people based on semantical contracts," in *3rd Workshop on Artificial Intelligence Techniques for Ambient Intelligence (AITAmI'08)*, 2008.

[42] Z. Fu, T. Delbruck, P. Lichtsteiner, and E. Culurciello, "An address-event fall detector for assisted living applications," *Biomedical Circuits and Systems, IEEE Transactions on*, vol. 2, no. 2, pp. 88–96, 2008.

[43] J. Corchado, J. Bajo, D. Tapia, and A. Abraham, "Using heterogeneous wireless sensor networks in a telemonitoring system for healthcare," *Information Technology in Biomedicine, IEEE Transactions on*, vol. 14, no. 2, pp. 234–240, 2009.

[44] J. Escayola, I. Martinez, J. Trigo, J. Garcia, M. Martinez-Espronceda, S. Led, and L. Serrano, "Recent innovative advances in biomedical engineering: Standard-based design for ubiquitous p-health," in *Computing in the Global Information Technology, 2009. ICCGI '09. Fourth International Multi-Conference on*, 2009, pp. 109–117.

[45] G. García-Sáez, M. E. Hernando, I. naki Martínez-Sarriegui, M. Rigla, V. Torralba, E. Brugués, A. de Leiva, and E. J. Gómez, "Architecture of a wireless personal assistant for telemedical diabetes care," *International Journal of Medical Informatics*, vol. 78, no. 6, pp. 391 – 403, 2009.

[46] A. Hein, M. Eichelberg, O. Nee, A. Schulz, A. Helmer, and M. Lipprandt, "A service oriented platform for health services and ambient assisted living," in *Advanced Information Networking and Applications Workshops, 2009. WAINA '09. International Conference on*, 2009, pp. 531–537.

[47] I. Iliev, "Ultra low-power acoustic detector applicable in ambient assistance living systems," *Bioautomation*, vol. 13, no. 4, pp. 72–78, 2009.

[48] D. Isern, A. Moreno, D. Sánchez, Á. Hajnal, G. Pedone, and L. Z. Varga, "Agent-based execution of personalised home care treatments," *Applied Intelligence*, vol. 34, no. 2, pp. 155–180, 2009.

[49] M. Isomursu, M. Ervasti, and V. Tormanen, "Medication management support for vision impaired elderly: Scenarios and technological possibilities," in *Applied Sciences in Biomedical and Communication Technologies, 2009. ISABEL 2009. 2nd International Symposium on*, 2009, pp. 1–6.

[50] S. Kieffer, J.-Y. Lawson, and B. Macq, "User-centered design and fast prototyping of an ambient assisted living system for elderly people," in *Information Technology: New Generations, 2009. ITNG '09. Sixth International Conference on*, 2009, pp. 1220–1225.

[51] W. Kurschl, S. Mitsch, and J. Schoenboeck, "Modeling situation-aware ambient assisted living systems for eldercare," in *Information Technology: New Generations, 2009. ITNG '09. Sixth International Conference on*, 2009, pp. 1214–1219.

[52] P. D. M. Lardizabal, "Ubiquitous care system to support independent living: Preliminary results," in *In Roots for the future of ambient intelligence*, 2009, pp. 308–315.

[53] H. J. Lee, S. H. Lee, K.-S. Ha, H. C. Jang, W.-Y. Chung, J. Y. Kim, Y.-S. Chang, and D. H. Yoo, "Ubiquitous healthcare service using zigbee and mobile phone for elderly patients," *International Journal of Medical Informatics*, vol. 78, no. 3, pp. 193–198, 2009.

[54] M. Lipprandt, M. Eichelberg, W. Thronicke, J. Kruger, I. Druke, D. Willemsen, C. Busch, C. Fiehe, E. Zeeb, and A. Hein, "OSAMI-D: An open service platform for healthcare monitoring applications," in *Human System Interactions, 2009. HSI '09. 2nd Conference on*, 2009, pp. 139–145.

[55] A. Lombardi, M. Ferri, G. Rescio, M. Grassi, and P. Malcovati, "Wearable wireless accelerometer with embedded fall-detection logic for multi-sensor ambient assisted living applications," in *Sensors, 2009 IEEE*, 2009, pp. 1967–1970.

[56] A. Lorenz and R. Oppermann, "Mobile health monitoring for the elderly: Designing for diversity," *Pervasive and Mobile Computing*, vol. 5, no. 5, pp. 478–495, 2009.

[57] M. Mancini, E. Farella, L. Rocchi, C. Tacconi, L. Benini, and L. Chiari, "A biofeedback based portable device to support elderly mobility in the home environment," in *World Congress on Medical Physics and Biomedical Engineering, September 7 - 12, 2009, Munich, Germany*, ser. IFMBE Proceedings. Springer Berlin Heidelberg, 2009, vol. 25/9, pp. 546–549.

[58] H. Martin, A. Bernardos, L. Bergesio, and P. Tarrio, "Analysis of key aspects to manage wireless sensor networks in ambient assisted living environments," in *Applied Sciences in Biomedical and Communication Technologies, 2009. ISABEL 2009. 2nd International Symposium on*, 2009, pp. 1–8.

[59] A. Mileo, D. Merico, S. Pinardi, and R. Bisiani, "A logical approach to home healthcare with intelligent sensor-network support," *Comput. J.*, vol. 53, no. 8, pp. 1257–1276, 2009.

[60] G. Moritz, E. Zeeb, F. Golatowski, D. Timmermann, and R. Stoll, "Web services to improve interoperability of home healthcare devices," in *Pervasive Computing Technologies for Healthcare, 2009. PervasiveHealth 2009. 3rd International Conference on*, 2009, pp. 1–4.

[61] N. Qadeer, R. Velik, G. Zucker, and H. Boley, "Knowledge representation for a neurosymbolic network in home care risk identification," in *2009 7th IEEE International Conference on Industrial Informatics*, 2009, pp. 277–282.

[62] M. D. Rodríguez, V. M. Gonzalez, J. Favela, and P. C. Santana, "Home-based communication system for older adults and their remote family," *Computers in Human Behavior*, vol. 25, no. 3, pp. 609–618, 2009.

[63] A. Rodrigues, I. Gomes, L. Bezerra, A. Sztajnberg, S. Carvalho, A. Copetti, and O. Loques, "Using discovery and monitoring services to support context-aware remote assisted living applications," in *Computational Science and Engineering, 2009. CSE '09. International Conference on*, vol. 2, 2009, pp. 1092–1097.

[64] M. Segarra and F. Andre, "Building a context-aware ambient assisted living application using a self-adaptive distributed model," in *Autonomic and Autonomous Systems, 2009. ICAS '09. Fifth International Conference on*, 2009, pp. 40–44.

[65] P. Siciliano, A. Leone, G. Diraco, C. Distante, M. Malfatti, L. Gonzo, M. Grassi, A. Lombardi, G. Rescio, and P. Malcovati, "A networked multisensor system for ambient assisted living application," in *Advances in sensors and Interfaces, 2009. IWASI 2009. 3rd International Workshop on*, 2009, pp. 139–143.

[66] N. Spanoudakis, P. Moraitis, and Y. Dimopoulos, "Engineering an agent-based approach to ambient assisted living," in *Proceedings of the 3rd European Conference on Ambient Intelligence (AmI09), Workshop on Interactions Techniques and Metaphors in Assistive Smart Environments (IntTech'09)*, 2009.

[67] H. Storf, M. Becker, and M. Riedl, "Rule-based activity recognition framework: Challenges, technique and learning," in *Pervasive Computing Technologies for Healthcare, 2009. PervasiveHealth 2009. 3rd International Conference on*, 2009, pp. 1–7.

[68] E. Stroulia, D. Chodos, N. Boers, J. Huang, P. Gburzynski, and I. Nikolaidis, "Software engineering for health education and care delivery systems: The smart condo project," in *Software Engineering in Health Care, 2009. SEHC '09. ICSE Workshop on*, 2009, pp. 20–28.

[69] K. Turner, L. Docherty, F. Wang, and G. Campbell, "Managing home care networks," in *Networks, 2009. ICN '09. Eighth International Conference on*, 2009, pp. 354–359.

[70] U. Weimar, R. Simpson, N. Barsan, T. Heine, W. Simmendinger, M. Malfatti, B. Margesin, L. Gonzo, M. Grassi, A. Lombardi, P. Malcovati, A. Leone, G. Diraco, P. Siciliano, O. v. Sicard, R. Pohle, M. Fleischer, A. Redaelli, A. Giacosi, and C. Bonassi, "Microsystem technology for ambient assisted living (aal)," *Procedia Chemistry*, vol. 1, no. 1, pp. 710—713, 2009.

[71] N. Bal and M. Schwarz, "Ambient assisted living for type 2 diabetic patients," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2010 4th International Conference on*, 2010, pp. 1–3.

[72] A. Bamis, D. Lymberopoulos, T. Teixeira, and A. Savvides, "The BehaviorScope framework for enabling ambient assisted living," *Personal and Ubiquitous Computing*, vol. 14, no. 6, pp. 473–487, 2010.

[73] M. Bennebroek, A. Barroso, L. Atallah, B. Lo, and G.-Z. Yang, "Deployment of wireless sensors for remote elderly monitoring," in *e-Health Networking Applications and Services (Healthcom), 2010 12th IEEE International Conference on*, 2010, pp. 1–5.

[74] K. Berns and S. Mehdi, "Use of an autonomous mobile robot for elderly care," in *Advanced Technologies for Enhancing Quality of Life (AT-EQUAL), 2010*, 2010, pp. 121–126.

[75] D. Cascado, S. Romero, S. Hors, A. Brasero, L. Fernandez-Luque, and J. Sevillano, "Virtual worlds to enhance ambient-assisted living," in *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*, 2010, pp. 212–215.

[76] A. Coronato, G. D. Pietro, and G. Sannino, "Middleware services for pervasive monitoring elderly and ill people in smart environments," in *2014 11th International Conference on Information Technology: New Generations*, 2010, pp. 810–815.

[77] A. Costa, P. Novais, R. Costa, J. M. Corchado, and J. Neves, "Multi-agent personal memory assistant," in *Trends in Practical Applications of Agents and Multiagent Systems*, ser. Advances in Intelligent and Soft Computing. Springer Berlin Heidelberg, 2010, vol. 71, pp. 97–104.

[78] A. Dohr, R. Modre-Opsrian, M. Drobics, D. Hayn, and G. Schreier, "The internet of things for ambient assisted living," in *Information Technology: New Generations (ITNG), 2010 Seventh International Conference on*, 2010, pp. 804–809.

[79] M. Eichelberg, A. Hein, F. Busching, and L. Wolf, "The GAL middleware platform for AAL," in *e-Health Networking Applications and Services (Healthcom), 2010 12th IEEE International Conference on*, 2010, pp. 1–6.

[80] J. Fayn and P. Rubel, "Toward a personal health society in cardiology," *Information Technology in Biomedicine, IEEE Transactions on*, vol. 14, no. 2, pp. 401–409, 2010.

[81] F. Fernández-Luque, J. Zapata, and R. Ruiz, "A system for ubiquitous fall monitoring at home via a wireless sensor network," in *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*, 2010, pp. 2246–2249.

[82] D. Han, M. Lee, and S. Park, "THE-MUSS: Mobile u-health service system," *Computer Methods and Programs in Biomedicine*, vol. 97, no. 2, pp. 178–188, 2010.

[83] R. Hartmann, F. Al Machot, P. Mahr, and C. Bobda, "Camera-based system for tracking and position estimation of humans," in *Design and Architectures for Signal and Image Processing (DASIP), 2010 Conference on*, 2010, pp. 62–67.

[84] R. Helaoui, M. Niepert, and H. Stuckenschmidt, "A statistical-relational activity recognition framework for ambient assisted living systems," in *Ambient Intelligence and Future Trends-International Symposium on Ambient Intelligence (ISAmI 2010)*, ser. Advances in Soft Computing. Springer Berlin Heidelberg, 2010, vol. 72, pp. 247–254.

[85] T. Helfenbein, L. Vajda, and R. Claywell, "A maintenance-free wireless sensor network based system for aal applications," in *Telecommunications: The Infrastructure for the 21st Century (WTC), 2010*, 2010, pp. 1–6.

[86] Y.-J. Hong, I.-J. Kim, S. C. Ahn, and H.-G. Kim, “Mobile health monitoring system based on activity recognition using accelerometer,” *Simulation Modelling Practice and Theory*, vol. 18, no. 4, pp. 446–455, 2010, modeling and Simulation Techniques for Future Generation Communication Networks.

[87] M. Kranz, T. Linner, B. Ellmann, A. Bittner, and L. Roalter, “Robotic service cores for ambient assisted living,” in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2010 4th International Conference on-NO PERMISSIONS*, 2010, pp. 1–8.

[88] G. Krassnig, D. Tantinger, C. Hofmann, T. Wittenberg, and M. Struck, “User-friendly system for recognition of activities with an accelerometer,” in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2010 4th International Conference on-NO PERMISSIONS*, 2010, pp. 1–8.

[89] A. Leone, G. Diraco, and P. Siciliano, “An automated active vision system for fall detection and posture analysis in ambient assisted living applications,” in *Industrial Electronics (ISIE), 2010 IEEE International Symposium on*, 2010, pp. 2301–2306.

[90] A. Mertens, D. Koch-Korfges, N. Jochems, and C. Schlick, “Touchscreen-based input technique for people with intention tremor,” in *Human System Interactions (HSI), 2010 3rd Conference on*, 2010, pp. 236–240.

[91] A. Mileo, S. Pinardi, and R. Bisiani, “Movement recognition using context: A lexical approach based on coherence,” in *6th International Workshop on Modeling and Reasoning in Context, MRC 2010*, ser. CEUR Workshop Proceedings, vol. 618, 2010, pp. 37–48.

[92] S. Nefti, U. Manzoor, and S. Manzoor, “Cognitive agent based intelligent warning system to monitor patients suffering from dementia using ambient assisted living,” in *Information Society (i-Society), 2010 International Conference on*, 2010, pp. 92–97.

[93] M. J. O’Grady, C. Muldoon, M. Dragone, R. Tynan, and G. M. P. O’Hare, “Towards evolutionary ambient assisted living systems,” *Journal of Ambient Intelligence and Humanized Computing*, vol. 1, no. 1, pp. 15–29, 2010.

[94] C. Peter, G. Bieber, and B. Urban, “Affect- and behaviour-related assistance for families in the home environment,” in *Proceedings of the 3rd International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA ’10, 2010, pp. 47:1–47:5.

[95] J. Rashid, “Towards the development of an ubiquitous networked robot systems for ambient assisted living,” in *Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC), 2010 IEEE International Conference on*, 2010, pp. 359–366.

[96] P. Rashidi and D. J. Cook, “Mining and monitoring patterns of daily routines for assisted living in real world settings,” in *Proceedings of the 1st ACM International Health Informatics Symposium*, ser. IHI ’10, 2010, pp. 336–345.

[97] G. Rodrigues, V. Alves, R. Franklin, and L. Laranjeira, “Dependability analysis in the ambient assisted living domain: An exploratory case study,” in *Software Components, Architectures and Reuse (SBCARS), 2010 Fourth Brazilian Symposium on*, 2010, pp. 150–159.

[98] I. Sánchez-Tato, J. Senciales, J. Salinas, L. Fanucci, G. Pardini, F. Costalli, S. Dalmiani, J. de la Higuera, Z. Vukovic, and Z. Cicigoj, “Health @ home: A telecare system for patients with chronic heart failure,” in *Broadband and Biomedical Communications (IB2Com), 2010 Fifth International Conference on*, 2010, pp. 1–5.

[99] K. Sim, G.-E. Yap, C. Phua, J. Biswas, A. A. P. Wai, A. Tolstikov, W. Huang, and P. Yap, “Improving the accuracy of erroneous-plan recognition system for activities of daily living,” in *e-Health Networking Applications and Services (Healthcom), 2010 12th IEEE International Conference on*, 2010, pp. 28–35.

[100] N. Spanoudakis, B. Grabner, C. Kotsiopoulou, O. Lymperopoulou, V. Moser-Siegmeth, S. Pantelopoulos, P. Sakka, and P. Moraitis, “A novel architecture and process for ambient assisted living - the hera approach,” in *Information Technology and Applications in Biomedicine (ITAB), 2010 10th IEEE International Conference on*, 2010, pp. 1–4.

[101] A. Toth, G. Bakonyi-Kiss, and L. Vajda, “A system prototype description for health services and ambient assisted living,” in *Telecommunications: The Infrastructure for the 21st Century (WTC), 2010*, 2010, pp. 1–6.

[102] A. Valls, K. Gibert, D. Sánchez, and M. Batet, “Using ontologies for structuring organizational knowledge in home care assistance,” *International Journal of Medical Informatics*, vol. 79, no. 5, pp. 370–387, 2010.

[103] D. D. Vergados, "Service personalization for assistive living in a mobile ambient healthcare-networked environment," *Personal and Ubiquitous Computing*, vol. 14, no. 6, pp. 575–590, 2010.

[104] M. Vergara, P. Díaz-Hellín, J. Fontecha, R. Hervás, C. Sánchez-Barba, C. Fuentes, and J. Bravo, "Mobile prescription: An NFC-based proposal for AAL," in *Near Field Communication (NFC), 2010 Second International Workshop on*, 2010, pp. 27–32.

[105] M. R. Yuce, "Implementation of wireless body area networks for healthcare systems," *Sensors and Actuators A: Physical*, vol. 162, no. 1, pp. 116–129, 2010.

[106] H. Al Shamsi, S. Ahmed, and F. Redha, "Monitoring device for elders in UAE," in *Current Trends in Information Technology (CTIT), 2011 International Conference and Workshop on*, 2011, pp. 32–36.

[107] F. Aiello, F. Bellifemine, G. Fortino, S. Galzarano, and R. Gravina, "An agent-based signal processing in-node environment for real-time human activity monitoring based on wireless body sensor networks," *Engineering Applications of Artificial Intelligence*, vol. 24, no. 7, pp. 1147– 161, 2011.

[108] D. Anastasiou, "Speech-to-speech translation in an assisted living lab," in *Proceedings of the 4th International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '11, 2011, pp. 60:1–60:2.

[109] B. Ando, S. Baglio, S. La Malfa, A. Pistorio, and C. Trigona, "A smart wireless sensor network for AAL," in *Measurements and Networking Proceedings (M N), 2011 IEEE International Workshop on*, 2011, pp. 122–125.

[110] C. Armbrust, S. A. Mehdi, M. Reichardt, J. Koch, and K. Berns, "Using an autonomous robot to maintain privacy in assistive environments," *Sec. and Commun. Netw.*, vol. 4, no. 11, pp. 1275–1293, 2011.

[111] A. Belbachir, S. Schraml, and A. Nowakowska, "Event-driven stereo vision for fall detection," in *Computer Vision and Pattern Recognition Workshops (CVPRW), 2011 IEEE Computer Society Conference on*, 2011, pp. 78–83.

[112] A. Belbachir, A. Nowakowska, S. Schraml, G. Wiesmann, and R. Sablatnig, "Event-driven feature analysis in a 4d spatiotemporal representation for ambient assisted living," in *Computer Vision Workshops (ICCV Workshops), 2011 IEEE International Conference on*, 2011, pp. 1570–1577.

[113] S. Bhattacharyya, "Context aware healthcare application," *International Journal of Computer Applications*, vol. 22, no. 3, pp. 7–12, 2011.

[114] V. Bianchi, F. Grossi, I. De Munari, and P. Ciampolini, "MuSA: A multisensor wearable device for AAL," in *Computer Science and Information Systems (FedCSIS), 2011 Federated Conference on*, 2011, pp. 375–380.

[115] N. M. Boers, D. Chodos, P. Gburzynski, L. Guirguis, J. Huang, R. Lederer, L. Liu, I. Nikolaidis, C. Sadowski, and E. Stroulia, "The smart condo project: services for independent living," in *E-Health, Assistive Technologies and Applications for Assisted Living: Challenges and Solutions.* IGI Global, 2011, pp. 289–314.

[116] B.-h. Busch, R. Welge, and L. Saxony, "Domain specific services for continuous diagnoses in the context of ambient assisted living—AAL," in *Proceedings of the IADIS European Conference on Data Mining 2011, Part of the IADIS Multi Conference on Computer Science and Information Systems 2011, MCCSIS 2011*, 2011.

[117] W. Carswell, J. Augusto, M. Mulvenna, J. Wallace, S. Martin, P. McCullagh, H. Zheng, H. Wang, K. McSorley, B. Taylor, and W. Jeffers, "The NOCTURNAL ambient assisted living system," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*, 2011, pp. 208–209.

[118] P. Chahuara, F. Portet, and M. Vacher, "Location of an inhabitant for domotic assistance through fusion of audio and non-visual data," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*, 2011, pp. 242–245.

[119] S. Chiriac, B. Saurer, G. Stummer, and C. Kunze, "Introducing a low-cost ambient monitoring system for activity recognition," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*, 2011, pp. 340–345.

[120] J. Criel, M. Geerts, L. Claeys, and F. Kawsar, "Empowering elderly end-users for ambient programming: The tangible way," in *Advances in Grid and Pervasive Computing*, ser. LNCS. Springer Berlin Heidelberg, 2011, vol. 6646, pp. 94–104.

[121] E. Dovgan, M. Luštrek, B. Pogorelc, A. Gradišek, H. Burger, and M. Gams, "Intelligent elderly-care prototype for fall and disease detection," *Zdravniški Vestnik*, vol. 80, no. 11, pp. 824–831, 2011.

[122] C. Fabbricatore, M. Zucker, S. Ziganki, and A. Karduck, "Towards an unified architecture for smart home and ambient assisted living solutions: A focus on elderly people," in *Digital Ecosystems and Technologies Conference (DEST), 2011 Proceedings of the 5th IEEE International Conference on*, 2011, pp. 305–311.

[123] C. Fernández-Llatas, J. Garcia-Gomez, J. Vicente, J. Naranjo, M. Robles, J. Benedi, and V. Traver, "Behaviour patterns detection for persuasive design in nursing homes to help dementia patients," in *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*, 2011, pp. 6413–6417.

[124] A. Hochgatterer, L. Roedl, A. Martinez, I. Etxeberria, E. Aldaz, B. Wockl, and J. Bund, "Requirements for a behaviour pattern based assistant for early detection and management of neurodegenerative diseases," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*, 2011, pp. 346–353.

[125] S. Hossain, P. Valente, K. Hallenborg, and Y. Demazeau, "User modeling for activity recognition and support in ambient assisted living," in *Information Systems and Technologies (CISTI), 2011 6th Iberian Conference on*, 2011, pp. 1–4.

[126] C.-C. Hsu and J.-H. Chen, "A novel sensor-assisted rfid-based indoor tracking system for the elderly living alone," *Sensors*, vol. 11, no. 11, pp. 10 094–10 113, 2011.

[127] R. Istepanian, A. Sungoor, A. Faisal, and N. Philip, "Internet of m-health things "m-iot"," in *Assisted Living 2011, IET Seminar on*, 2011, pp. 1–3.

[128] A. J. Jara, M. A. Zamora, and A. F. Skarmeta, "An internet of things-based personal device for diabetes therapy management in ambient assisted living (AAL)," *Personal Ubiquitous Comput.*, vol. 15, no. 4, pp. 431–440, 2011.

[129] M. Kaczmarek, J. Ruminski, and A. Bujnowski, "Multimodal platform for continuous monitoring of elderly and disabled," in *Computer Science and Information Systems (FedCSIS), 2011 Federated Conference on*, 2011, pp. 393–400.

[130] B. Kaluža, E. Dovgan, V. Mirchevska, B. Cvetković, M. Luštrek, and M. Gams, "A multi-agent system for remote eldercare," in *Trends in Practical Applications of Agents and Multiagent Systems*, ser. Advances in Intelligent and Soft Computing. Springer Berlin Heidelberg, 2011, vol. 90, pp. 33–40.

[131] M. Lawo and O. Herzog, "Wearable computing for medical applications: Personal health system for parkinson's disease patients," in *Emerging Technologies for a Smarter World (CEWIT), 2011 8th International Conference Expo on*, 2011, pp. 1–5.

[132] K. Lee, T. Lunney, K. Curran, and J. Santos, "Context-aware support for assistive systems and services," in *Assisted Living 2011, IET Seminar on*, 2011, pp. 1–4.

[133] A. Leone, G. Diraco, and P. Siciliano, "Topological and volumetric posture recognition with active vision sensor in aal contexts," in *Advances in Sensors and Interfaces (IWASI), 2011 4th IEEE International Workshop on*, 2011, pp. 110–114.

[134] T. Linner, M. Kranz, L. Roalter, and T. Bock, "Robotic and ubiquitous technologies for welfare habitat," *Journal of Habitat Engineering*, vol. 3, no. 1, pp. 101–110, 2011.

[135] E. Martín, P. Haya, and R. M. Carro, "User modeling and adaptation for daily routines: Providing assistance to people with special and specific needs," in *Advances in User Modeling, UMAP 2011 Workshops*, ser. LNCS. Springer Berlin Heidelberg, 2011, vol. 7138, pp. 304–308.

[136] J. F. Martínez, M. S. Familiar, I. Corredor, A. B. García, S. Bravo, and L. López, "Composition and deployment of e-health services over wireless sensor networks," *Mathematical and Computer Modelling*, vol. 53, no. 3Ű4, pp. 485–503, 2011.

[137] M. R. McGee-Lennon, M. K. Wolters, and S. Brewster, "User-centred multimodal reminders for assistive living," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '11, 2011, pp. 2105–2114.

[138] J. McNaull, J. Augusto, M. Mulvenna, and P. McCullagh, "Multi-agent interactions for ambient assisted living," in *Intelligent Environments (IE), 2011 7th International Conference on*, 2011, pp. 310–313.

[139] R. Miñón and J. Abascal, "Supportive adaptive user interfaces inside and outside the home," in *Proceedings of the 19th International Conference on Advances in User Modeling*, ser. UMAP'11, 2011, pp. 320–334.

[140] A. Muñoz, J. C. Augusto, A. Villa, and J. A. Botía, "Design and evaluation of an ambient assisted living system based on an argumentative multi-agent system," *Personal and Ubiquitous Computing*, vol. 15, no. 4, pp. 377–387, 2011.

[141] M. Mulvenna, W. Carswell, P. McCullagh, J. Augusto, H. Zheng, P. Jeffers, H. Wang, and S. Martin, "Visualization of data for ambient assisted living services," *Communications Magazine, IEEE*, vol. 49, no. 1, pp. 110–117, 2011.

[142] H. Nikamalfard, H. Zheng, H. Wang, M. Mulvenna, P. McCullagh, and P. Jeffers, "A sleep pattern analysis and visualization system to support people with early dementia," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*, 2011, pp. 510–513.

[143] P. Panek, W. Hlauschek, M. Schrenk, K. Werner, and W. Zagler, "Experiences from user centric engineering of ambient assisted living technologies in the living lab schwechat," in *Concurrent Enterprising (ICE), 2011 17th International Conference on*, 2011, pp. 1–8.

[144] P. Pivato, S. Dalpez, D. Macii, and D. Petri, "A wearable wireless sensor node for body fall detection," in *Measurements and Networking Proceedings (M N), 2011 IEEE International Workshop on*, 2011, pp. 116–121.

[145] A. Reichman and M. Zwiling, "The architecture of ambient assisted living system," in *Microwaves, Communications, Antennas and Electronics Systems (COMCAS), 2011 IEEE International Conference on*, 2011, pp. 1–4.

[146] M. D. Rodríguez, J. P. García-Vázquez, and A. G. Andrade, "Design dimensions of ambient information systems to facilitate the development of aal environments," in *Proceedings of the 4th International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '11, 2011, pp. 4:1–4:7.

[147] A. Rodrigues, C. Resende, L. Carvalho, P. Saleiro, and F. Abrantes, "Performance analysis of an adaptable home healthcare solution," in *e-Health Networking Applications and Services (Healthcom), 2011 13th IEEE International Conference on*, 2011, pp. 134–141.

[148] A. Sikora, "Wireless network and gateway architectures for home care applications," in *Intelligent Data Acquisition and Advanced Computing Systems (IDAACS), 2011 IEEE 6th International Conference on*, vol. 2, 2011, pp. 832–836.

[149] C.-J. Su and C.-Y. Wu, "JADE implemented mobile multi-agent based, distributed information platform for pervasive health care monitoring," *Applied Soft Computing*, vol. 11, no. 1, pp. 315–325, 2011.

[150] Z. Szeman and C. Kucsera, "HAPPY AGEING: Users' expectations," in *Proceedings of the 4th International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '11, 2011, pp. 62:1–62:4.

[151] V. Venkatesh and T. Park, "Healthcare data fusion and presentation using service-oriented architecture (soa) orchestration mechanism," *IJCA Special Issue on Artificial Intelligence Techniques-Novel Approaches & Practical Applications*, vol. 2, pp. 17–23, 2011.

[152] J. J. Villacorta, M. I. Jiménez, L. d. Val, and A. Izquierdo, "A configurable sensor network applied to ambient assisted living," *Sensors*, vol. 11, no. 11, pp. 10 724–10 737, 2011.

[153] J. Wan, C. Byrne, G. O'Hare, and M. O'Grady, "Orange alerts: Lessons from an outdoor case study," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*, 2011, pp. 446–451.

[154] Y.-h. Wu, M. Chetouani, V. Cristancho-Lacroix, J. Le, B. Le Pevedic, D. Duhaut, C. Granata, and A.-s. Rigaud, "ROBADOM: An assistive robot for the elderly with mild cognitive impairment: System design and usersŠ perspectives," in *5th Companion Robotics Institute Workshop AAL User-Centric Companion Robotics*, 2011.

[155] F. Zhou, J. Jiao, S. Chen, and D. Zhang, "A case-driven ambient intelligence system for elderly in-home assistance applications," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 41, no. 2, pp. 179–189, 2011.

[156] M. Ziefle, C. Rocker, and A. Holzinger, "Perceived usefulness of assistive technologies and electronic services for ambient assisted living," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2011 5th International Conference on*, 2011, pp. 585–592.

[157] B. Abibullaev, J. An, S.-H. Lee, S.-H. Jin, and J.-I. Moon, "A study on the bci-robot assisted stroke rehabilitation framework using brain hemodynamic signals," in *Ubiquitous Robots and Ambient Intelligence (URAI), 2012 9th International Conference on*, 2012, pp. 500–504.

[158] W. Allègre, T. Burger, P. Berruet, and J.-Y. Antoine, "A non-intrusive monitoring system for ambient assisted living service delivery," in *Impact Analysis of Solutions for Chronic Disease Prevention and Management*, ser. LNCS. Springer Berlin Heidelberg, 2012, vol. 7251, pp. 148–156.

[159] D. Anastasiou, C. Jian, and D. Zhekova, "Speech and gesture interaction in an ambient assisted living lab," in *Proceedings of the 1st Workshop on Speech and Multimodal Interaction in Assistive Environments*, ser. SMIAE '12, 2012, pp. 18–27.

[160] B. Ando, "Measurement technologies to sense "users in the environment" for ambient assisted living," *Instrumentation Measurement Magazine, IEEE*, vol. 15, no. 6, pp. 45–49, 2012.

[161] M. Aquilano, F. Cavallo, M. Bonaccorsi, R. Esposito, E. Rovini, M. Filippi, D. Esposito, P. Dario, and M. Carrozza, "Ambient assisted living and ageing: Preliminary results of RITA project," in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, 2012, pp. 5823–5826.

[162] I. Ayala, M. Amor, and L. Fuentes, "Self-StarMAS: A multi-agent system for the self-management of AAL applications," in *Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2012 Sixth International Conference on*, 2012, pp. 901–906.

[163] ——, "Self-configuring agents for ambient assisted living applications," *Personal and Ubiquitous Computing*, vol. 17, no. 6, pp. 1159–1169, 2012.

[164] J. Baskar, H. Lindgren, D. Surie, C. Yan, and F. Yekeh, "Personalisation and user models for support in daily living," in *The 27th annual workshop of the Swedish Artificial Intelligence Society (SAIS) 2012*, 2012, pp. 7–16.

[165] K. Benghazi, M. V. Hurtado, M. J. Hornos, M. L. Rodríguez, C. Rodríguez-Domínguez, A. B. Pelegrina, and M. J. Rodríguez-Fórtiz, "Enabling correct design and formal analysis of ambient assisted living systems," *Journal of Systems and Software*, vol. 85, no. 3, pp. 498–510, 2012.

[166] M. Bocca, S. Gupta, O. Kaltiokallio, B. Mager, Q. Tate, S. Kasera, N. Patwari, and S. Venkatasubramanian, "RF-based device-free localization and tracking for ambient assisted living," in *Proceedings of the EvAAL Workshop*, 2012, pp. 1–4.

[167] J. A. Botia, A. Villa, and J. Palma, "Ambient assisted living system for in-home monitoring of healthy independent elders," *Expert Systems with Applications*, vol. 39, no. 9, pp. 8136–8148, 2012.

[168] A. Bourke, S. Prescher, F. Koehler, V. Cionca, C. Tavares, S. Gomis, V. Garcia, and J. Nelson, "Embedded fall and activity monitoring for a wearable ambient assisted living solution for older adults," in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, 2012, pp. 248–251.

[169] B. H. Busch and R. Welge, "Unobtrusive vital sign acquisition in the domain of AAL," *Biomedical engineering/Biomedizinische Technik*, vol. 57, pp. 1085–1088, 2012.

[170] S. Chiriac, N. Roll, J. Parada, and B. Rosales, "Towards combining validation concepts for short and long-term ambient health monitoring," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on*, 2012, pp. 268–274.

[171] A. Coronato, "Uranus: A middleware architecture for dependable AAL and vital signs monitoring applications," *Sensors*, vol. 12, no. 3, p. 3145, 2012.

[172] Ângelo Costa, J. C. Castillo, P. Novais, A. Fernández-Caballero, and R. Simoes, "Sensor-driven agenda for intelligent home care of the elderly," *Expert Systems with Applications*, vol. 39, no. 15, pp. 12 192 – 12 204, 2012.

[173] H. Cruz-Sanchez, L. Havet, M. Chehaider, and Y.-Q. Song, "MPIGate: A solution to use heterogeneous networks for assisted living applications," in *Ubiquitous Intelligence Computing and 9th International Conference on Autonomic Trusted Computing (UIC/ATC), 2012 9th International Conference on*, 2012, pp. 104–111.

[174] D. De, S. Tang, W.-Z. Song, D. Cook, and S. K. Das, "ActiSen: Activity-aware sensor network in smart environments," *Pervasive and Mobile Computing*, vol. 8, no. 5, pp. 730 – 750, 2012.

[175] S. Eisa and A. Moreira, "Requirements and metrics for location and tracking for ambient assisted living," in *Indoor Positioning and Indoor Navigation (IPIN), 2012 International Conference on*, 2012, pp. 1–7.

[176] G. Fortino, R. Gravina, and A. Guerrieri, "Agent-oriented integration of body sensor networks and building sensor networks," in *Computer Science and Information Systems (FedCSIS), 2012 Federated Conference on*, 2012, pp. 1207–1214.

[177] D. Gachet Páez, F. Aparicio, M. de Buenaga, and V. Padrón, "Personalized health care system with virtual reality rehabilitation and appropriate information for seniors," *Sensors*, vol. 12, no. 5, p. 5502, 2012.

[178] J. Garcia-Rodriguez and M. Cazorla Quevedo, *Robotic Vision: Technologies for Machine Learning and Vision Applications.* IGI Global, 2012.

[179] S. Helal, C. Chen, E. Kim, R. Bose, and C. Lee, "Toward an ecosystem for developing and programming assistive environments," *Proceedings of the IEEE*, vol. 100, no. 8, pp. 2489–2504, 2012.

[180] D. Henriques, V. Basto-Fernandes, A. Seco, M. Felgueiras, and A. Pereira, "LOSTE-location oriented system technology for the elder," *Procedia Technology*, vol. 5, pp. 575–580, 2012.

[181] J. Hoey, C. Boutilier, P. Poupart, P. Olivier, A. Monk, and A. Mihailidis, "People, sensors, decisions: Customizable and adaptive technologies for assistance in healthcare," *ACM Trans. Interact. Intell. Syst.*, vol. 2, no. 4, pp. 20:1–20:36, 2012.

[182] A. Jara, P. Lopez, D. Fernández, B. Ubeda, M. Zamora, and A. Skarmeta, "Interaction of patients with breathing problems through NFC in ambient assisted living environments," in *Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2012 Sixth International Conference on*, 2012, pp. 892–897.

[183] A. Jara, M. Zamora, and A. Skarmeta, "Knowledge acquisition and management architecture for mobile and personal health environments based on the internet of things," in *Trust, Security and Privacy in Computing and Communications (TrustCom), 2012 IEEE 11th International Conference on*, 2012, pp. 1811–1818.

[184] J. Kropf, L. Roedl, and A. Hochgatterer, "A modular and flexible system for activity recognition and smart home control based on nonobtrusive sensors," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on*, 2012, pp. 245–251.

[185] O. Kwon, J. M. Shim, and G. Lim, "Single activity sensor-based ensemble analysis for health monitoring of solitary elderly people," *Expert Systems with Applications*, vol. 39, no. 5, pp. 5774–5783, 2012.

[186] M. Larizza, I. Zukerman, F. Bohnert, R. A. Russell, L. Busija, D. W. Albrecht, and G. Rees, "Studies to determine user requirements regarding in-home monitoring systems," in *User Modeling, Adaptation, and Personalization*, ser. LNCS. Springer Berlin Heidelberg, 2012, vol. 7379, pp. 139–150.

[187] A. MacWilliams, R. Pohle, M. Roshchin, I. Steinke, and F. Waidelich, "Automated assistance services: Experience from the smartsenior project," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on*, 2012, pp. 275–282.

[188] C. Mayer, M. Morandell, M. Gira, K. Hackbarth, M. Petzold, and S. Fagel, "AALuis, a user interface layer that brings device independence to users of AAL systems," in *Computers Helping People with Special Needs*, ser. LNCS. Springer Berlin Heidelberg, 2012, vol. 7382, pp. 650–657.

[189] J. McNaull, J. Augusto, M. Mulvenna, and P. McCullagh, "Multi-agent system feedback and support for ambient assisted living," in *Intelligent Environments (IE), 2012 8th International Conference on*, 2012, pp. 319–322.

[190] I. Mocanu and A. M. Florea, "A multi-agent supervising system for smart environments," in *Proceedings of the 2Nd International Conference on Web Intelligence, Mining and Semantics*, ser. WIMS '12, 2012, pp. 55:1–55:4.

[191] S. Mowafey and S. Gardner, "A novel adaptive approach for home care ambient intelligent environments with an emotion-aware system," in *Control (CONTROL), 2012 UKACC International Conference on*, 2012, pp. 771–777.

[192] A. Muñoz, E. Serrano, A. Villa, M. Valdés, and J. A. Botía, "An approach for representing sensor data to validate alerts in ambient assisted living," *Sensors*, vol. 12, no. 5, pp. 6282–6306, 2012.

[193] H. Pensas, K. Liolis, A.-M. Vainio, B. Wöckl, T. Kivimäki, and J. Vanhala, "Ambient communication and sense of presence device," in *Proceeding of the 16th International Academic MindTrek Conference*, ser. MindTrek '12, 2012, pp. 214–216.

[194] C. G. Pires, F. M. Pinto, V. D. Teixeira, J. Freitas, and M. S. Dias, "Living home center–a personal assistant with multimodal interaction for elderly and mobility impaired e-inclusion," in *International Conference on Computational Processing of the Portuguese Language, PROPOR 2012*, 2012.

[195] S. Prescher, A. Bourke, F. Koehler, A. Martins, H. Sereno Ferreira, T. Boldt Sousa, R. Castro, A. Santos, M. Torrent, S. Gomis, M. Hospedales, and J. Nelson, "Ubiquitous ambient assisted living solution to promote safer independent living in older adults suffering from co-morbidity," in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, 2012, pp. 5118–5121.

[196] M. D. Rodríguez and J. Favela, "Assessing the SALSA architecture for developing agent-based ambient computing applications," *Science of Computer Programming*, vol. 77, no. 1, pp. 46–65, 2012.

[197] C. Seguin, F. De Lamotte, and J.-L. Philippe, "System services partitioning in ambient assisted living environment," in *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, ser. UbiComp '12, 2012, pp. 778–781.

[198] D. Šimšík, A. Galajdová, D. Siman, J. Bujnák, M. Andrášová, and M. Novák, "MonAMI platform in elderly household environment," in *Computers Helping People with Special Needs*, ser. LNCS. Springer Berlin Heidelberg, 2012, vol. 7383, pp. 419–422.

[199] S. Spinsante and E. Gambi, "Home automation systems control by head tracking in aal applications," in *Satellite Telecommunications (ESTEL), 2012 IEEE First AESS European Conference on*, 2012, pp. 1–6.

[200] N. Suryadevara, A. Gaddam, R. Rayudu, and S. Mukhopadhyay, "Wireless sensors network based safe home to care elderly people: Behaviour detection," *Sensors and Actuators A: Physical*, vol. 186, pp. 277–283, 2012.

[201] G. van de Ven, I. Draskovic, E. M. Adang, R. A. Donders, A. Post, S. U. Zuidema, R. T. Koopmans, and M. J. Vernooij-Dassen, "Improving person-centred care in nursing homes through dementia-care mapping: design of a cluster-randomised controlled trial," *BMC Geriatrics*, vol. 12, no. 1, pp. 1–9, 2012.

[202] V. Venkatesh, V. Vaithyanathan, M. Kumar, and P. Raj, "A secure ambient assisted living (aal) environment: An implementation view," in *Computer Communication and Informatics (ICCCI), 2012 International Conference on*, 2012, pp. 1–7.

[203] J. Winkley, P. Jiang, and W. Jiang, "Verity: an ambient assisted living platform," *Consumer Electronics, IEEE Transactions on*, vol. 58, no. 2, pp. 364–373, 2012.

[204] X. Xing and O. Herzog, "Towards adaptive decision support for individual persons suffering from chronic diseases," in *Computer and Information Science (ICIS), 2012 IEEE/ACIS 11th International Conference on*, 2012, pp. 225–229.

[205] H. Alerndar, H. Ertan, O. Incel, and C. Ersoy, "ARAS human activity datasets in multiple homes with multiple residents," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2013 7th International Conference on*, 2013, pp. 232–235.

[206] R. Alesii, F. Graziosi, S. Marchesani, C. Rinaldi, M. Santic, and F. Tarquini, "Short range wireless solutions enabling ambient assisted living to support people affected by the down syndrome," in *EUROCON, 2013 IEEE*, 2013, pp. 340–346.

[207] H. Aloulou, M. Mokhtari, T. Tiberghien, J. Biswas, C. Phua, J. H. Kenneth Lin, and P. Yap, "Deployment of assistive living technology in a nursing home environment: methods and lessons learned," *BMC Medical Informatics and Decision Making*, vol. 13, no. 1, pp. 1–17, 2013.

[208] M. Bähr, S. Klein, S. Diewald, C. Haag, G. Hofstetter, M. Khoury, D. Kurz, A. Winkler, A. König, N. Holzer, M. Siegrist, A. Pressler, L. Roalter, T. Linner, M. Heuberger, K. Wessig, M. Kranz, and T. Bock, "PASSAge: Personalized mobility, assistance and service systems in an ageing society," in *Ambient Assisted Living*, ser. Advanced Technologies and Societal Change. Springer Berlin Heidelberg, 2013, pp. 109–119.

[209] A. S. Billis, E. I. Papageorgiou, C. Frantzidis, E. I. Konstantinidis, and P. D. Bamidis, "Towards a hierarchically-structured decision support tool for improving seniors' independent living: The usefil decision support system," in *Proceedings of the 6th International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '13, 2013, pp. 27:1–27:4.

[210] A. Bleda, R. Maestre, G. Santa, S. Pellicer, A. Jara, and A. Gomez Skarmeta, "Evolution towards better AAL environments," in *Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2013 Seventh International Conference on*, 2013, pp. 518–523.

[211] T. Bock, K. Sarah, D. Stefan, G. Barbara, W. Kerstin, and M. Kranz, "Better living by technical assistance and mobility in an aging society," in *4th European Conference on Technically Assisted Rehabilitation (TAR 2013)*, 2013.

[212] W. Bourennane, Y. Charlon, F. Bettahar, E. Campo, and D. Esteve, "Homecare monitoring system: A technical proposal for the safety of the elderly experimented in an alzheimer's care unit," *IRBM*, vol. 34, no. 2, pp. 92 – 100, 2013.

[213] D. Burmeister, A. Schrader, and D. Carlson, "A modular framework for ambient health monitoring," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2013 7th International Conference on*, 2013, pp. 401–404.

[214] S. Chernbumroong, S. Cang, A. Atkins, and H. Yu, "Elderly activities recognition and classification for applications in assisted living," *Expert Systems with Applications*, vol. 40, no. 5, pp. 1662 – 1674, 2013.

[215] A. Coronato and G. De Pietro, "Situation awareness in applications of ambient assisted living for cognitive impaired people," *Mob. Netw. Appl.*, vol. 18, no. 3, pp. 444–453, 2013.

[216] J. Dunkel, R. Bruns, and S. Stipkovic, "Event-based smartphone sensor processing for ambient assisted living," in *Autonomous Decentralized Systems (ISADS), 2013 IEEE Eleventh International Symposium on*, 2013, pp. 1–6.

[217] J. L. Falcó, E. Vaquerizo, L. Lain, J. I. Artigas, and A. Ibarz, "AmI and deployment considerations in AAL services provision for elderly independent living: The MonAMI project," *Sensors*, vol. 13, no. 7, pp. 8950–8976, 2013.

[218] A. Forkan, I. Khalil, and Z. Tari, "CoCaMAAL: A cloud-oriented context-aware middleware in ambient assisted living," *Future Generation Computer Systems*, vol. 35, pp. 114–127, 2013.

[219] K. Ganapathy, B. Priya, B. Priya, Dhivya, V. Prashanth, and V. Vaidehi, "SOA framework for geriatric remote health care using wireless sensor network," *Procedia Computer Science*, vol. 19, pp. 1012–1019, 2013.

[220] F. Goncalves, J. Macedo, M. Nicolau, and A. Santos, "Security architecture for mobile e-health applications in medication control," in *Software, Telecommunications and Computer Networks (SoftCOM), 2013 21st International Conference on*, 2013, pp. 1–8.

[221] A. Grguric, M. Mosmondor, M. Kusek, C. Stocklow, and D. Salvi, "Introducing gesture interaction in the ambient assisted living platform universaal," in *Telecommunications (ConTEL), 2013 12th International Conference on*, 2013, pp. 215–222.

[222] A. Kealy, K. McDaid, J. Loane, L. Walsh, and J. Doyle, "Derivation of night time behaviour metrics using ambient sensors," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2013 7th International Conference on*, 2013, pp. 33–40.

[223] V. Kilintzis, I. Moulos, V. Koutkias, and N. Maglaveras, "Exploiting the universaal platform for the design and development of a physical activity monitoring application," in *Proceedings of the 6th International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA '13, 2013, pp. 16:1–16:4.

[224] A. Leone, G. Diraco, and P. Siciliano, "TOF sensor network for AAL monitoring services," *Procedia Computer Science*, vol. 19, pp. 511–515, 2013.

[225] D. López-de Ipiña, B. Klein, S. Vanhecke, and J. Perez-Velasco, "Towards ambient assisted cities and citizens," in *Advanced Information Networking and Applications Workshops (WAINA), 2013 27th International Conference on*, 2013, pp. 1343–1348.

[226] S. Martin, J. C. Augusto, P. McCullagh, W. Carswell, H. Zheng, H. Wang, J. Wallace, and M. Mulvenna, "Participatory research to design a novel telehealth system to support the night-time needs of people with dementia: NOCTURNAL," *International Journal of Environmental Research and Public Health*, vol. 10, no. 12, p. 6764, 2013.

[227] D. Meersman, F. Hadzic, J. Hughes, I. Razo-Zapata, and P. De Leenheer, "Health service discovery and composition in ambient assisted living: the australian type 2 diabetes case study," in *System Sciences (HICSS), 2013 46th Hawaii International Conference on*, 2013, pp. 1337–1346.

[228] M. Petzold, F. Barbabella, J. Bobeth, D. Kern, C. Mayer, and M. Morandell, “Towards an ambient assisted living user interaction taxonomy,” in *CHI ’13 Extended Abstracts on Human Factors in Computing Systems*, ser. CHI EA ’13, 2013, pp. 49–54.

[229] F. Portet, M. Vacher, C. Golanski, C. Roux, and B. Meillon, “Design and evaluation of a smart home voice interface for the elderly: Acceptability and objection aspects,” *Personal Ubiquitous Comput.*, vol. 17, no. 1, pp. 127–144, 2013.

[230] A. Rocha, A. Martins, J. C. F. Junior, M. N. K. Boulos, M. E. Vicente, R. Feld, P. van de Ven, J. Nelson, A. Bourke, G. ÓLaighin, C. Sdogati, A. Jobes, L. Narvaiza, and A. Rodríguez-Molinero, “Innovations in health care services: The CAALYX system,” *International Journal of Medical Informatics*, vol. 82, no. 11, pp. e307–e320, 2013.

[231] P. Sernani, A. Claudi, L. Palazzo, G. Dolcini, and A. Dragoni, “Home care expert systems for ambient assisted living: A multi-agent approach,” in *The Challenge of Ageing Society: Technological Roles and Opportunities for Artificial Intelligence*, ser. CEUR Workshop Proceedings, vol. 1122, 2013.

[232] E. Stav, S. Walderhaug, M. Mikalsen, S. Hanke, and I. Benc, “Development and evaluation of soa-based AAL services in real-life environments: A case study and lessons learned,” *International Journal of Medical Informatics*, vol. 82, no. 11, pp. e269–e293, 2013.

[233] F. Steinke, T. Fritsch, A. Hertzer, H. Tautz, and S. Zickwolf, “Expected reliability of everyday- and ambient assisted living technologies,” *International Journal of Advanced Computer Science and Applications(IJACSA)*, vol. 4, 2013.

[234] M. Terroso, R. Freitas, J. Gabriel, A. Torres Marques, and R. Simoes, “Active assistance for senior healthcare: A wearable system for fall detection,” in *Information Systems and Technologies (CISTI), 2013 8th Iberian Conference on*, 2013, pp. 1–6.

[235] V. Vaidehi, M. Vardhini, H. Yogeshwaran, G. Inbasagar, R. Bhargavi, and C. Hemalatha, “Agent based health monitoring of elderly people in indoor environments using wireless sensor networks,” *Procedia Computer Science*, vol. 19, pp. 64–71, 2013.

[236] S. Wagner, F. O. Hansen, C. F. Pedersen, M. Memon, F. H. Aysha, M. Mathissen, C. Nielsen, and O. L. Wesby, “CareStore platform for seamless deployment of ambient assisted living applications and devices,” in *Proceedings of the 7th International Conference on Pervasive Computing Technologies for Healthcare*, ser. PervasiveHealth ’13, 2013, pp. 240–243.

Bibliography

[1] W. Lutz, W. Sanderson, and S. Scherbov, “The coming acceleration of global population ageing,” *Nature*, vol. 451, no. 7179, pp. 716–719, 2008.

[2] T. Kleinberger, M. Becker, E. Ras, A. Holzinger, and P. Müller, “Ambient intelligence in assisted living: Enable elderly people to handle future interfaces,” in *Universal Access in Human-Computer Interaction. Ambient Interaction*, ser. Lecture Notes in Computer Science, C. Stephanidis, Ed. Springer Berlin Heidelberg, 2007, vol. 4555, pp. 103–112.

[3] H. Sun, V. De Florio, N. Gui, and C. Blondia, “Promises and challenges of ambient assisted living systems,” in *Information Technology: New Generations, 2009. ITNG ’09. Sixth International Conference on*, 2009, pp. 1201–1207.

[4] World Health Organization, *Global health and ageing*. Geneve: World Health Organization, 2011.

[5] K. Christensen, G. Doblhammer, R. Rau, and J. W. Vaupel, “Ageing populations: the challenges ahead,” *The Lancet*, vol. 374, no. 9696, pp. 1196–1208, 2009.

[6] F. Sadri, “Ambient intelligence,” *ACM Computing Surveys*, vol. 43, no. 4, pp. 1–66, 2011.

[7] A. F. Dragoni, “Stable communities and social networking for the netmedicine of tomorrow (or today),” *Acta Informatica Medica*, vol. 17, no. 2, pp. 161–164, 2009.

[8] D. J. Cook, J. C. Augusto, and V. R. Jakkula, “Ambient intelligence: Technologies, applications, and opportunities,” *Pervasive and Mobile Computing*, vol. 5, no. 4, pp. 277–298, 2009.

[9] D. Calvaresi, A. Sturm, E. Yu, and A. Dragoni, “Exploring domain requirements and technology solutions: A goal modeling approach,” in *7th International iStar Workshop, iStar 2014*, ser. CEUR Workshop Proceedings, vol. 1157, 2014.

[10] S. Ben Allouch, J. van Dijk, and O. Peters, "The acceptance of domestic ambient intelligence appliances by prospective users," in *Pervasive Computing*, ser. Lecture Notes in Computer Science, H. Tokuda, M. Beigl, A. Friday, A. Brush, and Y. Tobe, Eds. Springer Berlin Heidelberg, 2009, vol. 5538, pp. 77–94.

[11] C. Lee and J. F. Coughlin, "Older adults' adoption of technology: An integrated approach to identifying determinants and barriers," *Journal of Product Innovation Management*, vol. 32, no. 5, pp. 747–759, 2015.

[12] J. L. Crowley and J. Coutaz, "An ecological view of smart home technologies," in *Ambient Intelligence*, ser. Lecture Notes in Computer Science, B. De Ruyter, A. Kameas, P. Chatzimisios, and I. Mavrommati, Eds. Springer International Publishing, 2015, vol. 9425, pp. 1–16.

[13] M. Chan, E. Campo, D. Estève, and J.-Y. Fourniols, "Smart homes — current features and future perspectives," *Maturitas*, vol. 64, no. 2, pp. 90–97, 2009.

[14] M. Alam, M. Reaz, and M. Ali, "A review of smart homes—past, present, and future," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 42, no. 6, pp. 1190–1203, 2012.

[15] S. Brownsell, D. Bradley, S. Blackburn, F. Cardinaux, and M. Hawley, "A systematic review of lifestyle monitoring technologies," *Journal of Telemedicine and Telecare*, vol. 17, no. 4, pp. 185–189, 2011.

[16] D. Ding, R. A. Cooper, P. F. Pasquina, and L. Fici-Pasquina, "Sensor technology for smart homes," *Maturitas*, vol. 69, no. 2, pp. 131–136, 2011.

[17] B. Kitchenham, O. Pearl Brereton, D. Budgen, M. Turner, J. Bailey, and S. Linkman, "Systematic literature reviews in software engineering - a systematic literature review," *Information and Software Technology*, vol. 51, no. 1, pp. 7–15, 2009.

[18] I. Plaza, L. Martín, S. Martin, and C. Medrano, "Mobile applications in an aging society: Status and trends," *Journal of Systems and Software*, vol. 84, no. 11, pp. 1977–1988, 2011.

[19] G. Demiris, D. P. Oliver, J. Giger, M. Skubic, and M. Rantz, "Older adults' privacy considerations for vision based recognition methods of eldercare applications," *Technology and Health Care*, vol. 17, no. 1, pp. 41–48, 2009.

[20] M. Vacher, F. Portet, A. Fleury, and N. Noury, “Development of audio sensing technology for ambient assisted living: Applications and challenges,” *International Journal of E-Health and Medical Communications*, vol. 2, no. 1, pp. 34–54, 2011.

[21] M. Papazoglou, “Service-oriented computing: concepts, characteristics and directions,” in *Web Information Systems Engineering, 2003. WISE 2003. Proceedings of the Fourth International Conference on*, 2003, pp. 3–12.

[22] M. Wooldridge and N. R. Jennings, “Intelligent agents: theory and practice,” *The Knowledge Engineering Review*, vol. 10, pp. 115–152, 6 1995.

[23] F. L. Bellifemine, G. Caire, and D. Greenwood, *Developing multi-agent systems with JADE.* John Wiley & Sons, 2007.

[24] D. Calvaresi, A. Claudi, A. Dragoni, E. Yu, D. Accattoli, and P. Sernani, “A goal-oriented requirements engineering approach for the ambient assisted living domain,” in *Proceedings of the 7th ACM International Conference on Pervasive Technologies Related to Assistive Environments*, ser. ACM International Conference Proceeding Series, vol. 2014-May, 2014, pp. 20:1–20:4.

[25] M. Pollack, “Intelligent technology for an aging population: The use of AI to assist elders with cognitive impairment,” *AI Magazine*, vol. 26, no. 2, pp. 9–24, 2005.

[26] M. O’Grady, C. Muldoon, M. Dragone, R. Tynan, and G. O’Hare, “Towards evolutionary ambient assisted living systems,” *Journal of Ambient Intelligence and Humanized Computing*, vol. 1, no. 1, pp. 15–29, 2010.

[27] A. Mileo, D. Merico, S. Pinardi, and R. Bisiani, “A logical approach to home healthcare with intelligent sensor-network support,” *The Computer Journal*, vol. 53, no. 8, pp. 1257–1276, 2010.

[28] N. Suryadevara, A. Gaddam, R. Rayudu, and S. Mukhopadhyay, “Wireless sensors network based safe home to care elderly people: Behaviour detection,” *Sensors and Actuators A: Physical*, vol. 186, pp. 277–283, 2012.

[29] S. Chernbumroong, S. Cang, A. Atkins, and H. Yu, “Elderly activities recognition and classification for applications in assisted living,” *Expert Systems with Applications*, vol. 40, no. 5, pp. 1662–1674, 2013.

[30] A. Billis, E. Papageorgiou, C. Frantzidis, M. Tsatali, A. Tsolaki, and P. Bamidis, “A decision-support framework for promoting independent

living and ageing well," *Biomedical and Health Informatics, IEEE Journal of*, vol. 19, no. 1, pp. 199–209, 2015.

[31] S. Petridis, T. Giannakopoulos, and C. Spyropoulos, "A low cost pupillometry approach," *International Journal of E-Health and Medical Communications*, vol. 6, no. 4, pp. 49–61, 2015.

[32] M. B. Doumbouya, B. Kamsu-Foguem, H. Kenfack, and C. Foguem, "Combining conceptual graphs and argumentation for aiding in the teleexpertise," *Computers in Biology and Medicine*, vol. 63, pp. 157–168, 2015.

[33] A. Bourke, J. O'Brien, and G. Lyons, "Evaluation of a threshold-based tri-axial accelerometer fall detection algorithm," *Gait & Posture*, vol. 26, no. 2, pp. 194–199, 2007.

[34] A. Leone, G. Diraco, and P. Siciliano, "Detecting falls with 3D range camera in ambient assisted living applications: A preliminary study," *Medical Engineering & Physics*, vol. 33, no. 6, pp. 770–781, 2011.

[35] C. Zhu and W. Sheng, "Wearable sensor-based hand gesture and daily activity recognition for robot-assisted living," *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, vol. 41, no. 3, pp. 569–573, 2011.

[36] P. Sernani, A. Claudi, L. Palazzo, G. Dolcini, and A. Dragoni, "Home care expert systems for ambient assisted living: A multi-agent approach," in *The Challenge of Ageing Society: Technological Roles and Opportunities for Artificial Intelligence*, ser. CEUR Workshop Proceedings, vol. 1122, 2013.

[37] L. Palazzo, M. Rossi, A. F. Dragoni, A. Claudi, G. Dolcini, and P. Sernani, "A multi-agent architecture for health information systems," in *Frontiers in Artificial Intelligence and Applications, Advanced Methods and Technologies for Agent and Multi-Agent Systems.* IOSPress, 2013, vol. 252, pp. 375–384.

[38] A. Claudi, P. Sernani, and A. Dragoni, "Towards multi-agent health information systems," *International Journal of E-Health and Medical Communications*, vol. 6, no. 4, pp. 20–38, 2015.

[39] P. Sernani, A. Claudi, and A. Dragoni, "Combining artificial intelligence and netmedicine for ambient assisted living: A distributed BDI-based expert system," *International Journal of E-Health and Medical Communications*, vol. 6, no. 4, pp. 62–76, 2015.

[40] P. Rashidi and A. Mihailidis, “A survey on ambient-assisted living tools for older adults,” *Biomedical and Health Informatics, IEEE Journal of*, vol. 17, no. 3, pp. 579–590, 2013.

[41] P. Bresciani, A. Perini, P. Giorgini, F. Giunchiglia, and J. Mylopoulos, “Tropos: An agent-oriented software development methodology,” *Autonomous Agents and Multi-Agent Systems*, vol. 8, no. 3, pp. 203–236, 2004.

[42] N. R. Jennings, “On agent-based software engineering,” *Artificial Intelligence*, vol. 117, no. 2, pp. 277–296, 2000.

[43] M. R. Genesereth and S. P. Ketchpel, “Software agents,” *Communications of the ACM*, vol. 37, no. 7, pp. 48–ff., 1994.

[44] H. Suguri, “A standardization effort for agent technologies: The foundation for intelligent physical agents and its activities,” in *Systems Sciences, 1999. HICSS-32. Proceedings of the 32nd Annual Hawaii International Conference on*, vol. Track8, 1999, pp. 1–10.

[45] A. S. Rao and M. P. Georgeff, “BDI agents: From theory to practice,” in *Proceedings of the First International Conference on Multiagent Systems, June 12-14, 1995, San Francisco, California, USA*, 1995, pp. 312–319.

[46] J. Ferber, *Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence.* Addison-Wesley Professional, 1999.

[47] N. Jennings and M. Wooldridge, “Software agents,” *IEE Review*, vol. 42, no. 1, pp. 17–20, 1996.

[48] P. Maes, “Artificial life meets entertainment: Lifelike autonomous agents,” *Communications of the ACM*, vol. 38, no. 11, pp. 108–114, 1995.

[49] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, 3rd ed. Prentice Hall, 2009.

[50] M. Bratman, *Intention, plans, and practical reason.* Cambridge, MA: Harvard University Press, 1987.

[51] M. Georgeff, B. Pell, M. Pollack, M. Tambe, and M. Wooldridge, “The Belief-Desire-Intention model of agency,” in *Intelligent Agents V: Agents Theories, Architectures, and Languages*, ser. Lecture Notes in Computer Science, J. P. Müller, A. S. Rao, and M. P. Singh, Eds. Springer Berlin Heidelberg, 1999, vol. 1555, pp. 1–10.

[52] F. Dalpiaz, P. Giorgini, and J. Mylopoulos, "Software self-reconfiguration: A BDI-based approach," in *Proceedings of The 8th International Conference on Autonomous Agents and Multiagent Systems - Volume 2*, ser. AAMAS '09. International Foundation for Autonomous Agents and Multiagent Systems, 2009, pp. 1159–1160.

[53] R. H. Bordini, J. F. Hübner, and M. Wooldridge, *Programming multi-agent systems in AgentSpeak using Jason.* John Wiley & Sons, 2007.

[54] P. Leitão, "Agent-based distributed manufacturing control: A state-of-the-art survey," *Engineering Applications of Artificial Intelligence*, vol. 22, no. 7, pp. 979–991, 2009.

[55] V. Rialle, J.-B. Lamy, N. Noury, and L. Bajolle, "Telemonitoring of patients at home: a software agent approach," *Computer Methods and Programs in Biomedicine*, vol. 72, no. 3, pp. 257–268, 2003.

[56] F. Bergenti and A. Poggi, "Multi-agent systems for e-health: Recent projects and initiatives," in *10th Workshop on Objects and Agents, WOA'09*, 2009.

[57] A. Borowczyk, M. Gawinecki, and M. Paprzycki, "BDI agents in a patient monitoring scenario," in *Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on*, 2008, pp. 82–85.

[58] C. Reinisch and W. Kastner, "Agent based control in the smart home," in *IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society*, 2011, pp. 334–339.

[59] S. Nefti, U. Manzoor, and S. Manzoor, "Cognitive agent based intelligent warning system to monitor patients suffering from dementia using ambient assisted living," in *Information Society (i-Society), 2010 International Conference on*, 2010, pp. 92–97.

[60] D. Cavone, B. De Carolis, S. Ferilli, and N. Novielli, "An agent-based approach for adapting the behavior of a smart home environment," in *12th Workshop on Objects and Agents, WOA-2011*, ser. CEUR Workshop Proceedings, G. Fortino, A. Garro, L. Palopoli, W. Russo, and G. Spezzano, Eds., vol. 741, 2011, pp. 105–111.

[61] M. Morandini, F. Dalpiaz, C. Nguyen, and A. Siena, "The tropos software engineering methodology," in *Handbook on Agent-Oriented Design Processes*, M. Cossentino, V. Hilaire, A. Molesini, and V. Seidita, Eds. Springer Berlin Heidelberg, 2014, pp. 463–490.

[62] B. Rechel, E. Grundy, J.-M. Robine, J. Cylus, J. P. Mackenbach, C. Knai, and M. McKee, "Ageing in the European Union," *The Lancet*, vol. 381, no. 9874, pp. 1312–1322, 2013.

[63] J. C. Allaire, A. C. McLaughlin, A. Trujillo, L. A. Whitlock, L. LaPorte, and M. Gandy, "Successful aging through digital games: Socioemotional differences between older adult gamers and non-gamers," *Computers in Human Behavior*, vol. 29, no. 4, pp. 1302–1306, 2013.

[64] D. Ludwick and J. Doucette, "Adopting electronic medical records in primary care: Lessons learned from health information systems implementation experience in seven countries," *International Journal of Medical Informatics*, vol. 78, no. 1, pp. 22–31, 2009.

[65] R. Haux, "Health information systems — past, present, future," *International Journal of Medical Informatics*, vol. 75, no. 3–4, pp. 268–281, 2006.

[66] M. E. Frisse, K. B. Johnson, H. Nian, C. L. Davison, C. S. Gadd, K. M. Unertl, P. A. Turri, and Q. Chen, "The financial impact of health information exchange on emergency department care," *Journal of the American Medical Informatics Association*, vol. 19, no. 3, pp. 328–333, 2012.

[67] P. Ferronato, S. Lotti, and D. Berardi, "Strategia architetturale per la sanità elettronica (Architectural strategy for e-health)," Italian Ministry for Innovation and Technologies, Tech. Rep., 2006. [Online]. Available: http://www.funzionepubblica.gov.it/media/566290/tse-ibse-strategia_architetturale-v01.00-def.pdf

[68] H. Takabi, J. Joshi, and G.-J. Ahn, "Security and privacy challenges in cloud computing environments," *Security Privacy, IEEE*, vol. 8, no. 6, pp. 24–31, 2010.

[69] S. Makonin, L. Bartram, and F. Popowich, "A smarter smart home: Case studies of ambient intelligence," *IEEE Pervasive Computing*, vol. 12, no. 1, pp. 58–66, 2013.

[70] T. Kleinberger, A. Jedlitschka, H. Storf, S. Steinbach-Nordmann, and S. Prueckner, "An approach to and evaluations of assisted living systems using ambient intelligence for emergency monitoring and prevention," in *Universal Access in Human-Computer Interaction. Intelligent and Ubiquitous Interaction Environments*, ser. Lecture Notes in Computer Science, C. Stephanidis, Ed. Springer Berlin Heidelberg, 2009, vol. 5615, pp. 199–208.

[71] G. Demiris, D. P. Oliver, G. Dickey, M. Skubic, and M. Rantz, "Findings from a participatory evaluation of a smart home application for older adults," *Technology and Health Care*, vol. 16, no. 2, pp. 111–118, 2008.

[72] B. Kormányos and B. Pataki, "Multilevel simulation of daily activities: Why and how?" in *Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA), 2013 IEEE International Conference on*, 2013, pp. 1–6.

[73] C. Godsey and M. Skubic, "Using elements of game engine architecture to simulate sensor networks for eldercare," in *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*, 2009, pp. 6143–6146.

[74] C. Lee and J. F. Coughlin, "Perspective: Older adults' adoption of technology: An integrated approach to identifying determinants and barriers," *Journal of Product Innovation Management*, vol. 32, no. 5, pp. 747–759, 2015.

[75] F. Steinke, N. Bading, T. Fritsch, and S. Simonsen, "Factors influencing trust in ambient assisted living technology: A scenario-based analysis," *Gerontechnology*, vol. 12, no. 2, pp. 81–100, 2014.

[76] J. Coughlin, L. D'Ambrosio, B. Reimer, and M. Pratt, "Older adult perceptions of smart home technologies: Implications for research, policy & market innovations in healthcare," in *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE*, 2007, pp. 1810–1815.

[77] S. Gaul and M. Ziefle, "Smart home technologies: Insights into generation-specific acceptance motives," in *HCI and Usability for e-Inclusion*, ser. LNCS, A. Holzinger and K. Miesenberger, Eds. Springer Berlin Heidelberg, 2009, vol. 5889, pp. 312–332.

[78] D. Townsend, F. Knoefel, and R. Goubran, "Privacy versus autonomy: A tradeoff model for smart home monitoring technologies," in *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*, 2011, pp. 4749–4752.

[79] T. Susi, M. Johannesson, and P. Backlund, "Serious games: an overview," School of Humanities and Informatics, University of Skövde, Tech. Rep. HS-IKI-TR-07-001, 2007.

[80] H. Hildmann and B. Hirsch, "Raising awareness for environmental issues through mobile device based serious games," *4th Microsoft Academic Days, Berlin, Germany*, 2008.

[81] M. Newbould and S. Furnell, "Playing safe: A prototype game for raising awareness of social engineering," in *Australian Information Security Management Conference*, 2009, pp. 24–30.

[82] G. Rebolledo-Mendez, K. Avramides, S. de Freitas, and K. Memarzia, "Societal impact of a serious game on raising public awareness: the case of floodsim," in *Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games*. ACM, 2009, pp. 15–22.

[83] P. Sernani, A. Claudi, P. Calvaresi, D. Accattoli, R. Tofani, and A. F. Dragoni, "Using 3D simulators for the ambient assisted living," in *3rd International Workshop on Artificial Intelligence and Assistive Medicine*, ser. CEUR Workshop Proceedings, vol. 1213, 2014, pp. 16–20.

[84] P. Calvaresi, D. Calvaresi, P. Sernani, M. Pierdicca, E. Morbidelli, D. Accattoli, and A. F. Dragoni, "A virtual caregiver for the AAL: Testing in a 3D simulator," in *Proceedings of the 1st Italian Workshop on Artificial Intelligence for Ambient Assisted Living, colocated with the 13th AI* IA Symposium on Artificial Intelligence*, 2014. [Online]. Available: http://aiia2014.di.unipi.it/_media/aal/aiaal2014_calvaresi.pdf

[85] P. Calvaresi, A. F. Dragoni, M. Pierdicca, D. Calvaresi, and P. Sernani, "Using a virtual environment to test a mobile app for the ambient assisted living," in *4th International Workshop on Artificial Intelligence and Assistive Medicine*, ser. CEUR Workshop Proceedings, vol. 1389, 2015, pp. 53–61.

[86] P. Sernani, F. Dalpiaz, A. F. Dragoni, and S. Brinkkemper, "Smart tales: An awareness game for ambient assisted living," in *Ambient Intelligence*, ser. Lecture Notes in Computer Science, B. De Ruyter, A. Kameas, P. Chatzimisios, and I. Mavrommati, Eds. Springer International Publishing, 2015, vol. 9425, pp. 187–204.

[87] A. Bowling, Z. Le, and F. Makedon, "SAL: A simulation and analysis tool for assistive living applications," in *Proceedings of the 2nd International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, 2009, pp. 4:1–4:6.

[88] M. Zancanaro, M. Marchesoni, and G. Armellin, "SIMDOMO: A tool for long-term simulations of ambient-assisted living," in *Ambient Intelligence*, ser. Lecture Notes in Computer Science, E. Aarts, B. de Ruyter, P. Markopoulos, E. van Loenen, R. Wichert, B. Schouten, J. Terken, R. Van Kranenburg, E. Den Ouden, and G. O'Hare, Eds. Springer International Publishing, 2014, vol. 8850, pp. 47–50.

[89] J.-W. van't Klooster, B.-J. van Beijnum, A. Eliens, and H. Hermens, "Interactive scenario visualization for user-based service development," in *Collaboration Technologies and Systems (CTS), 2012 International Conference on*, 2012, pp. 498–503.

[90] C. Fernandez-Llatas, J. Mocholi, P. Sala, J. Naranjo, S. Pileggi, S. Guillen, and V. Traver, "Ambient assisted living spaces validation by services and devices simulation," in *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*, 2011, pp. 1785–1788.

[91] P. Rego, P. Moreira, and L. Reis, "Serious games for rehabilitation: A survey and a classification towards a taxonomy," in *Information Systems and Technologies (CISTI), 2010 5th Iberian Conference on*, 2010, pp. 1–6.

[92] D. Cascado, S. Romero, S. Hors, A. Brasero, L. Fernandez-Luque, and J. Sevillano, "Virtual worlds to enhance ambient-assisted living," in *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*, 2010, pp. 212–215.

[93] T. W. Malone and M. R. Lepper, "Making learning fun: A taxonomy of intrinsic motivations for learning," in *Aptitude, Learning, and Instruction Volume 3: Conative and Affective Process Analyses*, R. Snow and M. J. Farr, Eds. Lawrence Erlabaum Associates, 1987, pp. 223–253.

[94] T. M. Connolly, E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle, "A systematic literature review of empirical evidence on computer games and serious games," *Computers & Education*, vol. 59, no. 2, pp. 661–686, 2012.

[95] M. J. Simmonds and D. Zikos, "Computer games to decrease pain and improve mood and movement," in *Proceedings of the 7th International Conference on PErvasive Technologies Related to Assistive Environments.* ACM, 2014, pp. 56:1–56:4.

[96] S. Leonhardt, S. Kassel, A. Randow, and T. Teich, "Learning in the context of an ambient assisted living apartment: Including methods of serious gaming," in *Software Engineering Education for a Global E-Service Economy*, ser. Progress in IS, G. Motta and B. Wu, Eds. Springer International Publishing, 2014, pp. 49–55.

[97] C. Aguero, N. Koenig, I. Chen, H. Boyer, S. Peters, J. Hsu, B. Gerkey, S. Paepcke, J. Rivero, J. Manzo, E. Krotkov, and G. Pratt, "Inside

the virtual robotics challenge: Simulating real-time robotic disaster response," *Automation Science and Engineering, IEEE Transactions on*, vol. 12, no. 2, pp. 494–506, 2015.

[98] G. Echeverria, N. Lassabe, A. Degroote, and S. Lemaignan, "Modular open robots simulation engine: MORSE," in *Robotics and Automation (ICRA), 2011 IEEE International Conference on*, 2011, pp. 46–51.

[99] D. Calvaresi, D. Cesarini, M. Marinoni, P. Buonocunto, S. Bandinelli, and G. Buttazzo, "Non-intrusive patient monitoring for supporting general practitioners in following diseases evolution," in *Bioinformatics and Biomedical Engineering*, ser. Lecture Notes in Computer Science, F. Ortuño and I. Rojas, Eds. Springer International Publishing, 2015, vol. 9044, pp. 491–501.

[100] A. Brugués, S. Bromuri, M. Barry, O. J. del Toro, M. R. Mazurkiewicz, P. Kardas, J. Pegueroles, and M. Schumacher, "Processing diabetes mellitus composite events in MAGPIE," *Journal of Medical Systems*, vol. 40, no. 2, 2016.

[101] F. Miralles, E. Vargiu, E. Casals, J. A. Cordero, and S. Dauwalder, "Automatically assessing movement capabilities through a sensor-based telemonitoring system," *International Journal of E-Health and Medical Communications*, vol. 6, no. 4, pp. 39–48, 2015.

[102] F. Dignum, "Agents for games and simulations," *Autonomous Agents and Multi-Agent Systems*, vol. 24, no. 2, pp. 217–220, 2012.

[103] L. Palazzo, G. Dolcini, A. Claudi, G. Biancucci, P. Sernani, L. Ippoliti, L. Salladini, and A. Dragoni, "Spyke3D: A new computer games oriented BDI agent framework," in *Computer Games: AI, Animation, Mobile, Interactive Multimedia, Educational Serious Games (CGAMES), 2013 18th International Conference on*, 2013, pp. 49–53.

[104] B. M. Winn, "The design, play, and experience framework," in *Handbook of Research on Effective Electronic Gaming in Education.* IGI Global, 2007, vol. 5497, pp. 1010–1024.

[105] M. Csikszentmihalyi, *Flow and the Psychology of Discovery and Invention.* HarperPerennial, New York, 1997.

[106] K. Mitgutsch and N. Alvarado, "Purposeful by design? A serious game design assessment framework," in *Proceedings of the International Conference on the Foundations of Digital Games - FDG '12.* ACM Press, 2012, pp. 121–128.

[107] R. Hunicke, M. Leblanc, and R. Zubek, “MDA: A formal approach to game design and game research,” in *Proceedings of the AAAI Challenges in Game AI Workshop*, ser. AAAI Workshop - Technical Report, vol. WS-04-04, 2004, pp. 1–5.

[108] I. Mayer, G. Bekebrede, C. Harteveld, H. Warmelink, Q. Zhou, T. van Ruijven, J. Lo, R. Kortmann, and I. Wenzler, “The research and evaluation of serious games: Toward a comprehensive methodology,” *British Journal of Educational Technology*, vol. 45, no. 3, pp. 502–527, 2014.

[109] E. N. Wiebe, A. Lamb, M. Hardy, and D. Sharek, “Measuring engagement in video game-based environments: Investigation of the user engagement scale,” *Computers in Human Behavior*, vol. 32, no. 0, pp. 123–132, 2014.

[110] B. Marne, J. Wisdom, B. Huynh-Kim-Bang, and J.-M. Labat, “The six facets of serious game design: A methodology enhanced by our design pattern library,” in *21st Century Learning for 21st Century Skills*, ser. Lecture Notes in Computer Science, A. Ravenscroft, S. Lindstaedt, C. D. Kloos, and D. Hernández-Leo, Eds. Springer Berlin Heidelberg, 2012, vol. 7563, pp. 208–221.

[111] F. Bellotti, B. Kapralos, K. Lee, P. Moreno-Ger, and R. Berta, “Assessment in and of serious games: An overview,” *Advances in Human-Computer Interaction*, vol. 2013, pp. 1:1–1:11, 2013.

[112] F. Dalpiaz, P. Giorgini, and J. Mylopoulos, “Adaptive socio-technical systems: a requirements-driven approach,” *Requirements Engineering*, vol. 18, no. 1, pp. 1–24, 2013.