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ORIGINAL ARTICLE

Reliability and human factors in Ambient Assisted Living environments

The DOREMI case study

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Abstract Malnutrition, sedentariness, and cognitive decline in elderly people represent the target areas addressed by the DOREMI project. It aimed at developing a systemic solution for elderly, able to prolong their functional and cognitive capacity by empowering, stimulating, and unobtrusively monitoring the daily activities according to well-defined "Active Ageing" life-style protocols. Besides the key features of DOREMI in terms of technological and medical protocol solutions, this work is focused on the analysis of the impact of such a solution on the daily life of users and how the users' behaviour modifies the expected results of the system in a long-term perspective. To this end, we analyse the reliability of the whole system in terms of human factors and their effects on the reliability requirements identified before starting the experimentation in the pilot sites. After giving an overview of the technological solutions we adopted in the project, this paper concentrates on the activities conducted during the two pilot site studies (32 test sites across UK and Italy), the users' experience of the entire system, and how human factors influenced its overall reliability.

Keywords Ambient Assisted Living · Human factors · Reliability · Intelligent Environments

Decrease in cOgnitive decline, malnutrRtion and sedEntariness by elderly empowerment in lifestyle Management and social Inclusion.

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1 Introduction

Due to advancements in the medical therapies and to different life styles, all countries in Europe are experiencing an ageing of their populations. Health trends among the elderly are mixed: severe disability is declining in some countries but increasing in others, while mild disabilities and chronic diseases are generally increasing. As a consequence, long-term care costs will increase with the ageing of the population, but this will not inevitably lead to significantly higher health care expenditure if appropriate measures are implemented in time. According to the World Health Organization (WHO) recommendations [41], these actions include the following:

- reducing the risk of disease and promoting the maintenance of function;
- incrementing physical activity and social participation;
- developing adequate systems of long-term care;
- supporting economic and social integration.

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According to the University College of Dublin Institute of Food and Health Policy Seminar Series, three most notable health promotion and disease prevention programmes target the main causes of morbidity and premature mortality: obesity, hypertension, and mental disorders. These programs address malnutrition, sedentariness, and cognitive decline, as they are identified as the main conditions affecting the quality of life of elderly people and favouring the above-indicated diseases.

These three conditions represent the target areas of improvement treated in the DOREMI project, which aimed at developing a systemic solution for healthy ageing, based on a well-targeted problem definition and model, able to prolong the functional and cognitive capacity of the elderly by empowering, stimulating, and unobtrusively monitoring the daily activities, according to "Active Ageing" life-style protocols defined by physicians. The main characteristic of the DOREMI solution is the unified vision of "being elderly today" by means of a constructive interaction among mind, body, and social engagement. The set of elderly taken into account was represented by people presenting unhealthy habits and initial cognitive decline. The subject with cognitive decline is prone to increase unhealthy and sedentary habits. Malnutrition, expressed in terms of unhealthy dietary habits, due to the discrepancy between needs, intake, and utilization of nutrients represents the primary cause responsible in a deterioration of the health of the elderly user, and constitutes a major risk factor for many chronic-degenerative diseases. The protein-calorie unbalanced intake is, along with the deficiency of minerals and vitamins, quite common in the elderly, being affected about the 45% of the elderly population in Europe. Sedentariness (i.e., inappropriate mobilization) is responsible for high incidence of household falls and injuries, which happen to 1/3 of the >60s, with a consequent disability as well as physical and psychological repercussions, accelerating a physiological and functional decline. This loop can induce a state of depression or social isolation, often associated with cognitive decline. During the ageing, all humans develop some degree of cognitive decline; this natural process can be accelerated by disuse, illness (as depression, schizophrenia), psychological factors, social factors and so on, and it is responsible for social isolation. Physical activity is a key component of healthy life-styles; in [40], authors compare by sex, physical activity, and academic qualifications the symptomatology of depression among elders, identifying a significant correlation among physical activity, depression, and anxiety. In [42], authors explore the association between nutritional status and depression among healthy community-dwelling young-old (aged 65–74) and old-old elderly (aged 75 and older). This study reveals that not only the factors correlated with but also the symptoms of depression may vary among different age stratifications of the elderly, and depression and nutritional status are strongly correlated in young-old but not in old-old community-dwelling elderly.

The DOREMI system proposes a life-style protocol to contrast sedentariness, malnutrition, and cognitive decline trough the use of cognitive and exer-games, the control of the diet, and environmental and wearable sensing that monitor the physical activities and the social interaction (Fig. 1). All the collected data feed an artificial intelligence that embeds medical knowledge for a semi-automatic decision taking (supervised by a specialist). This solution enables DOREMI to maintain a 24/24 h control, to update its behaviour timely, and to keep up with the user progresses. The DOREMI solution was validated in a pilot study that lasted about 6 months and carried out in UK and in Italy.

This paper presents an overview of the DOREMI system, with the main focus on the differences between the two test sites, which had an impact on the related activities, the users' experience in both the countries, and the results we obtained. The paper is organized as follows: Section 2 presents other correlated projects and highlights the reliability and user-

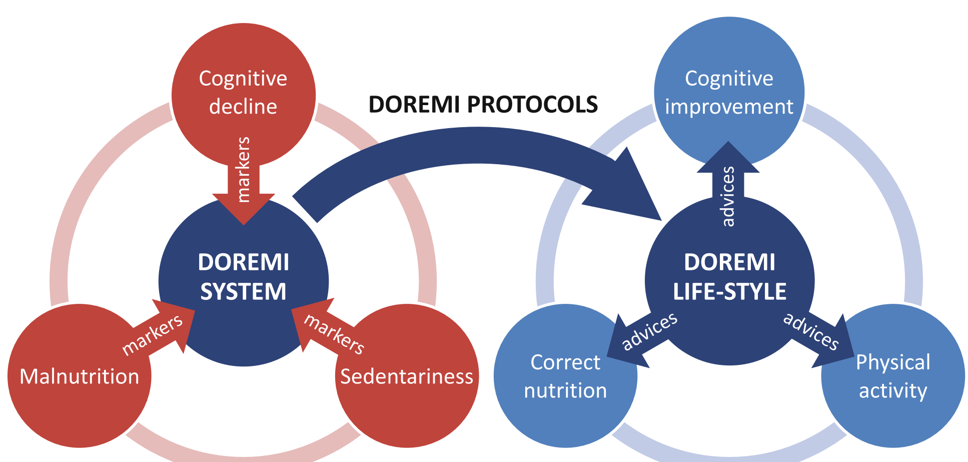


Fig. 1 The DOREMI areas of intervention

centred development aspects characterizing the DOREMI protocol; Section 3 describes the DOREMI system; Section 4 describes the monitoring environment, while the trials are described in Sect. 5. Section 6 presents the human factors analysis for the DOREMI reliable Ambient Assisted Living environment. Conclusions are presented in Sect. 7.

2 Related work

In the past decade, several research programs and initiatives have tried to address the main challenges of providing an active and independent ageing process for older adults: malnutrition, sedentariness, and cognitive decline. In this context, it is useful to identify the main goals and weakness of related initiatives, in order to better frame the proposed solution.

Besides the key features of DOREMI in terms of technological and medical protocol solutions, our research is also focused on the impact analysis of this solution on the users' daily life-style and how their behaviour modifies the expected results of the system in a long-term perspective. To this end, the reliability of the system becomes a key issue. One aspect of reliability, often neglected, is guaranteeing the consistency between system operation and user expectations, in particular in reaction to the following: (a) deviations from the medical protocol; (b) user interaction with the deployed hardware and software artefacts; (c) generation of possible inconsistent data due to an unpredictable use of the system. We call these aspects "human factors". To this end, a user-centred approach during all the phases of the project can highly influence the outcome of the system.

In the following, we analyse the related EU-funded initiatives and the approaches available in literature to user-centred design and human factors in reliability.

2.1 Related initiatives

As identified in the most recent global trends survey (Ageing In Place Technology Watch [30]), the technologies for active ageing can be categorized into four areas: safety and secure; health and wellness; communication and engagement; learning and contributing. In the Past years, a number of scientific research and deployment projects addressing the technologies for active and independent living have been developed by transnational consortia, significantly contributing to learning and development in the field of ICT solutions and services for elderly people. The H2020 "SOCIETAL CHALLENGES—Health, demographic change and well-being", the 7th Framework Programme (FP7), the Competitiveness and Innovation Framework Programme (CIP), and the Ambient Assisted Living (AAL) Joint Programme are the funding programmes most exploited at EU level to develop and test innovative technologies in the area of independent living.

The following list reports the acronym of the most known and successful projects, fitting into the four specific categories above mentioned, for each programme:

- **H2020**: SUSTAIN,[1] MARIO,[2] SENSE-Cog,[3] PRO-MISS,[4] My-AHA,[5] MINDMAP;[6]
- **FP7**: universAAL [22], OASIS [10], AALIANCE [11], BRAID [1], GiraffPlus [14];
- **CIP-ICT**: COMMONWELL,[7] DREAMING,[8] ISISEMD,[9] Long Lasting Memories,[10]SOCIABLE,[11] T-SENIORITY,[12] CLEAR,[13] NEXES,[14] HOME SWEET HOME;[15]
- **AAL**:
  - ICT-based solutions for prevention and management of chronic conditions: Agnes,[16] Amica,[17] eCAALYX;[18]
  - ICT-based solutions for advancement in social Interaction: Join-In,[19] Hopes,[20] Silver Game.[21]

Each of the listed projects addresses specific problems in the different technology areas, such as monitoring systems, tele-health, online social networks, etc.; however, all these projects present as a major drawback the lack of a systemic approach in both clinical and technological areas, as well as the lack of a sustainable model able to guarantee the cost effectiveness of the proposed technologies and services and their wide diffusion. In general, we can

1 http://www.sustain-eu.org/.
2 http://www.mario-project.eu/portal/.
3 http://www.sense-cog.eu/.
4 http://www.promiss-vu.eu/.
5 http://www.activeageing.unito.it/.
6 http://www.mindmap-cities.eu/.
7 http://commonwell.eu/.
8 http://www.dreaming-project.org/.
9 http://www.isisemd.eu/.
10 http://www.longlastingmemories.eu/.
11 http://www.sociable-project.eu/.
12 http://tseniority.idieikon.com/.
13 http://www.habiliseurope.eu/?q=node/5.
14 http://www.nexeshealth.eu/.
15 http://www.homesweethome-project.be/.
16 http://www.aal-europe.eu/projects/agnes/.
17 http://www.aal-europe.eu/projects/amica/.
18 http://www.aal-europe.eu/projects/ecaalyx/.
19 http://www.aal-europe.eu/projects/join-in/.
20 http://www.aal-europe.eu/projects/hopes/.
21 http://www.aal-europe.eu/projects/silver-game/.

say that all the technologies and services addressed by the mentioned projects were specifically devised to support elderly people in the management of chronic diseases and co-morbidities in the areas of cardiovascular, neuro-degenerative (e.g., Parkinson, Alzheimer, Dementia), and COPD diseases. Nevertheless, they do not holistically consider the psychological, social, and physical aspects as a whole. Moreover, the monitoring systems developed and implemented in the projects, both for personal and environmental data collection, mainly addressed home-based scenarios only. The outdoor environment has been mainly investigated by using the location-based services nowadays available with mobile smart phones but without posing the right attention to the power consumption. In many cases, monitoring activities were supported by wearable garment or smart t-shirts equipped with a network of sensors able to collect and transfer only physio-pathological parameters (e.g., cardio or respiratory data) without taking into consideration the overall daily behavioural aspects affecting the elderly health-care. Research aiming at recognizing the daily activities of people has steadily progressed, but little focus has been devoted to recognizing jointly activities as well as movements in a specific activity and user's context.

In the area of cognitive stimulation and monitoring, further than the above-mentioned limitation due to the target on chronic conditions (e.g., Alzheimer, Parkinson, etc.), the adopted solutions (e.g., games, social networks, interactive questionnaires, etc.) mainly focused on the cognitive decline assessment without considering the monitoring of relevant complementary impact factors such as the combination with physical activity and social interaction. Cognitive decline may be negatively affected by the impairment of the vascular endothelial functions of the cardiovascular system, favoured by sedentariness. Stimulation of physical activity may prevent or slowdown the deterioration of vascular and cognitive functions, as well.

As far as the physical activity stimulation and monitoring is concerned, most of the projects targeting this problem mainly focused on the implementation of home-based "wii-fit like" rehabilitation exer-games stimulating the target user through virtual exercising and monitoring the performance in front of a PC. Instead, the physiological stimulus to preserve efficiency has to be a continuous, daily activity carried out both indoor and outdoor.

In the area of social interaction, some projects addressed the development of a virtual world, where the elderly establish social relationships, robot systems interact with older users, interactive TV and video conferencing, etc. This is done in order to encourage better dialog among people and social networks concerning the same disease experience. However, despite the recognized importance of the technology to support the social interaction, none of the projects so far analysed set up a systemic solution combining social engagement, stimulation systems, and interaction monitoring systems, able to track the level of social interaction and to analyse, through a behavioural analysis approach, how the social network interaction can stimulate the real life social interaction as an important factor for well-being.

DOREMI approached the problem by combining all the aspects together and developing a systemic solution.

2.2 User-centred design and human factors in reliability

Projects related to the AAL scenario put together different technological areas coming from Pervasive Computing, Internet of Things, Smart Environments, and Ambient Intelligence. These areas have common building blocks (e.g., sensing technologies, interconnected devices, and back-end platforms) and objectives (e.g., context- and situation-awareness) that are exploited in order to provide useful services to humans, realizing the so-called Intelligent Environment paradigm [2]. In AAL projects, the users' expectations should be maximized in order to ensure a high acceptance level of the system. In this context, the involvement of all the stakeholders in the various phases of the project (i.e., requirements elicitation, design, development, and deploy) becomes crucial, especially when dealing with a so heterogeneous collection of hardware and software artefacts. This aspect is usually called "User-Centred Design" [39]: users are at the heart of the methodology during each phase of the development process.

User-Centred Design (UCD) is a multi-stage design process heavily focused on Usability, Human Factors (HF) engineering, and User Experience (UX) optimisation [20]. The International Standards Organization (ISO) 9241-210 standard describes HCD as an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" [17]. The ISO standard specifically recommends six process requirements that a UCD/HCD process should meet: (a) explicit understanding of users, tasks, and environments; (b) involvement of users throughout the design and development process; (c) consideration of the whole use of the system; (d) user-centred evaluation driven/refined design; (e) iterative process; (f) adoption of multidisciplinary skills and perspectives.

The UCD approach especially recognises the importance of incorporating as much human input and end-user testing into the process as early and as often as possible. The application of the UCD approach has proved effective in improving the usability and the user experience of a wide variety of health and wellness systems [12,27,28].

In the broader context of Intelligent Environments and "System of Systems" (SoS), a novel methodology has been proposed in [3], the so-called U-C IEDP: User-Centred Intelligent Environments Development Process. It considers not only software in building intelligent environment (IE) systems but also hardware, networks, and interfaces. The authors focus on how to put technologies together and to create the software infrastructure providing the required services. The major challenge, identified by the authors, relates to the gaining of confidence in systems in the real world, in terms of behavioural correctness, performance qualities, and their validation. In addition, the range of stakeholders involved, including the owners and operators of constituent systems, their integrators, and ultimately those who experience the system behaviour of the SoS, implies the need of using methods and tools that support collaborative working from the elicitation of requirements to the testing and maintenance.

Several studies highlighted the importance of users' acceptance and their involvement in the area of intelligent environments [16], in particular how this influences the success of a project [37]. A key factor is represented by the reliability of the proposed solutions, especially when designed for the long-term evaluation in a real environment. Reliability is an attribute of any computer-related component (software, or hardware, or a network, for example) that consistently performs according to its specifications; more formally, it describes the ability of a system or component to function under stated conditions for a specified period of time [24]. The application of this definition to the field of intelligent environments has deep implications, since all the architectural layers of an IE should be designed and tested with reliability in mind and by adopting suitable design processes and verification methodologies [13,15,23].

When dealing with the application of a system in real-world scenarios, Human Factors (HF) should be put in the loop of the design process. HFs describe human capabilities, constraints, structures, and processes involved in the interaction with designed artefacts and the environment itself. HFs can provide models and knowledge to feed the process of developing products that fit human requirements. As well described in [15], humans are the ultimate targets of any IE system and also for human users the system must "perform according to its specifications" or "function under stated conditions". Authors emphasize the importance of system operation to be understandable and predictable by its users, providing an effective and satisfactory user experience. This is even more evident in AAL environments:

If the system is not reliable despite the actions of users, they will perceive it as a useless and unpredictable system, which intrusively modifies the living environment without a clear benefit, and will wish themselves out.

DOREMI focused on these aspects during an extensive testing (pilots) of the system (over 30 test sites across UK and Italy) over the long period (about 3 months for each test site). The pilot was a key part of the user-centred cycle of development/deployment of the system, after a preliminary iterative phase involving a living lab experience, focus groups, and ethical committees.

3 The DOREMI approach

The final goal of DOREMI was to define and propose to elder users an "Active Ageing" life-style protocol. The protocol consists in prescriptions concerning personalized diets, physical and cognitive exercises. In turn, the protocol is supported by technological solutions aimed at making users able to correctly follow the protocol itself and at providing the specialists with daily observations of the users' progresses. The protocol was validated by means of an experimental "pilot" study conducted over 32 volunteers in Italy and UK.

In this section, we present the areas of intervention of DOREMI that drove the system design and the requirements concerning the system reliability.

3.1 Main areas

The DOREMI technological solutions address the following four main areas of intervention:

– *Sedentariness area.* The physical stimulation is done by means of a tablet application (exer-games) that shows the correct execution and duration of the physical exercises, personalized for each user. The physical conditions are monitored by observing both parameters like weight, balance, caloric consumption, hearth rate, and user activity parameters like number of steps (either indoor and outdoor). To this purpose, the DOREMI system uses some tools: (i) a wearable wristband, which embeds inertial and heart rate sensors, (ii) environmental sensors for the indoor localization, (iii) a balance board, for assessment of user's balance and weight, and (iv) a smart phone equipped with GPS for outdoor activity tracking. All the monitoring data concerning this area are collected in the DOREMI gateway station (Raspberry PI 2 Model B, with Raspbian OS a Debian-based Linux distribution tailored for the ARM processor of the Raspberry Pi device), where they are combined with information from the dietary area. The reasoning modules run in the DOREMI station and implement the life style protocol; the result of their elaboration is provided in aggregated form to the specialist by means of a dashboard.
– *Social area.* DOREMI uses a technological solution to provide a limited number of indicators concerning this area. Namely, environmental sensors are installed in the apartment for indoor socialization, and activity recognition and reasoning modules were developed aimed at detecting the presence of visitors at the user home. In the

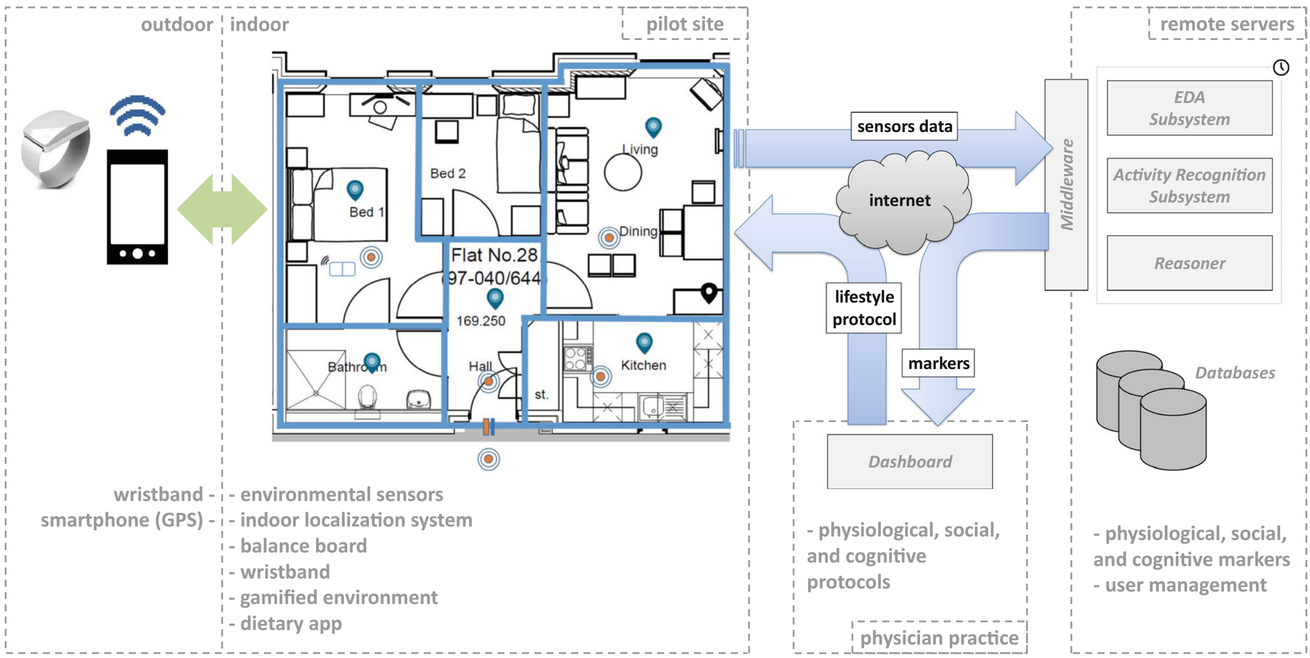


Fig. 2 The indoor and outdoor environments

outdoor scenario, GPS traces are analysed in order to infer the number and duration of meetings among DOREMI users.

- *Dietary area.* This area includes a dietary registry kept by the user by means of an application for the tablet called METADIETA™,[22] which has been integrated in the DOREMI system. The dietary area interacts with the sedentariness area, because dietary data are used by the reasoner components to assess the required intensity and duration of the daily physical exercises.
- *Cognitive area.* This area stimulates and monitors the cognitive capabilities of the users by means of cognitive games on the tablet. This area does not require exchange of data with other areas because all the information concerning the users' cognitive status is obtained and used by the games themselves. However, information about the cognitive status and progress of the user is available to the specialist by means of the dashboard.

The DOREMI technological environment is shown in Fig. 2, both for the indoor and the outdoor cases. In the indoor scenario, data from the various sources are sent to the DOREMI station for elaboration. In the outdoor scenario, data from the wristband are saved on the smart phone, which acts as a data storage. Once returned home, the smart phone automatically sends all the stored data to the DOREMI station for elaboration.

The information about physical exercises, weight, and balance is used to feed-back the games in order to adapt the life-style protocol to the user needs and progress. To this purpose, the data from the sensors (both wearable and environmental) and from the games are processed by an activity recognition system that provides high-level information about user performance. In turn, this information is processed by a reasoner that embeds medical knowledge to propose changes to the life-style protocol, for example to rise or to reduce the complexity of the cognitive games or the difficulty of the exer-games. The decisions of the reasoner are not automatically applied, but to become operative they need to be approved by the specialist through the dashboard. The responsibilities of the reasoning system can be summarized as follows:

- *Analysis of exercise data.* It creates alarms if a user fails in performing regular exercises and proposes an increase in physical exercise level if certain thresholds are met.
- *Analysis of cognitive data.* It proposes increase/decrease in game difficulty if certain thresholds are met or not, respectively. Moreover, depending on the types of games a user plays, it promotes playing certain games only.
- *Analysis of social data.* It promotes social activity, such as challenging another user to play games.
- *Analysis of dietary data.* It observes user's food intake habits to promote a healthier diet under the supervision of a specialist.
- *Warnings and reminders.* If a user has no physical, cognitive, or social activity, it generates appropriate warnings for the specialist.
- *Data visualization.* Data collected are visualized on the dashboard.

22 http://www.metadieta.it/.

3.2 Reliability aspects

The technical objective of DOREMI was to build in users' apartments an intelligent environment comprising a monitoring system, activity recognition, and reasoning components and serious games (both cognitive and exer-games). The data collected by games and sensors have to be delivered to a centralized server where are processed by the activity recognition and reasoning system providing feedbacks to the user and adapting the life-style protocol in accordance with the user's status (under the supervision of a medical specialist).

The main project's aim was to use the DOREMI system in a medical study to prove the feasibility and validity of the DOREMI life-style protocol. The medical study was planned in a pilot conducted over 32 users living in their apartments that, overall, lasted about 6 months. To the purpose of validation, the study divided the participants into two sets: the set of users that received the DOREMI protocol (intervention group, 25 users) and the set of users that did not receive it (control group, 7 users). The comparison between the improvements achieved by these two sets of users during the pilots was expected to give an indication of the validity of the DOREMI life-style protocol.

From a technical point of view, the design and implementation of all the ICT components had at least to guarantee the correct execution of the pilots. At the same time, the reliability of the system was also an important factor that we considered. Being DOREMI a very complex system, we considered three types of reliability:

- *R1-Medical validation*: reliability of the medical validation, which concerns the validation of the medical protocols used in the pilot studies;
- *R2-Application*: reliability of the applications, which concerns the activity recognition, the reasoning and the serious games components;
- *R3-Data*: reliability of the data, which concerns the reliability of the monitoring system.

The reliability of the medical validation addressed the lifestyle protocol that users had to follow during the pilot, in order to reach meaningful conclusions about the validity of the protocol. On the one hand, this concerned the organisation of the pilots (number of users involved, medical protocol, and duration of the pilot study), which had been approved by the ethical committees in Italy and UK. On the other hand, this also concerned the users' commitment to their assigned treatment protocols, which includes also the correct use of the DOREMI devices in their use. To enforce commitment of the users, the project adopted a careful selection of the volunteers for the pilots and devoted 15 days at the beginning of the pilots for their training.

The reliability of applications concerned the games and the data analysis components (activity recognition and reasoning), with the objective of guaranteeing to the specialists a correct and consistent information from games and data analysis components during the pilot. For what concerns the activity recognition components, given the aims of the DOREMI project and the nature of the involved computational learning tasks to be addressed, we adopted Machine Learning solutions with a particular emphasis on the methodologies in the field of Neural Networks for temporal data processing, and especially Echo State Networks [18,25]. Such methodologies allow to effectively learn computational tasks in temporal domains, with the ability to deal with heterogeneous sensor sources in a robust to noise fashion, and have been experimentally validated in real-world problems pertaining to the areas of Ambient Intelligence, Ambient Assisted Living, and Human Activity Recognition, as reported in recent literature works (see, e.g., [4,6,32]). The flexibility of the adopted learning approach requires a preliminary phase of training on data gathered through measurement campaigns conducted in living lab settings. This data collection is a sampling of the activities of interest for the project that are compliant with the DOREMI protocol adopted during the pilots phase. The medical staff and pilots managers were trained in order to transfer the correct protocol information to the users. In this regard, the noise tolerance and the generalization ability of the adopted learning methodologies result in an activity recognition system that is robust to small deviations from the execution of the exercises in the DOREMI protocol.

The reliability of data concerns the ability of the DOREMI monitoring system to collect data from the users' houses during the pilots and to grant their access to the application-level components (activity recognition, reasoner and games). In particular, this involved the management of faults due to damage accidentally caused by the users to the home-installed devices, or to faults occurring to the server-side and database. It should be highlighted that there were no explicit requirements in terms of mean time to failure or targets such as maximum amount of data lost during the pilots due to failures. Furthermore, the target of minimum amount of data to collect in the pilot was also unknown at the time of system design, because it was not yet known the relationship between games and data collected by sensors and their interpretation by the medical specialists. For all these reasons, the decision was to design a system according to a fault detection, management and repair model. The fault detection phase was implemented on the server-side using the Mantis[23] bug-tracking system, which was also used as a fault management tool. Mantis is a web-based bug-tracking system written in PHP that uses a MySQL database. The database is described

[23] http://www.mantisbt.org/.

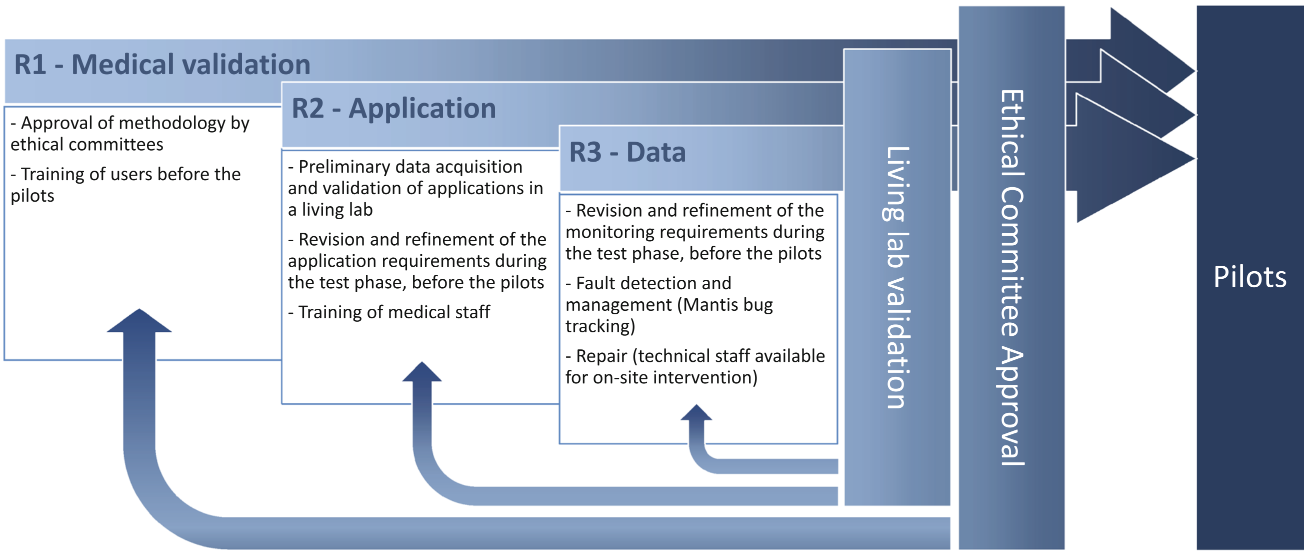


Fig. 3 Reliability requirements and relative measures undertaken in the design/methodology

by a relational schema, allowing importing/exporting bug data in XML files. A bug in Mantis is named "issue". Consequently, a Mantis model is a set of issues, each one being identified by a unique number.

The repair phase was carried by technicians who had to intervene on site (either at home of the users or on the servers). In practice, due to the relatively short duration of the pilots, the back-end components proved to be reliable for the entire duration of the pilots. Although the fault detection was designed to identify faults in a short time (it was based on a frequent check of the communication capability of the components), the repair phase was necessarily much longer. The DOREMI consortium thus organized an on-site support that had to intervene and fix faults within 1 day from the detection. This design reflected the expectation that faults were most likely in the devices in use by the user or installed in the users homes due to improper use or accidental damages caused by the user themselves or due to battery shortages (some sensors were battery-powered).

Figure 3 provides an overview of the methodology adopted design, implementation, and testing phases of the project with a focus on the reliability requirements and the relative measures undertaken in the project design. In particular, before reaching the pilot, the DOREMI system passed through the approval of the Ethical Committees and through a long validation phase in a living lab. The recommendations provided by the Ethical Committees were input to the design of the medical validation methodology. In particular, such recommendations suggested the number of end users and the duration of the pilots, while keeping the overall project budget as a constraint, to improve the reliability of the medical validation protocol. Concerning, instead, the living lab validation phase, it provided valuable feedbacks to improve the reliability of the applications and of the data. Specifically, the living lab experimentation provided a preliminary dataset used to train and validate all the activity recognition components. Furthermore, it allowed to check all the system components (including the fault detection and management) in realistic conditions and with real users (although such users were not with the end users of the pilots), and to consequently refine the applications requirements, and introduce the necessary adaptations to all the system components.

To all those purposes, the full DOREMI system was thus assembled and tested in the living lab for over 6 months before the pilots. During the same period, as the selection of the end users to be involved in the pilots reached its conclusion, the blueprints of the houses for the installation and special needs of the end users become available (for example the presence of pets in the houses); hence it was possible at this phase to refine, validate, and finalize all the system components (especially the activity recognition modules).

The pilots began 1 month after the living lab validation; this was the time required to deliver the material on site, to proceed with the physical installation and to train the managers of the pilots.

4 The monitoring environment

The DOREMI monitoring environment is constituted by a Wireless Sensor Network (WSN) formed by a set of heterogeneous devices for retrieving data from users to measure the following Key Performance Indicators (KPI): physical activity, vital parameters, and social interactions. By the correct measurement of these indicators, the whole DOREMI system gets feedback about the performance of the gamified

Table 1 KPIs identified in the Active Ageing Life-style Protocol and sensors used to monitor them

KPI type	KPI	Data	Device
Clinical	Vital parameters	Weight	Balance board
		Balance	
	Physical activity	Heart rate	DOREMI wristband
		Wrist acceleration	
		Number of steps	
		Indoor position	
		Sensors activations	Environmental WSN
Social	Number of interactions		
		GPS	Smartphone

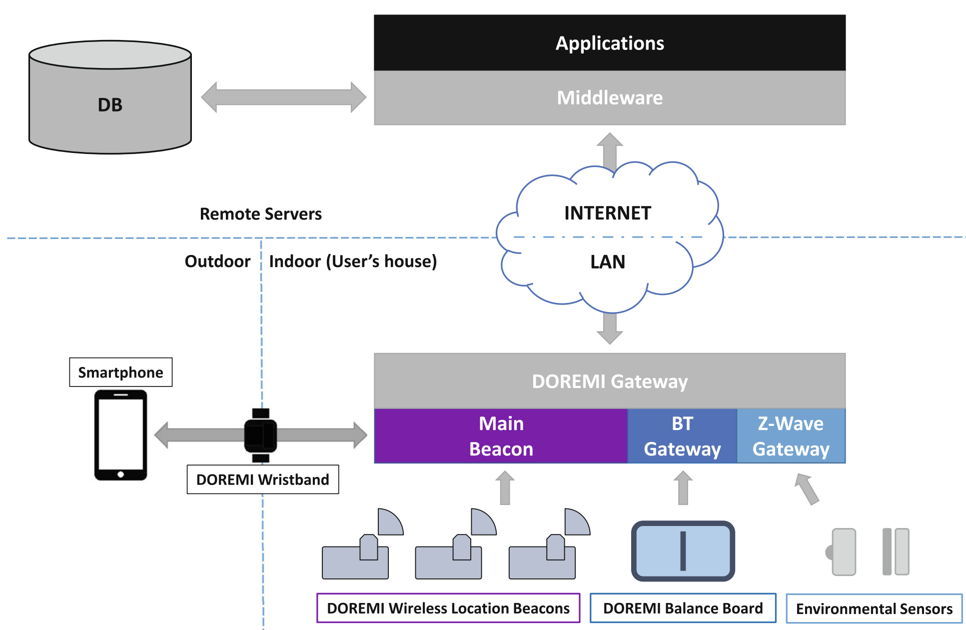
environment, the physical exercises and, in general, all the actions performed by the user. Several technologies and subsystems are used to monitor the following parameters: step counting, indoor location (at room level), physical activity level, interactions with people and social inclusion indicator, outdoor location, heart rate, weight, and balance. The schema in Table 1 relates the KIPs with the type of sensors used.

User monitoring takes place both at home and outdoor, with a different modality. The overall monitoring deployment is shown in Fig. 4. All data generated in the WSN are sent to the middleware [7,9,21,33], an end-to-end communication system that enables secure transmission and retention of sensors data. It also stores data in the sensor database through a data recorder module. The data collected by the WSN pertain to weight and balance (balance board), indoor activity (environmental sensors), heartbeat and body movements (wearable wristband), and Indoor Location (indoor location system and wristband), outdoor Location (wristband and smartphone with GPS). To collect these data, the WSN leverages both the devices installed in the apartment of the DOREMI user (i.e., the environmental sensors, the networking and the computing facilities) and the personal devices that are mainly used outdoor (i.e., the wearable sensor and the mobile phone).

4.1 Environmental sensors

The environmental sensors are intended to get suitable data from the daily life of the user to evaluate the social interactions in an unobtrusive, user-unaware way. These sensors are called "environmental" since they are installed in the rooms of the user's house and do not require any user intervention, thus not interfering in his daily life. DOREMI uses two types of environmental sensors: presence detectors, based on Passive InfraRed (PIR) technology, and door detectors, based on magnetic contacts. Measurements from these two kinds of devices are combined to assess, among others, an indication of indoor user socialization by estimating the number of interactions with visitors at home [5]. The environmental sensors are also used to monitor, over the long period, the behaviour of the user related to his indoor mobility [8,34]. The selection of the sensors has been performed considering requirements from the life-style protocol, the smart environment, and the WSN. The devices used in DOREMI are commercial products of the Z-Wave catalog. This technology has been selected due to its maturity and wide availability of

Fig. 4 The deployment of the DOREMI monitoring environment



devices, accomplishing the requirements for the project (API to access the full data, low energy consumption, wireless, and ease of deployment). The Z-Wave technology requires a gateway to set up and manage the network and to retrieve all the data generated by each Z-Wave sensor. In DOREMI, this gateway is also responsible to offer data access to a middleware integration layer running on the DOREMI Gateway; a commercial Z-Wave gateway has been selected to perform this task.

4.2 Indoor localization

The Real-Time Location System (RTLS) is used to automatically identify and track the location of objects or people in real time, within a building or other contained area, by means of fixed reference points devoted to receive signals from wireless RTLS tags attached to objects or worn by people. The RTLS technology in DOREMI uses a wearable wristband as a tag that communicates via Bluetooth Low Energy (BLE) with fixed beacons recovering data from the wristband and send them to the gateway. BLE beacons have recently been widely used as a valid technology for indoor positioning, especially in scenarios where the RTLS obtrusiveness must be kept low (e.g., avoiding training phases like in Wi-Fi fingerprinting or high costs and dedicated hardware like in Ultra Wide Band-based systems) [31].

The tags location is computed by triangulation, using the power of the signal received by the beacons. The beacon advertisement occurs approximately every three seconds. The location system needs fixed beacons connected to a power socket in every room and a concentrator beacon (Main Beacon) connected to the DOREMI gateway for sending data. DOREMI has also exploited the presence of both BLE and environmental sensors, in order to increase the accuracy of the RTLS thanks to the contextual information of the sensors' activations [38].

4.3 Balance assessment

The balance board is the home device that enables the day-by-day weight measurement and the periodic balance assessment. In DOREMI we used the Balance Board gaming device produced by Nintendo; it is a force platform that evaluates forces on the z-axis at the four corner ends of its surface by using four strain gauge sensors placed inside the 4 scale feet (Fig. 5).

The Balance Board allows to access data via a Bluetooth 2.0 communication channel. Each sample produced by the balance board includes weight (in kilograms) at each of the four corners (Real number), status of the button (Boolean for pressed/not pressed), and status of the light (Boolean for on/off). Several scientific works show that, even if the Wii Balance Board cannot be considered as a laboratory grade

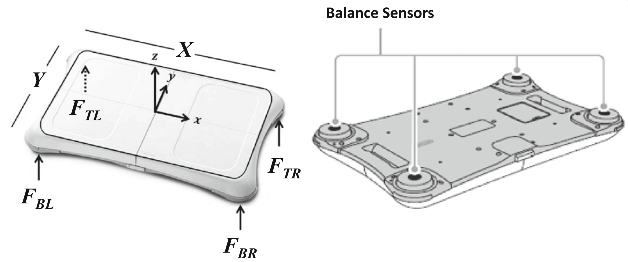


Fig. 5 The balance board used in DOREMI: measured forces and sensors

equipment for balance analysis, it provides good reliability at a very low cost. Data from the Balance Board is gathered during the execution by the user of a simple balance exercise of very short duration (≈10 s). After pre-processing and segmentation, such data are then used as input for the Neural Network models in the activity recognition modules for the estimation of the user's balance abilities (see details in [19]).

4.4 Wearable sensors

The wearable sensor, developed inside the project, is constituted by a wristband aimed at taking continuous measurements of physical activity parameters, as well as vital signs of the DOREMI user during his daily life. Compared to most of the well-known commercially available products, the device provides raw accelerometer and heartbeat data instead of preprocessed and aggregated data; this feature is particularly important for the development of the activity recognition tasks customized on the elderly. The acceleration data (3 axis accelerometer) are gathered at no less than five samples per second; from these data, it estimates a step counter with less than 20% error (same as average commercial pedometer), provided at a rate equal to or higher than six times per minute. The heart rate is gathered with less than 25% error (same as average commercial heart rate monitor) at no less than three samples per minute. The location is obtained by means of radio signal transmission to the location system at no less than 6 times per minute. All gathered data (acceleration raw data, step counter and heart rate) are sent via BLE to the main beacon of the location system, which, at its turn, addresses the data to the DOREMI station. In outdoor conditions, a smartphone is used as a mobile gateway for the data generated by the wristband, associating to them the GPS position too. Data produced by the wristband are stored in the phone memory; when the user goes back home, the smartphone establishes an Internet connection with the WIFI of the user's house and the smartphone app stops the data collection and starts the data transmission to the DOREMI gateway.

4.5 Gamification

In the elderly, it is important to determinate both the level of physical capacity and the mental impairment for determin-

(a) Example of villages in UK **(b)** View of Genoa city, Italy

Fig. 6 Pilot sites locations

ing their ability to lead an independent life and to have an active social life. For this aim, two categories of games have been developed in DOREMI, one group devoted to assess the physical level (exer-games) and the second one to assess the mental decline (cognitive games) [35,36].

With the exer-games, DOREMI monitored the users' level of Physical Activity (PA) and mobility, in association with wristband and the WSN. Another important issue addressed by the DOREMI PA protocol is the indoor activity, since the proportion of sedentary time is strongly related to health condition, independent of PA. Older people may benefit from reducing the total sedentary time and avoiding prolonged periods of inactivity by increasing the number of breaks during the sedentary time. Therefore, an indoor PA program tailored to increase the number of breaks was designed according to the individual habit of PA and sedentariness. DOREMI PA protocol is also focused on outdoor activity. This element presents a double motivation: physical and psycho-social. Outdoor walking is considered relatively easy, feasible, and an action that can be performed by older adults to reach a good level of physical activity. Furthermore, walking can stimulate socialization: working in a group can be a psychological stimulus to improve physical status and give a feeling of safety against possible ailments. Each indoor and outdoor session is focused on three main areas: articular mobility, stretching, and muscular strengthening, which are presented through a tablet, while the physical parameters related to the PA are registered through the wristband. The exer-games were developed using video exercise sessions shaped for the DOREMI target group.

Cognitive gamification, instead, involved the design of a set of games-related activities and game mechanics to achieve a "serious" or real-world objective. The application of game elements in non-game contexts can make every day activities more enjoyable and engaging, which has the potential for impacting public health initiatives. To influence this behaviour in DOREMI, a gamification system of rewards has been utilised to provide positive reinforcement when active ageing protocols (e.g., exercise participation) are followed. Motivation underlies the concept of gamification: if participants are not motivated to engage with the health protocols for social engagement, nutrition, exercise, and social participation, they may not experience a full benefit, or they withdraw from the study. In DOREMI, it was important to address participants' motivations to engage with the technology used, as unfamiliarity and/or feelings of incompetence could have been a barrier to participation.

5 The trials

The pilot sites designed to implement the DOREMI study in UK and IT presented some differences that had an impact on the activities. In particular, in UK, the sites selected to conduct the study were residences in Shenley Wood (Milton Keynes), St. Crispin (Northampton), and Showell Court (Wolverhampton) villages, while in Italy the study has been conducted in private apartments in Genoa (Fig. 6). In total, 32 people were enrolled, 15 in UK and 17 in Italy.

The group of users was selected according to the following criteria:

(a) *Age*: aged between 65 and 80 years old;
(b) *Gender*: group of potential candidates representing a balanced rate of male and female based on the average population composition of the selected countries;
(c) *Residential status*: living alone in their homes;
(d) *Computers skills*: possessing basic computer skills (using computers and the internet at least occasionally, any experience of having used a touch screen device;
(e) *Nutritional choice*: having the opportunity to actively choose their diet.

5.1 The inclusion criteria

For the cognitive ability evaluation, the Montreal Cognitive Assessment (MoCA) [29] was used. The MoCA is a short test designed to detect mild to moderate cognitive impairment. It assesses multiple cognitive domains: attention and concentration, executive functions, memory, language, visual constructional skills, conceptual thinking, calculation, and orientation. The MoCA can provide a global cognitive function score and was used to identify individuals with an estimate of mild cognitive impairment as indicated by a score of 19–26. The nutritional screening and assessment aimed at evaluating whether there were individuals of the pre-selected samples that were at risk of malnutrition. To this end, the Mini Nutritional Assessment (MNA) was used, a validated nutritional screening and assessment tool to identify users who are malnourished or at risk of malnutrition. The inclusion criteria identified as potential trial participants only individuals with an MNA score between 17 and 23.5 points. The Physical Activity Scale for Elderly (PASE) is a brief instrument for the assessment of physical activity. The inclusion interval that we used is a score lower than 105 points. The Degree of Balance assessment aims at measuring the degree of balance of people by assessing performance of functional tasks. For this aim, we used the Berg Balance Scale (BBS). The inclusion criteria considered suitable for the selecting individuals for the trial of DOREMI system has been quantified as a BBS scores between 30 and 56 points.

In both countries, UK and Italy, the recruitment was a long process, interviewing more than 1000 residents and potential participants. After a long selection, 15 people in UK, split on two villages, were involved in the DOREMI experimentation, and 17 in Italy, in Genoa. The main difference between the two test sites consisted in the fact that in UK villages all selected people lived in apartments equal to each other sharing, at their will, common rooms with the possibility to meet in common areas. Moreover, once done an installation in an apartment, the other installations were a simple replication of the first one. The Genoa pilot site instead was composed by private apartments spread all over the city, making thus impossible for participants to meet in common areas and making each DOREMI system installation a per se installation, due to the very large variety of the apartments' structures.

5.2 Baseline data collection

In addition to the PASE and BBS tests performed in the selection phase, the 6 min walking test (6MWT) was used for each user baseline data collection. The 6MWT is useful to evaluate the aerobic functionality and measures the distance an individual is able to walk over a total of 6 min on a hard, flat surface. The goal is for the individual to walk as far as possible in 6 min. Covered distance is then quantified in metres, while heart rate is recorded by the bracelet. Moreover, haemodynamic parameters, such as blood pressure, heart rate, and Rate Pressure Product (RPP), before and after 6MWT, were measured in order to collect information about the ability of the subjects to perform daily living activities.

5.3 Tests performed

Every day, participants registered their weight and balance using the balance board. The participants consulted gamified environment to receive their daily exercise suggestions together with feedback and recommendations based on the previous activities. Participants selected a physical activity from a set of videos pre-selected by the system in accordance with the characteristics of their personalized plan. The WSN registered participants' movements and the compliance degree with the exercise shown in the video. Outdoor physical activities were registered by the system through the bracelet and the smartphone. Every week the participants had to play at least three times the cognitive games, selecting them from the games list. Every week the participants had to

- perform cognitive training as suggested by the avatar;
- utilise the social cognitive functionality of the cognitive games;
- receive cognitive coaching on demand, in order to solve possible problems from the staff member overseeing the project.

The DOREMI system registered cognitive games daily logs, in order to produce the following information for each participant:

- time spent in games;
- game level reached for every cognitive function;
- time taken to complete a level;
- attempts needed to correctly perform a game;
- comparison between the beginning and the reached level at the end of the project;
- type of game more used (competitive, solo play, etc.);
- number of errors.

Finally, on a daily basis, the system measured the dietary habits of the participants as below:

- *From a user perspective, the participants*:
  - transmitted three weekly photo food diaries to the Nutritionist remotely without having feedback, through METADIETA®;
  - received nutritional coaching remotely on demand in order to solve possible problems.
- *From a clinically relevant perspective, the DOREMI system performed the following:*
  - used the daily weight of participants to calculate the BMI;
  - used the step counting information and heart rate data of participants to calculate the daily caloric consumption;

- registered daily logs to METADIETA® in order to produce the following information per each participant: daily compliancy with the suggested diet, number of meals per day, daily consumption of fruit and vegetables, daily calories intake, daily composition of food intake (fats, proteins, etc.), suggestions and recommendations and revision of the personal diet plan.

6 Human factor analysis

This section analyses the human factors that had an impact on the reliability of the overall DOREMI system. This analysis is based on the experience of the DOREMI pilot sites with respect to the critical aspects that were an issue to the reliability of the experimentation (as identified in Sect. 3.2 with the following points: R1-medical validation; R2-application; R3-data), and which required different interventions of the project technical and medical staff.

Table 2 gives a statistical overview of the DOREMI pilot sites in terms of numbers of users involved, amount of collected data (both raw and observations), and timing. We call “raw data” all the data gathered from the sensing devices without preprocessing or elaboration from the reasoning modules. We call “observations” all the outputs from the exploratory data analysis (i.e., daily statistics on heart rate, steps, walked distance, caloric intake, occupied rooms, social interaction events) and activity recognition (i.e., physical activity expenditure estimation, indoor behavioural monitoring, autonomous balance assessment) modules.

In prevention to potential, unexpected issues during the pilots, the DOREMI consortium took particular care to classify a number of potential problems and devised corresponding interventions/strategies to solve them. In particular, since the pilots required a deep involvement of the participants, which were volunteers in the age range of 65–80, the adoption of the DOREMI life-style protocol and the use of modern technologies could have been problematic; for this reason, effort was invested to adequately prepare the users. The DOREMI life-style protocol was personalized for each user by the medical partners at the beginning of the pilots. As discussed in the previous sections, it included personalized protocols for the physical and cognitive exercises and for the diet, and a “social” protocol that consisted in the organization of joint exercise sessions with all the users. Finally, the protocol also included instructions for the correct use of the monitoring system devices. The user had to execute his daily physical and cognitive exercises, to insert the data concerning his meals in the diet app, and to perform some very short exercise on the balance board to activate the assessment of his balance, while registering the weight. Moreover, the user had to remember to daily recharge wristband, tablet, and smartphone. No other user intervention was required. At the very beginning of the pilot, each user was instructed about the protocol by a team of partner-instructors, at their turn preliminary instructed by the medical and technical staff of the project. Despite all this, during the pilots several expected and unexpected issues occurred that required a reaction by the consortium with the adoption of specific measures, either planned or defined at the time. Most of the issues, even those unexpected, were detected by the technical staff observing anomalies in the monitoring system, especially in the first days of the pilot studies. However, some issues were raised by the users themselves or by the staff of DOREMI managing the pilots. In the rest of this section we report a brief description of such main issues, both expected and unexpected, classified according to the reliability aspect they concern. These issues are also summarized in Table 3, which reports the qualitative impacts (Limited, Medium, or High), estimated by the medical (R1) or technology (R2 and R3) specialists after the pilot sites experimentation. For R1, this estimation has been achieved by validating the medical protocol by means of comparison between baseline and post-intervention tests on the user. For R2, we validated the impact of the activity recognition models against a ground truth collected in the living lab experiments. For R3, we based our impact measure on the ratio between collected and expected amount of data during pilots and by the additional required effort to solve the issue.

Table 2 Overall statistics of the DOREMI pilot sites

	UK	Italy	Total
Total number of participants (male/female)	15 (2/13)	17 (2/15)	32 (4/28)
Average age	76	74	75
Total raw data received	18,656,696	9,205,072	27,861,768
Average raw data per user	~1,243,780	~541,474	~870,680
Total number of observations received	360,931	169,781	530,712
Average observations per user	~25,780	~8951	~16,091
Period of observation	Feb–Apr 2016	May–Jul 2016	Feb–Jul 2016

6.1 Main issues on R1: reliability of the medical validation

- *I1: Users in the control group in UK deliberately organized autonomous social initiatives and sessions of joint*

Table 3 Overview of the issues encountered during the DOREMI pilot sites and their impact

Human factor issue	Reliability aspect	Impact (limited/medium/high)
I1: Users of the control set in UK deliberately organized autonomous social initiatives and sessions of joint exercises	R1	Limited: One user has greatly changed his habits in physical activity, so it had no great impact on the final results
I2: Social protocol in the Italian pilot	R1	Medium: This issue affected the socialization protocol in terms of duration of the intervention period and sample size
I3: Some users did not execute the diet protocol correctly	R1	Limited: The presence of main UK foods in the database, together with suggestions to choose healthier foods, has limited the impact of this issue
I4: One user withdrew from the project	R1	Limited: The number of remaining was sufficient to conduct the medical experiment
I5: Non-compliance with the DOREMI protocol for balance assessment	R2	Medium: Some days of measurements had been lost, until the users had been instructed again. The robustness to noise of the methodologies employed in the activity recognition modules, however, has avoided that this problem had a greater impact on the estimate of the users balance abilities
I6: Users with pets	R2	Limited: Small performance degradation of few AR algorithms
I7: Some users refused to install some sensors	R2	Limited: Small performance degradation of few AR algorithms
I8: Lack of motivation of some users	R2	High in Italy, Medium in UK: Data loss for limited staff support (see I12)
I9: Imposed user privacy	R2	Limited: Difficult to estimate the actual impact. Apparently some limited effect on the users motivations
I10: Blackout	R3	Limited: Data loss of non-battery powered sensors in Italian houses for a few hours
I11: Lack of connectivity	R3	Limited: 5% of raw data lost in the involved UK test sites, while 3% in Italy
I12: Monitoring devices unavailability and system maintenance	R3	High in Italy, Limited in UK: 12% of raw data lost in Italy, 4% or raw data lost in UK
I13: Users hacking the tablets	R3	Medium: Additional effort required to redesign the tablet configurations and to issue a software update

exercises. The protocol assigned to the control group was different from that of the intervention one: control group users had to continue their normal daily routine. However, in UK, where almost all the users lived in the same village, thus very close to each other, some users decided together to change their habits, motivated by the fact of being involved in the project, even if only in the control set. Hence they began to make more physical exercises (although without the support of exer-games), to meet more frequently, and to take more care in their diet. This issue was completely unexpected and it was not solvable by the consortium, which had to accept it. Its impact was on R1, because it affected the medical experimentation by altering the results of the control set, but it was not possible to assess its precise effect on the final results of the experimentation. The lesson that emerges is that a greater control over the control group is necessary to make sure that they continue their lives everyday without any changes, although, in the case of DOREMI, we can say that what happened has certainly improved their life-style, even if not directly involved in the experimentation.

- *I2: Social protocol in the Italian pilot*. The organization of social events and joint exercise sessions among users proved to be very difficult in the Italian pilot in Genoa. This because the houses of the users were too spread all around the town, and moving the users to a common place was too costly in terms of time. The situation in UK was completely different because users lived in small villages and could be easily involved in joint sessions of exercises or meetings. For this reason, in the Italian pilot only these events were not organized. This affected R1 with a medium impact on the intervention period and sample size.

– *I3: Some users in UK did not properly follow the diet protocol*. Some users in UK did not want to change too much their dietary habit by limiting some foods, as suggested by the DOREMI diet protocol. To keep the daily logs about the meals, the diet protocol was based on the METADIETA® software developed in Italy and, thus, containing detailed information about Italian food but not detailed information for some typical UK food. In the UK pilot, this created a problem, as some users could not appropriately insert data in the log meals. This fact was known at design time, and, to overcome it, the consortium stipulated an agreement with the software producer to enlarge the UK food database. This guaranteed at least the coverage of the most typical UK foods, but not a complete coverage by the time of the pilots. The impact of those issues was on R1, and the reaction of the consortium was to review and reconsider the individual diet protocol assigned to these users. However, the impact on the experimentation was limited.
– *I4: One user withdrew from the project*. The user withdrew for personal reasons, not concerning the project itself. However, the impact of this withdrew was limited because the number of participants, which was agreed by the ethical committee, was sufficient and already took into account the possibility of a limited number of withdraws.

6.2 Main issues on R2: reliability of applications

– *I5: Non-compliance with the DOREMI protocol for balance assessment*. Although it was expected that some of the users occasionally did not precisely follow the instructions for the execution of the exercise for the balance assessment, it happened that in some cases they have systematically performed a series of actions that are non-compliant with the DOREMI protocol. This was due to a misunderstanding between the instructors and the technical staff of the project, and it was corrected by instructing again those users about the use of the balance board. In the end, it mainly affected R2, causing the loss of a few days of measurements with the balance boards for some users. Specifically, the segmentation of the data streams pertaining to the execution of the balance exercise in such cases could not be correctly performed by the pre-processing modules, which required a relaxation of the applied constraints. The robustness to noise of the methodologies employed in the activity recognition modules, however, has avoided that this problem had a greater impact on the estimate of the users balance abilities.
– *I6: Users with pets*. This issue was raised by the recruitment team that was completing the selection of the participants, still during the phase of technical development of the solution. The presence of pets could have been critical for the PIR environmental sensors, which could also be activated by the pets, thus leading to incorrect decisions of the activity recognition tasks. On the other hand, the PIRs were used for a limited number of tasks only, in combination with other environmental and wearable sensors (door switches and indoor localization). Moreover, the presence of pets could potentially affect also the measurements on the balance board, this problem was effectively avoided by the pre-processing and data segmentation phases. Overall, the redundancy in the sensors and the noise tolerance of the activity recognition modules allowed to limit the downgrade of the activity recognition tasks due to incorrect information produced by possible pets; hence, the consortium decided to provide a solution with limited performance downgrade for the users with pets. Overall, we had one and six users with pets in UK and Italy, respectively.
– *I7: Some users refused to install some sensors*. For the activity recognition tasks concerning the socialization events, each installation required the use of a PIR sensor installed out of the apartment, on top of the entrance door. One user in Italy refused the installation of this PIR to avoid being recognized as a participant to the project by her/his neighbours. This request was unexpected; however, its impact on the pilots was limited. Indeed, although in this isolated case it resulted in the inability to process one of the indicators of indoor socialization, the richness of information overall provided by the DOREMI system about users' location and socialization allowed to overcome the difficulties in the lack of a PIR, and thereby the impact of this issue. Similarly, some other users expressed concern about possible damage of the apartment walls due to the installation of other PIR sensors in the house. This issue was solved by assuring them about the reparation of the wall in negative case and that nothing would have been damaged. No damages were registered.
– *I8: Lack of motivation of some users*. This issue was expected, and for this reason the users were constantly monitored and assisted by the project staff. In the case of the cognitive games, it was necessary to introduce some improvement in the interface to make the games more interesting and involving.
– *I9: Imposed user privacy*. Both the Italian and the British ethical committees required to enforce anonymity of the users, even among themselves. For this reason, the social section of the games, where the users can share their performance, were anonymous as well, as the users appeared based on an ID rather than a name. This fact was annoying to the pilot participants that requested the names to be visualized. However, it was not possible to meet this request. It is hard to judge the impact of this issue; proba-

bly it is limited although it may have an effect in reducing the motivation of the users.

6.3 Main issues on R3: reliability of data

- *I10: Blackout in Genoa*. On May 30th, 2016, a large blackout in the city of Genoa caused the interruption of connectivity between the pilot houses and the servers (hosted at the Austrian partner premises), and the interruption of the monitoring system in the components connected to the mains (the balance board and the environmental sensors), whose data were lost. However, the system was designed to log all the data in case of lack of connectivity; hence it was possible to recover the data from the battery-powered sensors (the wristbands) and from the games. Although some interruptions were expected, a so large blackout involving many houses in the pilots was an unexpected event. At the same time, its impact was limited to Italian houses for a few hours.
- *I11: Lack of connectivity*. Due to organization problems, the internet connection was not available in five (UK) and two (Italy) houses for a week. This caused an initial data loss, since the ability to log sensor data on the smartphone and on the gateway was insufficient to deal with such a prolonged lack. The overall impact was limited in both pilots (5% of raw data lost in the involved UK test sites, while 3% in Italy).
- *I12: Monitoring devices unavailability and system maintenance.* Occasionally, some users caused damages to some environmental devices. The reasons were many: sometimes these damages had been accidental, in one case one user intentionally removed one PIR, in another case a user turned off a PIR (to turn off the light of its led signaling its activity), in other cases, the users did not properly recharge the wristband, the smartphone or the tablet. These problems were largely expected; for this reason the monitoring system was constantly supervised and the consortium was ready to guarantee a fast intervention. This approach proved very effective in the pilots in UK, since the vicinity between users and intervention staff (all in the same village) allowed solving all such issues within the same day they occurred. Unfortunately, in Genoa it was much more complicated by the local staff to intervene due to the completely different configuration of the pilots, with houses spread in a large area and with a more complicated urban mobility. In both cases, since users lived in their own apartments, it was necessary to call them and fix an appointment, but this action added further delays to the interventions especially in Genoa. Overall, this issue had a high impact on the pilots in Genoa in the extent of data loss (12% of raw data in Italy, 4% in UK), costs, and effort for the system maintenance.
- *I13: Users hacking the tablets*. All the tablets were preconfigured to be used with limited rights and to provide easy access to the DOREMI applications. In particular, the (anonymous) identity of the user of the tablet was also used to tag the data collected from the tablet and associate them with the other data concerning the same user. However, unexpectedly, in the pilots in UK, some users (or, more likely, some of their family members or friends) found a way to change the user profile on the tablet. We do not know precisely why they did this: in some cases, it was by accident and in some others the users were probably trying to activate more functions of the tablet. Anyway, the tablets connected with another user profile were no more associated with proper user in the DOREMI databases, and this caused loss of data from the games until the issue was solved. From the point of view of the data, the loss was limited; however, it required a technical intervention to devise a better protection of the DOREMI environment in the tablet, which also implied the installation of a software update that definitively fixed the problem.

6.4 Statistical analysis of collected data

In this section, we focus on the issues which had a main impact in terms of data loss during the experimentation, and for which we can present statistics about the data acquired/data loss in support to our analysis. In particular, such issues are I8 (lack of motivations of the users), I10 (blackout in Genoa), I11 (lack of connectivity), and I12 (system unavailability due to delayed maintenance). Figure 7 reports the number of collected data $\#NCD$ per single user in UK (a) and Italy (b), respectively, sorted on the base of $\#NCD$. The users have been clustered on this metric by using a k-mean clustering algorithm (with $k = 2$) [26]; the cluster with a lower mean L is reported in blue in the figure while the cluster with a higher mean H is reported in green. The figure clearly shows the distribution of $\#NCD$, from which it is seen the difference between the results in UK and Italy: in UK, for many reasons, the value of $\#NCD$ per user is generally higher and even the difference between the two clusters is smoother than in Italy. In particular, the mean H is 1.95e+6 in UK and only 1.34e+6 in Italy, while the mean L in UK is 0.63e+6 and only 0.3e+6 in Italy. The figure also shows that in UK the two clusters (with means L and H) have the same size, while in Italy the cluster with higher mean H is significantly smaller than cluster with mean L.

As discussed in the previous sections, the reason for such different behaviour between the users in Italy and UK is due to the different context in which the two pilots were conducted. In particular, the value of $\#NCD$ was affected mainly by the aforementioned issues I8, I10 (only in Italy),

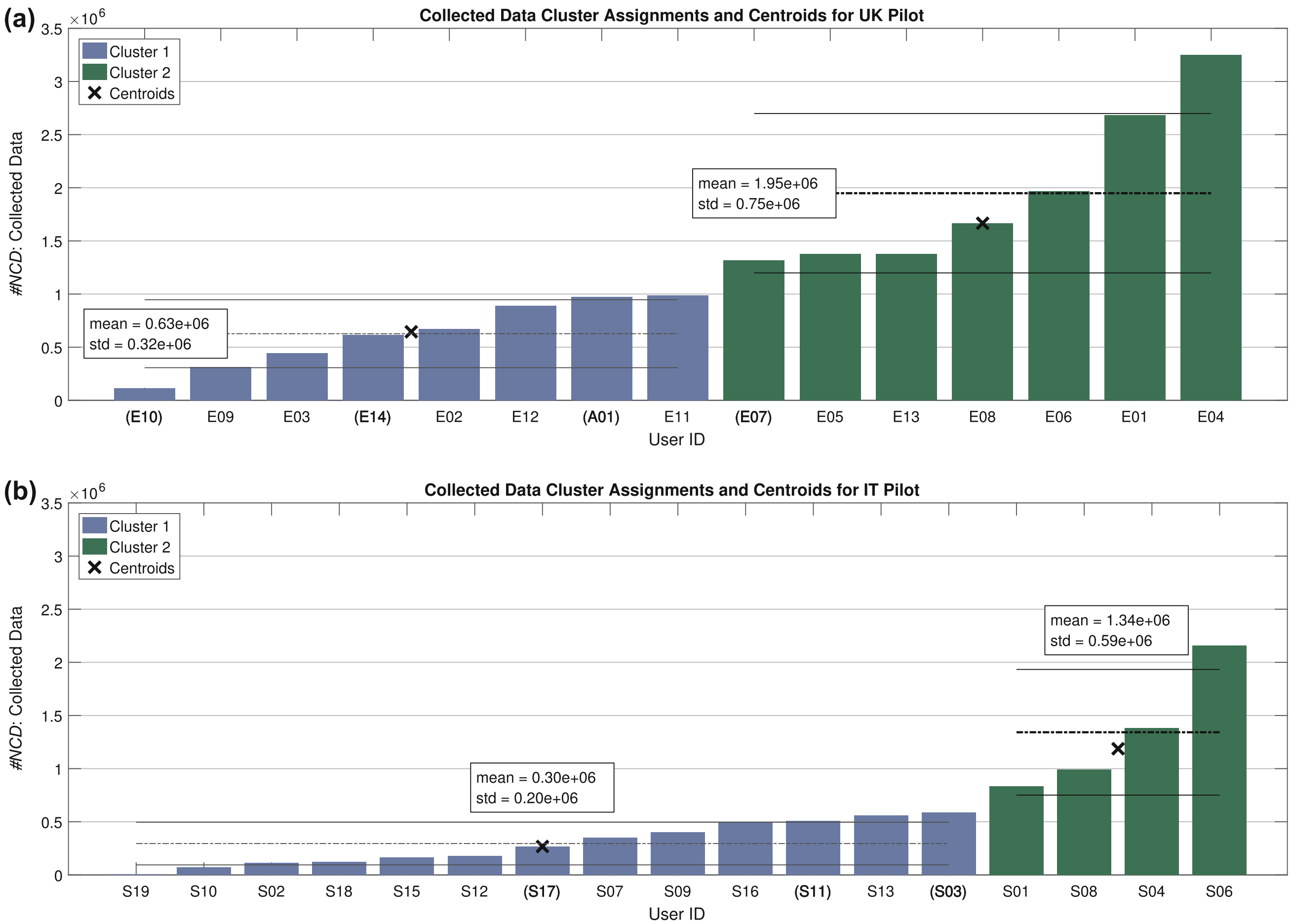


Fig. 7 Collected data $\#NCD$ per single user in UK (**a**) and Italy (**b**), respectively. Users have been clustered in two groups based on the resulting mean values: low (*blue*) and high (*green*). Users are anonymously represented by the ID assigned during the recruitment. Control groups IDs are indicated in *bold* and *brackets* (color figure online)

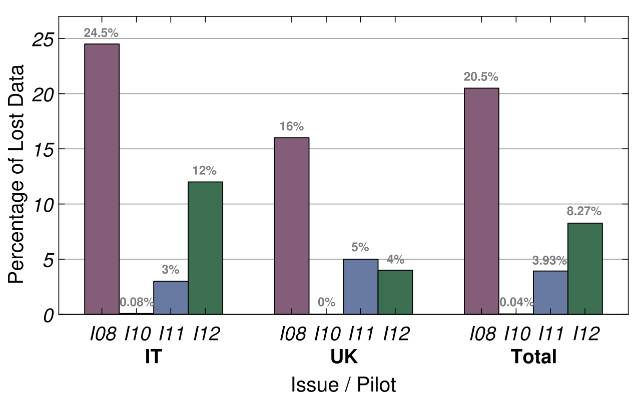


Fig. 8 Percentages of data loss per user (with respect to the expected data) due to each of such issues, in Italy, in UK, and overall

I11 and I12. Figure 8 reports the percentages of data loss per user (with respect to the expected data) due to each of such issues, in Italy, in UK and overall. The total amount of data expected in Italy was of 24 Million data (considering the raw data expected from all the sensors, either wearable or environmental), while in UK it was of 21 Million data (note that in UK the number of participant was 15 and in Italy it was 17). Despite this, the total number of data received in UK was larger than in Italy. In particular, three causes of data loss were directly measurable on the datasets; these are losses due to the blackout in Genoa (I10), to lack of connectivity (I11) and to delayed maintenance (I12). The figure shows that all these amount for about 9% of data loss in UK and for about 16% of the data loss in Italy. In particular, data loss due to I11 is smaller in Italy than UK because the pilot in UK was the first in time, and we experienced some logistic problems in providing in time the Internet connection to all houses, while in Italy we were ready in time. On the other hand, issue I12 (delayed maintenance) had a much larger impact in Italy due to the difficulties encountered in managing the installations in private houses spread in a large town rather than in a small village (as it was the case of UK).

Figure 8 also reports the data loss due to lack of motivations of the users. As it is not possible to assess this number directly, we evaluated it implicitly from the other figures (expected amount of data, amount of received data, amount of data loss due to other causes). The result is that the data loss in UK due to this cause was about 16%, much smaller than that experienced in Italy, which was about 24.5%. Again, we believe this is imputable to the different context of the two pilots. In fact, in UK the users were very close to each other, they could sustain themselves and they could also count on the constant presence of personnel of the project that could motivate them everyday. In Italy, the situation was completely different because the users were quite far from each other, they could meet less frequently, and the personnel of the project was also less present.

7 Conclusion

The user experience was, in general, very positive and the system well accepted. The DOREMI experience was excellent for the UK residents, as DOREMI has allowed forming friendships in a group of residents who otherwise might not have got the chance, while encouraging a healthy life-style and active mind. While some of the residents were quite skeptical of the DOREMI system at first, with some training they soon became proficient and were using it not just for the project, but also for their own enjoyment. From the reliability point of view, the planned management of issues during the pilots mostly worked as expected, and guaranteed a correct conclusion of the pilots with a limited impact on the validation of the DOREMI system. On the other hand, unexpected issues (and especially those caused by human factors) proved more difficult to be managed, as they required a firmer commitment of the consortium, and a case-by-case management. The management of the pilots in Italy and UK was very different; in particular the management of the pilots in Italy resulted more challenging although, in a certain sense, more realistic. In Italy, the users lived in private apartments, far from each other; they did not know each other and had limited opportunities to support or to share experiences among them; at the same time, they were more difficult to reach from the managers of the pilots both for technical and medical support. This caused longer delays than in UK to solve the unexpected issues. Furthermore, the several environments themselves, composed by private apartments different from each other (as compared to the UK apartments that were almost similar in structure and size), implied an additional overhead on the technical staff of the project both in personalizing and planning the installation and in managing it during the pilots. Finally, we underline that DOREMI was a EU-funded project, with a constrained budget and time for system development and for pilots. For this reason, the reliability requirements were scaled to the size of the project, and, with a pragmatic approach, they were tuned to guarantee the sustainability of the medical experimentation. We cannot claim DOREMI to be a "reliable system", but the overall approach to reliability adopted in the project (combining a mix of automatic and human effort) proved sufficient to reach the desired level of reliability and guaranteed a successful (although not issue-proof) conclusion of the pilots. This paper is a mean to share our experience in the pilots with other researchers planning to organize similar experimentations with constrained budget and time.

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References

1. Afsarmanesh H, Brielmann M, Camarinha-Matos L, Ferrada F, Oliveira A, Rosas J, Bond R et al (2011) Consolidated vision of ICT and ageing. BRAID, Brussels
2. Augusto JC, Callaghan V, Cook D, Kameas A, Satoh I (2013) Intelligent environments: a manifesto. Hum Centric Comput Inf Sci 3(1):12
3. Augusto J, Kramer D, Alegre U, Covaci A, Santokhee A (2017) The user-centred intelligent environments development process as a guide to co-create smart technology for people with special needs. Univers Access Inf Soc 1–16. doi:10.1007/s10209-016-0514-8
4. Bacciu D, Barsocchi P, Chessa S, Gallicchio C, Micheli A (2014) An experimental characterization of reservoir computing in ambient assisted living applications. Neural Comput Appl 24(6):1451–1464
5. Bacciu D, Chessa S, Ferro E, Fortunati L, Gallicchio C, La Rosa D, Llorente M, Micheli A, Palumbo F, Parodi O et al (2016) Detecting socialization events in ageing people: the experience of the DOREMI project. In: 2016 12th international conference on intelligent environments (IE). IEEE, New York, pp 132–135
6. Bacciu D, Chessa S, Gallicchio C, Micheli A, Ferro E, Fortunati L, Palumbo F, Parodi O, Vozzi F, Hanke S et al (2015) Smart environments and context-awareness for lifestyle management in a healthy active ageing framework. In: Portuguese conference on artificial intelligence. Springer, Berlin, pp 54–66
7. Barbon G, Margolis M, Palumbo F, Raimondi F, Weldin N (2016) Taking Arduino to the Internet of Things: the ASIP programming model. Comput Commun 89:128–140
8. Barsocchi P, Cimino MG, Ferro E, Lazzeri A, Palumbo F, Vaglini G (2015) Monitoring elderly behavior via indoor position-based stigmergy. Pervasive Mob Comput 23:26–42
9. Barsocchi P, Ferro E, Fortunati L, Mavilia F, Palumbo F (2014) EMS@CNR: an energy monitoring sensor network infrastructure for in-building location-based services. In: 2014 International conference on high performance computing and simulation (HPCS). IEEE, New York, pp 857–862
10. Bonfiglio, S.: Open architecture for accessible services integration and standardisation (OASIS). FIMI SRL Italy, Funded under 7th FWP, ICT-2007.7.1 (2007)
11. van den Broek G, Cavallo F, Wehrmann C (2010) AALIANCE ambient assisted living roadmap, vol 6. IOS, Amsterdam

12. Chan J, Shojania KG, Easty AC, Etchells EE (2011) Does user-centred design affect the efficiency, usability and safety of CPOE order sets? J Am Med Inform Assoc 18(3):276–281
13. Cohen TN, Wiegmann DA, Shappell SA (2015) Evaluating the reliability of the human factors analysis and classification system. Aerosp Med Hum Perform 86(8):728–735
14. Coradeschi S, Cesta A, Cortellessa G, Coraci L, Galindo C, Gonzalez J, Karlsson L, Forsberg A, Frennert S, Furfari F et al (2014) GiraffPlus: a system for monitoring activities and physiological parameters and promoting social interaction for elderly. In: Hippe ZS, Kulikowski JL, Mroczek T, Wtorek J (eds) Human-computer systems interaction: backgrounds and applications 3, Springer, pp 261–271
15. Corno F, Guercio E, De Russis L, Gargiulo E (2015) Designing for user confidence in intelligent environments. J Reliab Intell Environ 1(1):11–21
16. De Russis L (2015) Interacting with smart environments: users, interfaces, and devices. J Ambient Intell Smart Environ 7:115–116
17. DIS (2009) ISO:9241-210:2010. Ergonomics of human system interaction-part 210: human-centred design for interactive systems. International Standardization Organization (ISO), Geneva
18. Gallicchio C, Micheli A (2011) Architectural and Markovian factors of echo state networks. Neural Netw 24(5):440–456
19. Gallicchio C, Micheli A, Pedrelli L, Fortunati L, Vozzi F, Parodi O (2016) A reservoir computing approach for balance assessment. Lecture notes in computer science, vol 9785. Springer International Publishing, Berlin
20. Giacomin J (2014) What is human centred design? Des J 17(4):606–623
21. Girolami M, Palumbo F, Furfari F, Chessa S (2013) The integration of ZigBee with the GiraffPlus robotic framework. In: International joint conference on ambient intelligence. Springer, Berlin, pp 86–101
22. Hanke S,Mayer C, Hoeftberger O, Boos H, Wichert R, Tazari M-R, Wolf P, Furfari F (2011) UniversAAL—an open and consolidated AAL platform. In: Wichert R, Eberhardt B (eds) Ambient assisted living. Springer, pp 127–140
23. Hu Y, Tilke D, Adams T, Crandall AS, Cook DJ, Schmitter-Edgecombe M (2016) Smart home in a box: usability study for a large scale self-installation of smart home technologies. J Reliab Intell Environ 2(2):93–106
24. IEEE (1991) IEEE standard computer dictionary: a compilation of IEEE standard computer glossaries, vol 610. IEEE, New York
25. Jaeger H, Haas H (2004) Harnessing nonlinearity: predicting chaotic systems and saving energy in wireless communication. Science 304(5667):78–80
26. Lloyd S (1982) Least squares quantization in PCM. IEEE Trans Inf Theory 28(2):129–137
27. Martin JL, Clark DJ, Morgan SP, Crowe JA, Murphy E (2012) A user-centred approach to requirements elicitation in medical device development: a case study from an industry perspective. Appl Ergon 43(1):184–190
28. McCurdie T, Taneva S, Casselman M, Yeung M, McDaniel C, Ho W, Cafazzo J (2012) mHealth consumer apps: the case for user-centered design. Biomed Instrum Technol 46(s2):49–56
29. Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, Cummings JL, Chertkow H (2005) The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. J Am Geriatr Soc 53(4):695–699
30. Orlov LM (2012) Technology for aging in place. In: Aging In Place Technology Watch
31. Palumbo F, Barsocchi P, Chessa S, Augusto JC (2015) A stigmergic approach to indoor localization using bluetooth low energy beacons. In: 2015 12th IEEE international conference on advanced video and signal based surveillance (AVSS). IEEE, New York, pp 1–6
32. Palumbo F, Gallicchio C, Pucci R, Micheli A (2016) Human activity recognition using multisensor data fusion based on reservoir computing. J Ambient Intell Smart Environ 8(2):87–107
33. Palumbo F, La Rosa D, Chessa S (2014) Gp-m: mobile middleware infrastructure for ambient assisted living. In: 2014 IEEE symposium on computers and communications (ISCC). IEEE, New York, pp 1–6
34. Palumbo F, La Rosa D, Ferro E (2013) Stigmergy-based long-term monitoring of indoor users mobility in Ambient Assisted Living environments: the DOREMI project approach. In: Bandini S, Cortellessa G, Palumbo F (eds) AI*AAL2016 Artificial Intelligence for Ambient Assisted Living 2016, vol 1803 in CEUR workshop proceedings. Aachen, pp 18–32
35. Pannese L (2016) Games keep you forever young in mind and body. In: De Carvalho CV, Escudeiro P, Coelho A (eds) Serious games, interaction, and simulation. Springer, pp 6–8
36. Pannese L, Wortley D, Ascolese A (2016) Gamified wellbeing for all ages—how technology and gamification can support physical and mental wellbeing in the ageing society. In: XIV Mediterranean conference on medical and biological engineering and computing 2016. Springer, Berlin, pp 1281–1285
37. Pennings L, Veugen T, De Korte A (2010) When are intelligent sensor environments successful? Technol Soc 32(3):197–203
38. Potortì F, Palumbo F (2015) CEO: a context event only indoor localization technique for AAL. J Ambient Intell Smart Environ 7(6):745–760
39. Sanders EBN, Stappers PJ (2008) Co-creation and the new landscapes of design. CoDesign 4(1):5–18
40. Teixeira CM, Vasconcelos-Raposo J, Fernandes HM, Brustad RJ (2013) Physical activity, depression and anxiety among the elderly. Soc Indic Res 113(1):307–318
41. World Health Organization et al (2015) World report on ageing and health. World Health Organization, Geneva
42. Yoshimura K, Yamada M, Kajiwara Y, Nishiguchi S, Aoyama T (2013) Relationship between depression and risk of malnutrition among community-dwelling young-old and old-old elderly people. Aging Ment Health 17(4):456–460