Ambient Assisted Living Technologies, Systems and Services: A Systematic Literature Review

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Abstract. This paper intends to demonstrate that it is possible to classify Ambient Assisted Living (AAL) services using the International Classification of Functioning, Disability and Health (ICF), in particular its components activities, participation and environmental factors. For this purpose a systematic review of the literature on AAL services was undertaken and existing AAL services summarized and characterized. To be included in this review articles must have defined innovative concepts or characterized innovative technologies, products or systems that can contribute to the development of the AAL paradigm, with the aim of enabling people with specific demands (e.g. elderly) to live longer in their natural environment. Results indicate that most publications regarding AAL are technology-oriented with only a few articles describing applications and scenarios. Results also indicate that it is possible to link tasks to categories of the ICF components activities, participation and environmental factors.

1 Introduction

1.1 Ambient Assisted Living

A digital environment with a pervasive and unobtrusive intelligence that is able to proactively support people in their daily lives is the fundamental idea of the Ambient Intelligence (AmI) concept [1]. AmI deals with new paradigms where computing devices are spread everywhere (ubiquity) to allow intelligent and natural interactions between the human being and the physical environment.

Within the AmI concept, AAL emerges as one of the most important developing areas. The general goal of AAL solutions is to apply the AmI concept and technologies to enable people with specific needs (e.g. elderly) to live longer in their natural environment. In technological terms, the AAL comprises a heterogeneous field of systems ranging from quite simple devices such as intelligent medication

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dispensers, fall sensors or bed sensors to complex systems such as networked homes and interactive systems.

The automation in an AAL environment can be viewed as a cycle that goes from perceiving the state of the environment, to reasoning about it in order to achieve a specific goal or anticipate outcomes of possible actions, and acting upon the environment to change its state [2].

Like all intelligent agents, a smart environment relies on sensory data collected from the real world. The perception of the environment requires that devices are embedded in the environment with the purpose to allow the interaction of the occupants with the technology.

When using the sensory data, the technological structure is able to perform reasoning processes to select actions that can be taken to change the state of the environment. Therefore, the data collected by the sensors have to be transmitted by a communication network and pre-processed by a complex technological structure, which collates and harmonizes data from different devices (it processes the raw data into more useful knowledge such as models or patterns). To make that information useful to the occupants of the environment, AAL systems must have a high level of reasoning and decision-making abilities in order to arrive at a diagnosis and advice or assist the human beings accordingly [2].

Action execution flows top-down. The action is transmitted by the communication network to the physical actuators. These change the state of the surrounding environment according to the instructions received.

Therefore, sensing, communicating and acting are crucial issues in the AAL paradigm [3, 4]: i) sensing - a sensorial network is indispensable to obtaining accurate information about the environment and its users; ii) communicating - all the components of an AAL environment have to be interconnected in order to communicate among them; iii) acting - any AAL environment must be able to act, through various types of actuators, in order to achieve its objective.

Furthermore, AAL systems must be able; i) to properly distinguish the people present in the environment; ii) to recognize the individual roles, needs, preferences and limitations; iii) to recognize situational context; iv) to allow different answers according to personal needs and situational contexts; v) to anticipate desires and needs without conscious mediation.

Having all this information about its users, the AAL technological structure will then be able to decide which services to provide, when and how to provide them and to whom. This means, that the AAL technological structure should present a broad range of intelligent functions for user management interface and context awareness [5].

The existence of a variety of devices, such as sensor or video cameras, poses a set of complex problems in terms of privacy and security, which require additional developmental efforts.

An AAL environment comprises numerous invisible devices and ubiquitous systems. Effective architectures are required to mask the effects of heterogeneous physical devices, communication networks and intelligent components and systems.

Last but not least, the acceptance of the AAL paradigm is, obviously, closely related to the quality of the available systems (e.g. private houses and home-care assistance in the presence of users with different abilities and needs).

1.2 International Classification of Functioning, Disability and Health (ICF)

One of the objectives of AAL services is to improve the performance of a person in their daily life. The AAL services use advanced technology to make that possible. However, the focus of these services should be in the task that the person needs to perform rather than in the technology used to perform it. As mentioned above, the development of these services intends to give more autonomy and independency and to increase the quality of life of the elderly. This development should be user-centered.

The user-centered paradigm is also present in the care delivery where the International Classification of Functioning, Disability and Health (ICF) will have an important role [6]. The ICF offers a framework for conceptualizing functioning associated to health conditions [7] and it considers that there are many factors that affect and have influence on the individual's performance and thereby on the decisions made on the type of service needed or how it should be delivered (e.g. care staff, relatives, aid appliances and technology).

The ICF structure distinguishes between the body, activities, participation and contextual factors [8] and considers that they are all part of the individual's functioning. Additionally, it considers the context (environmental factors and personal factors) as components that can either enhance or hinder the performance of the individual, depending on how he or she experiences limitations (e.g. due to possible weakness, illness and/or handicap).

The environmental factors can have a positive (i.e. be facilitators) or negative impact (i.e. be barriers) on the individual's performance as a member of society, on the individual's capacity to execute actions or tasks, or on the individual's body functions or structures. When coding an environmental factor as a facilitator, issues such as the accessibility of the resource, and whether access is dependable or variable, of good or poor quality, should be considered.

In the case of barriers, it might be relevant to take into account how often a factor hinders the person, whether the hindrance is great or small, or avoidable or not. It should also be kept in mind that an environmental factor can be a barrier either because of its presence (e.g. negative attitudes towards people) or its absence (e.g. the unavailability of a needed service).

The ICF contains 1,424 codes organized according to an alphanumeric system. Each code begins with a letter that corresponds to its component domain: b (Body Functions), s (Body Structures), d (Activities and Participation) or e (Environmental Factors). The letter is followed by between one and five numeric digits. Items are organized as a nested system so that users can telescope from broad to very detailed items depending upon the needs presented by particular applications of the ICF. The broadest descriptor of functioning is represented by the chapter (domain) in which the item appears. For example, chapter 5 of the Activities and Participation (d) component of the ICF is Self-care. The next level of coding is what the ICF refers to as the second level of detail or specification. These codes consist of the letter indicating the component domain (b, s, d, or e) followed by three numeric digits. The first numeric digit always corresponds to a chapter in that component domain in which the code is found. Within the Self-care chapter, the code d540 (Dressing) represents the second level of detail.

Assuming that AAL services intend to highlight environmental factors, i.e. technology, to improve participation and quality of life it should be possible to classify these services, taking into account how they impact on the user activities and participation, particularly on his/her quality of life [9]. It can also be considered that the AAL services may be classified as environmental factors, because they are embedded in the context where a person performs the activities and they may either facilitate or hinder to the individual's performance.

2 Methods

The objective of this paper is to review the AAL literature and classify the existing AAL services and to link these services to ICF activities, participation and environmental factors. In order to achieve these aims, a systematic review of the AAL literature published after 2007 was undertaken. The main features and areas of the products and systems described in the literature reviewed which interlink and improve new or existing technologies and systems were described. The methodology used to conduct this systematic review is detailed in the following sections.

2.1 Data Sources and Searches

Studies were sought using health databases (PubMed, Web of Science, Academic Search Complete and Science Direct) and Engineering and Technology databases (Cite Seer and IEEE Xplore). Two key words were used without language restriction: Ambient Assisted Living, as this was the main focus of this review, and Ambient Intelligence because AAL is a sub-area of AmI. This means that technologies such as user interaction or context awareness that are classified as AmI technologies are also used in the AAL. However, not all the AmI systems are considered AAL systems. The search was performed on the 23rd of February of 2011 and included all references published since the 1st of January 2007. This data limit was established as 2007 was the year the Joint Programme "Ambient Assisted Living" from the European Union was proposed [10].

2.2 Study Selection

After the initial screening, abstracts were sub classified by AQ, AGS and NPR into one of 7 areas: i) architectures and frameworks; ii) physical devices; iii) context awareness; iv) user interaction; v) privacy and security; vi) systems; vii) conceptual articles. The operational definitions used in this review for each one of these areas are:

- Architectures and frameworks - abstraction of the structure and rules needed to reason about AAL systems and how to implement them, including different middleware approaches. In this class, we also included the articles describing methodologies required to enable efficient, engineering deployment and runtime management of ALL systems [11];

- Physical devices - the hardware components required for the implementation of an AAL system, including networks of sensors and actuators required to collect and disseminate a range of environmental data [12];
- Context awareness - technologies and methodologies to abstract and model the situation of a person, place or object considered relevant to the interaction between a user and a system [13];
- User interaction - technologies and methodologies that enhance the effectiveness and usability of a system and its interfaces [14];
- Privacy and security - privacy and security challenges imposed by the AAL implementation [15, 16];
- Systems - practical AAL systems applied in a specified context and with a well defined aim [17];
- Conceptual articles - innovative concepts related to the AAL or that may contribute to its development.

Considering that the final aim of AAL is to develop systems to enhance people's quality of life, it was decided to do a more detailed analysis of the articles included in the sub-area systems. These articles were characterized in terms of: objectives, users, settings, domains, developmental status and whether could be considered as real AAL services. The activities that the services aimed to facilitate and the environmental factors considered were also linked to categories from the ICF components activities and participation and environmental factors, respectively-

3 Included and Excluded Articles

The databases searches resulted in 2427 references, of which 462 were duplicates and 1067 did not meet the inclusion criteria and, therefore, were excluded. Thus, a total of 845 references were included in this review (Figure 1).

Among the excluded articles, there were 28 that, despite not meeting the previously defined inclusion criteria, were related to AAL and we decided to include their references for further reading. These were on topics concerning ethical and legal issues (n=18), market studies (n=8) and assessment of AAL systems (n=2).

3.1 Included Articles

Of the 845 included studies, 192 (23%) were classified as architectures and frameworks, 130 (15%) as physical devices, 246 (29%) as referring to context awareness, 113 (13%) as user interaction, 34 (4%) as related to privacy and security, 88 (11%) as systems and 42 (5%) as conceptual papers defining innovative concepts.

The higher number of publications on context awareness may be related to the knowledge that the individual performance is not only affected by the individual abilities but also by the characteristics of the environment, which can either facilitate or hinder the individual performance [8].

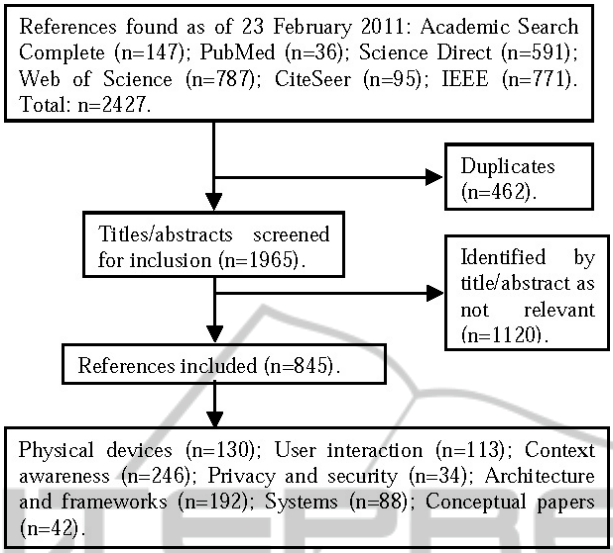

Fig. 1. Flow chart for the systematic review.

Table 1. Number of articles in each area and sub-area.

Area and Sub-area
Architecture and Framework (192):
Architecture (152); Design and Development Methodologies (37); Safety (3).
Physical Devices (130):
Sensors Network (75); Robotic (32), New technologies (23).
Context-awareness (246):
Environment (18); Location / Tracking (32); Identity Management (12); Identity Management and Location (8); Detection of Specific Events and Situations (18); Activity / Interactions (41); Human Behavior (25); Emotions (10); Reasoning (82).
User Interaction (113):
New Interfaces (52); Personalized Information (7); Design (44); Evaluation (10).
Privacy and Security (34).
Systems (88).
Conceptual papers (42):
Sensors network (2); User Interaction (6); Technology Development (6); Context awareness (2); Living Lab (5); Future Challenges for the AAL Systems (21).

It was necessary to sub-divide the major 7 areas identified in the study selection because the areas they covered very broad subjects. Thus, the main area of architectures and frameworks was sub-divided into architecture, design and developmental methodologies and safety. The main area of physical devices was sub-divided into sensors networks, robotics and new technologies. Context-awareness technologies were sub-classified into environment, identity management and location,

location/tracking, detection of specific events and situations, activity/interaction, human behavior, emotions and reasoning. User interaction included the sub-areas of new interfaces, personalized information, design and evaluation of user interfaces. AAL systems included the issues of security and privacy related to the individual and to the context so that the user receives adequate support. However, there were not clearly distinct areas of research within this topic and, consequently, the articles were not sub-classified. A total of 42 articles were classified as conceptual papers on the following sub-areas: sensors network, user interaction, technology development, context awareness, living lab and future challenges for the AAL systems. A total of 88 articles were classified as systems. The Table 1 shows the number of articles identified by area and sub-area.

4 Results and Discussion

As AAL is related to the complex interaction of a variety of technology and system components that aim to enhance people's life we decided to perform a more detailed analysis of the articles classified as systems as referred in the methodology.

Most systems were intended for use both indoor and outdoor in any environment or at home. This may be related with an attempt to improve people's life in their natural environment. The system described by Chuan-Jun and Bo-Jung [18] is to be used in outdoor environment and allows the location of the elderly anywhere in the community. Caregivers may locate care-receivers easily in a community with RFID while a Mobile Agent furnishes timely and accurate information for care provision.

Systems were conceived to be used in a variety of areas with the general aim of directly or indirectly improve the individuals' quality of life. Most systems were conceived to help care delivery either by health professionals or by any formal or non-formal caregiver. Most of these aimed at monitoring and controlling biological signs and behaviors' such as heart rate or falls. The ultimate goal is to provide the caregiver with accurate, up to date information so that the right care can be delivered at the right time. The remaining systems are on very diverse areas with very diverse objectives such as security, information, domotics, user interface, entertainment, mobility, shopping, self-care, culture, tourism, involvement in community events, physical activities and education.

The World Health Organization (WHO) defined Health, Participation and Security as the three pillars of a policy framework for active ageing. The ALLIANCE Project supported by the European Commission, that aimed to coordinate a European AAL Community, also defends that this three areas are very important to the elderly [19]. When considering the scope of the analyzed systems, one was classified as Security, while the others were classified as Health or Participation. Interestingly, a high percentage of articles describe systems that aim to enhance fundamental activities such as involvement in community events, self-care or mobility. This may indicate that the priority of existing systems is to facilitate the fundamental activities of an individual. However a few studies also describe systems that aim to facilitate activities more related to quality of life (e.g. physical activities or tourism). These studies use technologies that take advantage of existing knowledge on context

awareness. For example, the research presented by Ahn [20] is a novel approach to evaluate customer aid functions with agent-based models of customer behavior and evolution strategies that builds on existing knowledge on context-awareness technology. Agent-based modeling is used to imitate users' rational behavior at Internet stores with regard to browsing and collecting product information.

Of the 88 abstracts classified as systems, 77 described systems that use existing or new technologies to solve very specific problems (e.g. a robot to assist elderly in a particular daily activity). The other 11 articles (Table 2) describe systems showing a higher level of complexity and aggregating functions to answer to a broad range of needs in daily life situations [21]; [22]; [23]; [24]; [25]; [26]; [27]; [28]; [29]; [30]; [31]. An example is the system described by Bravo et al. [23] that is to be used in a day centre or at home to monitor the behavior of patients with Alzheimer disease as well as their vital signs. This information is then sent to caregivers and allows them to identify emergency situations and provide the appropriate care. However, the system is also used to assist patients in daily activities in order to promote their autonomy.

Table 2. Objectives of the AAL systems found.

Objective	*Article*
Diagnose, prevent and treat patients with diabetes mellitus	[21].
Personal assistant	[22].
Complement and support daily activities	[23]; [24]; [25]
Promote well-being and health	[26]; [30].
Monitor and collect vital signals	[27].
Promote autonomy	[28].
Promote participation	[29].
Assist tourism	[31].

One of the objectives of this paper was to analyze the 11 articles considered as real AAL services and describe the activities and participation that these services aim to improve. As mentioned above, it is possible to link the tasks involved in the AAL services and categories of the ICF component activities and participation. The activities and participation found in the articles were linked to the following categories: Focusing attention (d160); Reading (d163); Writing (d170); Calculating (d172); Solving problems (d175); Caring for body parts (d520); Looking after for one's health (d570); Caring for household objects (d650); Assisting others (d660); Informal social relationship (d750); Family relationship (d760); Community life (d910); Recreation and leisure (d920); and Religion and spirituality (d930).

Table 3 shows the activities and participation presented in the articles linked to the ICF categories.

As referred in the introduction, external factors can contribute to improve person's performance (i.e. the context where the tasks are completed may influence the performance of a person). The concept of AAL can be defined as the use of technologies to improve a person's performance in a specific life situation. Thus, it is possible to link the AAL services to ICF's environmental factors.

Table 3. ICF's activities and participation described in the articles classified as real AAL systems.

Activities and Participation	*Articles*
d160, d163, d166, d170, d172, d175	[27].
d520	[21].
d570	[21]; [22]; [26]; [28]; [29].
d650	[22]; [28].
d660	[23]; [24]; [27].
d750, d760, d930	[29].
d910	[22]; [26]; [29].
d920	[21]; [22]; [26]; [29]; [31].

When analyzing the 11 articles classified as AAL services, it was possible to identify 10 environmental factors, according to the ICF: Products and technology for personal use in daily living (e115); Design, construction and building products and technology for gaining access to facilities in buildings for private use (e1551); Immediate family (e310); Extended family (e315); Friends (e320); Acquaintances, peers, colleagues, neighbours and community members (e325); Health professionals (e355); Transportation services (e5400); Social security services (e5700); and Health services (e5800). Table 4 presents the environmental factors classified according to the ICF.

Table 4. ICF's environmental factors described in the articles classified as real AAL systems.

Environmental Factors	*Articles*
e115	[21]; [22]; [26]; [27]; [29]; [31].
e1551	[21]; [22]; [26]; [27].
e310	[24]; [29].
e315, e320, e325, e5700	[29].
e355	[23]; [24].
e5400	[31].
e5800	[21]; [23]; [24]; [26]; [27].

It is clear from Tables 3 and 4 that the activities, participation and environmental factors described in real AAL systems are only a small part of those described in the ICF.

5 Conclusions

The results of this systematic review indicate that there is a great amount of literature on AAL encompassing very diverse areas.

Most of the literature on AAL is technology-oriented, what is reflected in the high number of articles on specific components (89%) when compared to only 88 articles (11%) on complete systems. In addition, a considerable number of these 88 articles

on systems focus on how the technology can be used in the AAL context instead of looking at the users' needs and proposing ways in which the technology can be used to solve them. The focus is on the technology rather than on the person.

A high number of systems are conceived to help care delivery either by health professionals or any formal or non-formal caregiver. This is probably related to the continuous ageing of the population. With ageing there is a decrease in functioning associated with an increase in a variety of chronic diseases which leads to a higher consumption of healthcare services [32]. This challenges the traditional healthcare system. It is likely that the scarcity and costs of health resources compromise the ability of the health system to appropriately respond to a population that not only wants to live longer, but to live with autonomy and quality of life [33]. Furthermore, AAL systems can contribute to the reorientation of health systems that are currently organized around acute, episodic experiences of disease, by allowing the development of a broad range of systems promoting care prevention and care promotion and home-caregiver support [34]. A considerable number of technologies/systems are developed for elderly users or users with disabilities, what may be related with the previously referred demographic changes and constitute an attempt to answer to the specific needs of these users. However, the emphasis needs to shift from specific groups of users to the general user/population by developing intelligent systems with the technology embedded in the environment that can automatically select the output and input information and mode according to the specific needs and characteristics of the users, in line with the principles of the Design for All [35]. Therefore, AAL technologies would be usable by all people, independently of their abilities, age or health condition. This will contribute to decrease the price of this technology which is one of the main barriers to its widespread use. Interestingly, an important step towards this direction is being given by using the intelligent AAL component (e.g. context awareness and user interaction) to develop technologies that consider not only the person, but the activity being performed and the context in which it is taking place. This is in line with the WHO International Classification of Functioning, which sees the environment as a crucial factor modulating the person's activity and participation as a member of the society [8].

The activities and participation considered in the AAL systems indicate that these services are directly related to the Health and Participation areas of the WHO's definition of active ageing. Only one activity and participation was found related to the Security area. This can be explained because one of the main objectives of AAL is to improve the active ageing what requires the creation of services adapted to the needs of the elderly using advanced technology, like sensors, monitoring devices or communication technologies. Most of the activities and participation that were implicit in communication or participation in society can also be seen as a way to promote health. For example, Busuoli [26] describes a service that is related to the virtual communities and aims to improve the knowledge on diabetes; Dadlani [27] uses computer games to cognitively stimulate the elderly. In what concerns security it is more difficult to identify activities and participation that can translate the feeling of security by the point of view of the caregiver. Services that refer to security were linked to the category d660 (Assisting others) of the component activity and

participation. Other possibility would have been to link it to a personal factor related to emotions, personality and personal characteristics of a person.

Considering the presence of environmental factors in AAL services it was clear that technologies and services that use actuators, sensors, and cameras may be classified as e115 (Products and technology for personal use in daily living) or e1551 (Design, construction and building products and technology for gaining access to facilities in buildings for private use). These two environmental factors were present in all the articles describing AAL services. One explanation for this is, as argued by Bravo [24], "the idea is that the user should focus on the task and that technology should disappear". The other environmental factors that were identified are related to the activities and participation and aimed to improve relationship, community life, recreation and leisure. Obviously, social support networks (formal or informal) have a major impact in these activities and according to the ICF can be classified as environmental factors.

To summarize, this review of existing literature on AAL highlights the need to rethink the future research approach on the development of AAL systems in order to take advantage of already existent technologies and systems. The difficulty found when classifying the articles also suggests the need for a common classification that could be used to characterize existing AAL systems. Furthermore, according to what was described in the previous sections, the needed requirements to deliver viable, adaptative and personalized AAL systems are still not fulfilled. There is a general tendency to develop AAL systems from the scratch with specific solutions. Therefore, there is a need for a normalized and coherent technological sub-stratum over which AAL systems could be developed to answer the real demands of the users.

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