Chapter 20
A crash Introduction to Ambient Assisted Living

Manuel Fernández-Carmona* and Cristina Urdiales

ISIS group, ETSI Telecomunicación, Campus de Teatinos s/n 29071-Málaga, Spain

*Correspondence: acurdiales@uma.es

20.1 From traditional Domotics to Smart Houses

Ambient Intelligence (AmI) was coined as a term by the European Commission in (Ducatel et al.,2005) and has received major attention in the last decade. An AmI environment is expected

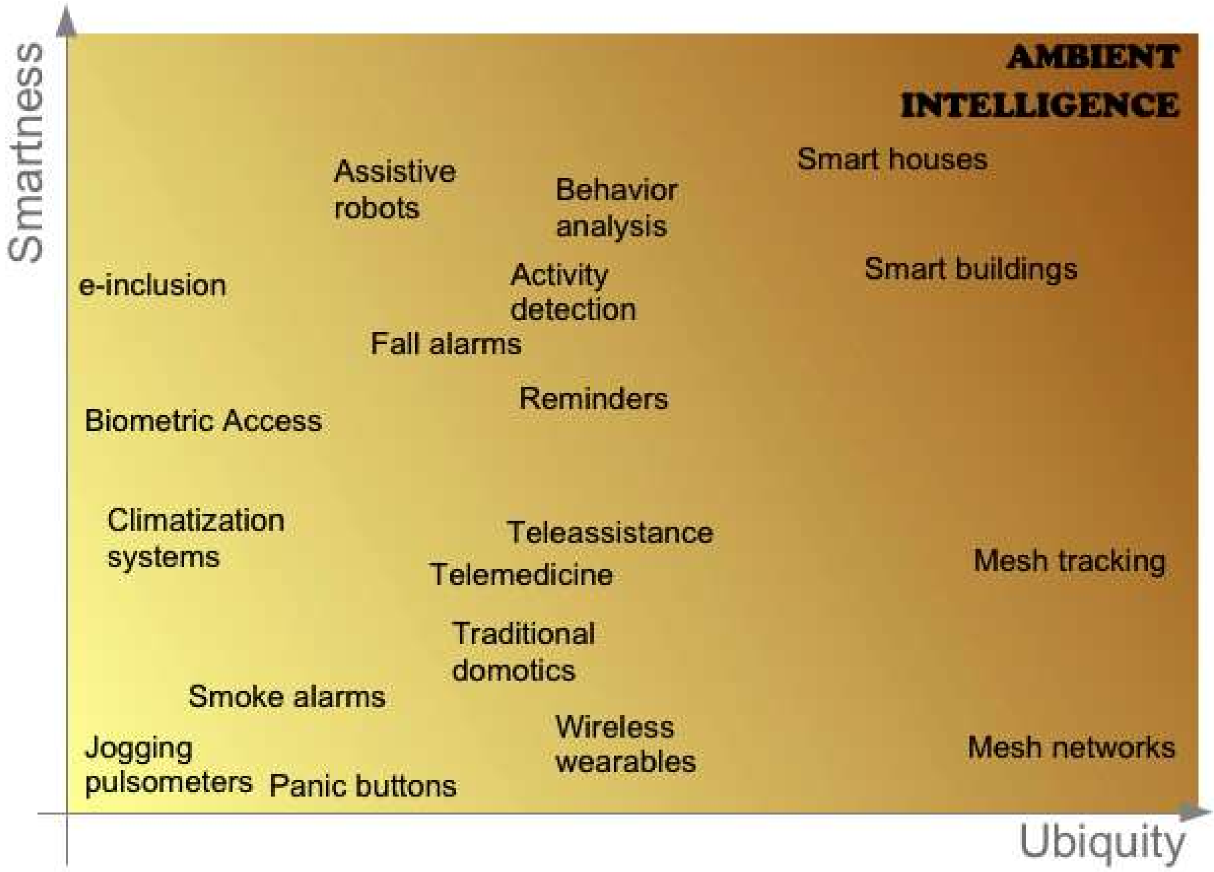

Figure 20.1: On the way to Ambient Intelligence

to be sensitive to the needs, personal requirements and preferences of its inhabitants, and capable of anticipating their needs and behavior to interacts with people in a user-friendly way (Sadri,2011). There are many similar definitions, but most authors agree that all of them imply the capability of embedding sensors in everyday objects to raise context awareness and processors to learn and adapt to the user's behavior (Gaggioli,2005) (Aarts et al.,2001). Indeed, if we plot applications related to AmI against embedding and context awareness, we obtain a diagram like Figure 20.1.

It can be noted that we use the term *smart* instead of *intelligent* because many authors state that we are still a long way off from real AI environments. Similarly, we have chosen *ubiquity* instead of *embedding* to generalize our description. It can be observed that there are very simple systems that have been in use for decades, like *panic buttons* or *smoke alarms*. These systems do not require any intelligence and only the most basic connectivity. Original air conditioning systems used to be reactive too, meaning that a splitter would open or close depending uniquely on the local temperature. Current HVAC systems, however, are a bit smarter and can be networked, temporized and even remotely activated. If we go for more complex systems where input signals need to be further processed to choose a proper action, we need to increase the system smartness (e. g. biometric access) or even gather information for a time period in order to build a user profile (e-inclusion). However, in these systems connectivity is not vital, since no networking is needed in general. A first step in this direction would be wearable systems that are connected to a network during operation, usually via a Personal Area Network (PAN), for example, the bracelets that people with mild cognitive problems wear for tracking. In this case, the device does not need to be too smart, just able to transmit. Please, note that this is not the same than a body sensor where one has to go to a station to download captured data from time to time, like a jogging pulsemeter or a dive computer. Nevertheless, many traditional systems of telemedicine were based exactly on this: having the user go to a networking unit connected with a biometrics sensor(s) with some regularity (telemedicine at home) or when a specialist is not locally available (telemedicine at care centers). Communication and sensor technology has improved enough nowadays to actually be able to develop multiparametric wearable sensors that can connect to a Wide Area Network (WAN) using a mobile phone as a gateway (e.g. Equivital). Alternatively, and specially if users are in their preferred environment, sensors can be deployed at the house. The first steps in this direction were traditional domotics systems, where several sensors were embedded in a house to trigger alarm or activate some automations (e. g. light switching, smoke alarms, person detection...). Most works in this area focused on developing a reliable standard to integrate devices from different manufacturers in a seamless way, like X10, I2C or KNX. Current installations are also connected to the Internet through a gateway to enable interaction with devices via web services, from a PC or a mobile phone. Many manufacturers aim at zero-installation by deploying their devices in a wireless mesh network, placing them wherever they are supposed to operate and switching them on. Current mesh networks allow communication among a large number of sensors with an average battery life from 1.5 to 2 years and there's been an effort to work with scavenger devices that can actually recharge from residual energy, like glass vibration due to city traffic. The best known approach to scavengers would be passive Radio Frequency IDentification (RFID), where tags can send their identification to a transmitter using just energy received from that transmitter. RFID has been widely used for context based awareness, by tagging everyday objects with passive tags and learning their sequence of activation. This technique indirectly provides behavior and activity analysis without all privacy concerns related to videocameras. If we combine a ubiquitous mesh network with smart devices and processors, we evolve into smart homes, which would be close enough to nowadays AmI environments.

According to (Friedewald et al.,2005), smart homes offer one or more of the following features: a) home automation; b) communication and socialization; c) rest, refreshing, and sport; and d) household work and learning. Home automation is the evolution of traditional domotics, whereas communication and socialization include communities and all profile based e-services, including e-government and e-participation. All biometrics and fitness programs fall within the third category and Household work and learning correspond to smart actuators, like robot vacuum cleaners, smart washing machines, etc. These services are often coordinated by an agent architecture (e.g. MavHome (Cook et al.,2006), SHARE-IT (Cortés et al., 2010), iDorm (Holmes et al., 2002)). There are already many existing smart homes used for research around the world, most of them under the Living-Lab paradigm. *MIT House-N* (Intille, 2002), for example, is used by OSBA (Open Source Building Alliance) to test new technologies and services -with a focus on advanced sensor networks- under the joined effort of developers, architects, manufacturers, installers and customers. It includes PlaceLab, a 1000 sq foot full service condominium prepared to gather fine grained data on human behavior. The *Aware Home Research Initiative* has given support to several small scale projects, including *Aging in Place*, was originally planned to support social connections between the elderly and their family and improve cognition aspects like memory and planning skills, but their functionality was extended later to behavior analysis as well, via heavier sensorization (Tran et al, 2010). *Gator Tech Smart House* focuses on elderly people with disabilities and it is equipped with a large number of smart-labelled furniture and appliances including gadgets like smart-floor for localization and falling detection, smart-closet to advise on clothes depending on the weather, a smart-mirror to display information or a smart-bed to monitor sleeping patterns (Helal et al, 2005). Some researchers have taken a step ahead and, instead of building their own smart home, they actually placed their technology in living facilities used by the elderly in a continuous way, like TigerPlace (Skubic et al, 2011). There are even more ambitious approaches to AAL, like a full smart city: FUSIONOPOLIS was proposed by A*Star Singapore (Agency for Science, Technology and Research), where areas of the city have been build or remodeled according to the AmI paradigm (e.g. Jurong Lake District), including Wide Area communication networks (e.g. WIMAX), intelligent energy distribution systems, smart climate control, crowd behavior analysis, etc.

It can be noted that most technologies necessary for AmI applications are available nowadays. However, there are still not so many of them deployed. The problem is, of course, the costs of such an installation. While personal computers and smartphones have already a prominent presence in many houses, sensor networks and actuators are still too expensive to, for example, afford ourselves a home capable of learning how we like our illumination and HVAC at all times. It is no surprise, consequently, that most state of the art approaches to smart homes are usually related to Assisted Living, with a special focus on the elderly, as covered in next section. Cost is not an issue for a person with special needs to achieve a certain degree of autonomy. Even if a given person can not afford an AmI installation, it is still way cheaper in terms of well-being and cost for social services, health systems or insurance companies to pay for ICT based AAL than to proceed to institutionalization. Assisted Living has the trifecta of *technology*, *cost* and *need (Urdiales, 2012)*.

20.2 Ambient Assisted Living

Assistive engineering and design is a field at the intersection between technology, the natural sciences, the humanities, the social sciences, and medicine. Assistive technologies are of special interest, as the average age of the population increases fast: there will be an estimated 74% growth in population 65 – 74 by the year 2020 (Camarinha and Afsarmanesh, 2001). This growth is exceeding the under 65 population which only sees a growth of 24% (Wan et al., 2005). Indeed, the share of the population aged over 80 years (3.6% in 2000) is expected to reach 6% by 2025 and 10% by 2050.

At the same time, the percentage of people with disabilities increases with age: data shows that half of senior 65+ have a disability. Only in the USA there are over 35 million people with disabilities (Pope and Tarlov, 1991). The association between old age and disability occurs because more people live longer and, thanks to the progresses of medicine, many more persons survive acute diseases resulting affected by chronic conditions and some disabilities. Clearly, human resources will not be sufficient to assist all elderly or people with disabilities, so ICT are expected to play a key role in this respect. Indeed, the main goals of assistive technologies are:

- To increase self-dependency.
- To allow community dwelling: demographic changes leaded a large number of elderly people to live alone.
- To increase the elderly users' participation in ICT based assistance
- To provide insightful data to health professionals, caregivers, familiars, psychologists, system designers...

The alternative to ICT based assistance is institutionalization, which has a major cost in social, personal and economical terms. Hence, it is only natural that most efforts in AmI has focused on developing smart homes for people with special needs. Just to mention an example, the Ambient

Assisted Living Joint Programme (AAL JP) in Europe had a total budget of 600 M EUR over 6 years, was co-funded by the European Commission and both public and private entities and has supported 60 projects since 2008.

Smart homes have been around for a while. Indeed, the original concept dates back from the 50s. However, the technology required to make them work has not been available until recently. According to (Sadri, 2011), a smart home should: i) automatically perform everyday tasks; ii) improve economy of usage of utilities like electricity; iii) improve safety and security; and iv) improve quality of life. Besides, the main challenge in human centred projects is to overcome the Digital Divide (DD) by following a “Design for all” paradigm. Elderly people conform a quite heterogeneous group with very different needs and skills and technology must be available and useful for all of them. The key aspects affecting the DD are reported to be age, technological skills, geographical location, culture, disabilities and gender. All Assisted Living projects must keep ergonomy and transparency in mind and make no assumptions regarding the technological skills of potential users. This target implies a high capacity for adaptation, that is typically achieved through experience based learning.

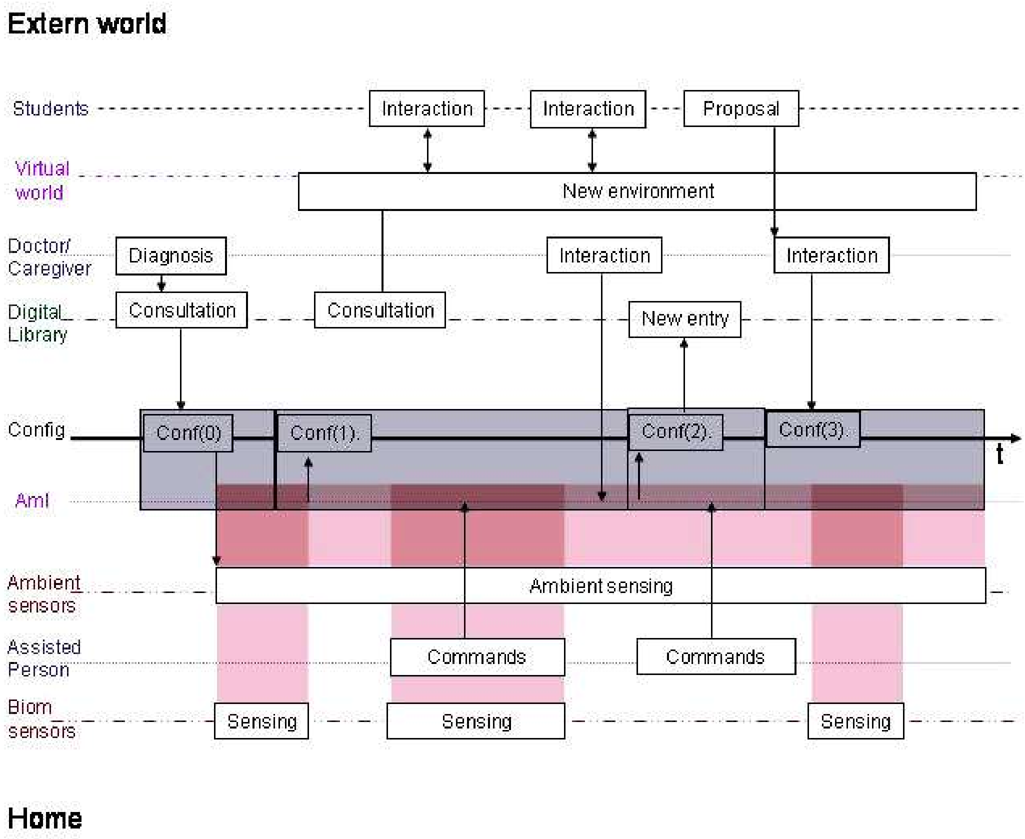

Figure 20.2. Full cycle of a smart assistive home

If we combine the commented goals of assistive technology with smart homes, we obtain a functional architecture like the one in Figure 20.2. In brief, both the house and the user are equipped with networking sensors that, in combination with the user's commands and actions, are analyzed by the system to create a user profile. This profile, that could be complemented by any medical information available for that particular user is user primarily to assist the user, personalize services and generate alarms, if necessary. It can potentially be used as well to provide insightful data to health professionals and system designers, by storing profiles, after they are devoid of sensitive information, into digital libraries. In extreme, information in these libraries can be used as well to generate virtual environments for teaching and training of future professionals in the area. However, AAL projects usually do not cover the full spectrum of applications. Instead, they focus on a number of the commented aspects.

An extensive analysis of the numerous projects on Assisted Living that have been developed in the last five years clearly shows that most of them have similar goals, even though they may be oriented to different target populations. Projects in (approximate) order of smartness, can be loosely categorized into (Table 20.1):

- *e-Inclusion*: These systems focus on integration of ICT technologies via adapted interfaces that can be personalized using profiles. Research here focuses on integration of communication standards and services, as well as developing or adapting new HCI and devices (MyLife, HOST, GoldUI).
- *Social interaction tools:* These systems have been traditionally implemented as call centers offered by social services and health providers to elderly people living alone. These call centers keep periodical communication with the user to prevent isolation and also whenever the user feels in danger. Most services at the moment include peer to peer and broadcast videoconference and sometimes are used to offer loosely supervised cognitive or physical exercises (HERA, CO-LIVING) that can be later evaluated by a professional to check on the user's condition. In recent years, the social networking boom has led to more ambitious tools that also aim at creating communities of the elderly without service supervision. Furthermore, the degree of participation of a person in these networks could be used to assist diagnosis of syndromes like Geriatric Depression. Some of these projects aim at reutilization of common devices like TV sets (HOMEdotOLD,

FOSIBLE), whereas others focus on new ones like smartphones or tablets (GO-MY_LIFE, Express to connect) or even develop their own platforms, like touch screens (ELISA, ConnectedVitalityNetwork) or even mobile robots (ALIAS, EXCITE). Innovation in this kind of projects is related to open standards, hardware integration and development of adapted, user-centred interfaces.

- *Remote monitoring:* Probably one of the simplest approaches in terms of intelligence, remote monitoring consists of periodically evaluating the state of a person -usually a chronic- by checking a set of parameters, typically biosignals (AMICA, ALADDIN), but also activity in general (PAMAP). In these cases employed sensors tend to be non-invasive either biometric ones or biosensors. The user may be required to perform the measures himself and send them to the monitorization center or he might be equipped with wearable sensors instead, that could transmit their readings automatically when necessary. This solution has been widely used in countries where there are many isolated population nuclei for primary attention and most effort has been dedicated to development of cheap and reliable communication networks and easy to use biometric devices.
- *Reminders*: These systems are based on reminding the user -typically a person with minor to mild cognitive disabilities- to perform a given action at an appropriate time of the day. These actions may range from the very simple, like taking a medication, to more complex tasks like dressing up. To do so, the system needs an (estimate) agenda of the Activities of Daily Living[1] (ADL) of the user and it must be able to provide feedback through an

1 ADL include activities like eating, getting in and out of bed, using the toilet, bathing or showering,

adapted interface, frequently audio. The reminder may be triggered simply by the clock or it also may require additional conditions, like not being in a place of designation at the time. If this is the case, ambient sensors may be needed.

- *Alarm generation*: Users and/or environments are equipped with a set of sensors that can reliably captured isolated and potentially dangerous situations, e.g. inertial sensors and fall detection (CARE, eCAALYX, HOPE). When one of this situations is detected, the system automatically informs caregivers or social services, so they can act in consequence. In their simplest version they do not even require sensors: they have been available for years in the shape of a panic button, that the user pushes in a dangerous situation. It needs to be noted that these are purely reactive systems and most innovations to this respect occur in the employed sensors, often wearable ones (e.g. ISACTIVE) but also external (e. g. CARE).
- *Behavior analysis:* These systems are more complex than the previous ones in the sense that they do analyze the user's actions as a whole, create a profile and check for irregularities. To do so, the user and/or the house must be equipped with a set of sensors that capture his activity and correlate it with his location, time of the day and nearby elements. Repeating patterns and sequences conform the so called user profile, that is expected to be repeated over time. Unlike the agenda for reminders, profiles are not available a priori, but learnt over time. When these profiles are available, the system may check for deviations in current behaviors with respect to the profile, rank them from neglectful to serious and, if necessary, generate the proper alarms. This information can

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dressing, using the telephone, shopping, preparing meals, housekeeping, doing laundry, or managing medications also be use for diagnosis support (BEDMOND, REMOTE), as it is gathered through long time periods and, hence, helps to understand better the progress of a given condition and/or treatment (H@H, ROSETA).

- *Autonomous assistance:* It can be observed that most commented systems can be defined by the information they capture, but there is usually a human in the loop to make the ultimate decision or provide required care. A last stage in an assistive system is to include actuators that can provide physical assistance to the system user. These assistive devices may vary greatly, from wearable drug dispensers (HELP) to assistive robots. These robots must be distinguished from social robots (ALIAS, EXCITE) that, in fact, do not support activity. Robots in this group (DOMEO, SHARE-IT) rather provide assistance to mobility (robotic wheelchairs and walkers). Note that most systems provide assistance of some kind. The specifics of these ones are that the amount and type of assistance must be automatically estimated by the system and that some physical interaction with the user is required.

	E-inclusion	Social interaction	Remote monitoring	Reminders	Alarm generation	Behavior analysis	Autonomous Assistance
New interfaces	Y	-	N	-	-	-	Y

WPAN	N	N	-	Y	-	Y	-
WLAN	N	N	Y	Y	Y	Y	Y
Web Services	Y	Y	N	-	-	-	-
Internet	Y	Y	N	N	-	-	-
Ambient sensors	N	N	Y	-	-	Y	-
Biometric sensors	N	N	Y	-	-	-	-
Wearables	N	N	Y	Y	-	Y	-
Actuators	N	N	N	N	N	N	Y
Reactive AI	N	N	N	Y	Y	-	Y
Deliberative AI	N	N	N	-	N	Y	Y
Profiling	Y	-	N	N	N	Y	Y

Table 20.1: Requirements for Assisted Living Projects

20.3 Localization for contex awareness

The main challenge in AmI environments is probably **context awareness**. Early definitions of context awareness state it provides information on "where you are, who you are with, and what resources are nearby" (Schilit et al. 1994). Other authors state that context is the set of variables that may be of interest for an agent and that influence its actions (Bolchini et al., 2009). (Chen and Kotz, 2000) propose a 4-dimensional space composed of computing context, physical context, time context, and user context. Sensors and actuators are specifically related to the so called physical context and, specifically, to device/user location, which has been reported as key information for context awareness.

Given the importance of the user's location with respect to items for context awareness, it is not surprising that much effort has been focused on estimating it. Localization has been traditionally solved by means of triangulation and most systems in AmI still rely on this procedure[2]. However, while GPS is extensively used outdoors, indoor localization relies on other signal beacons to operate. This procedure is globally known as RSSI-based localization (Received Signal Strength Indication) and it can be based on different wireless protocols that work both indoors and outdoors, like WiFi, BT, ZigBee or RFID (Table 20.2). There are also hybrid systems that combine different radio frequency technologies to combine their strengths (LaMarca et al, 2005). The main issues regarding this approach are power consumption, range and precision. For example, WiFi is likely to cover a wider area with less emitters than Bluetooth or Zigbee, but its power consumption is way higher. If we compare BT to Zigbee, beacons would likely consume less power in the second case, since transmitters would be off most of the time. In applications where device feeding is an issue (typically wide area applications outdoors, like tsunami detection, volcano alarms …), it is preferable to use a larger number of low power consumption devices, whereas in environments where beacons can be plug to a power line, it is usually better to rely on just a few wide range ones. Regarding costs, it is

2 Many indoor systems rely on using video-cameras to localize the user, but recent trends avoid this approach due to privacy-related issues, so they are not going to be included in this chapter.

always better to rely on signals that are already deployed in the environment, like GSM or 3G outdoors (Zhu & Durgin, 2005) or WiFi networks indoor (Youssef & Agrawala 2005), if possible.

It also needs to be noted that working with technology that can be used to other purposes makes the system cheaper. For example, the mobile phone network makes it easy to localize any user with a mobile phone without any extra technology. Interferences may be a problem in these cases, though: WiFi and BT networks are quite frequent everywhere and out of the designer control (laptops and mobile phones of neighbors and by-passers), so frequency-hopping based devices like BT or Zigbee might find in extreme no room to settle themselves in the spectrum (Trapero et al., 2007). In these cases, BT would overpower Zb, but localization beacon packets are so tiny that they may manage to squeeze themselves in any opening in these cases. This problem can obviously be avoided working with protocols with non-overlapping operation bandwidths.

The main issue with the commented localization techniques is precision. Usually, RSSI-based techniques have an uncertainty between 1 and 2 meters at best, depending on the processing algorithms they use. In some application, this is enough, but sometimes more precision is needed. In these cases, there are commercial solutions based on detection: the user carries a tag, either active or passive, that can be read only at certain distances, so the system knows if the person is nearby one of the readers. Indeed, NFC (Near Field Communications) and, more specifically, RFID based localization have been widely employed in hospitals to track not only people, but also material and equipment (Table 20.2). (Torres-Solís et al., 2010) presents a deeper survey on indoor localization technologies.

RFID			
Product	Use	Notes	url
Identec	User tracking Asset tracking	Propietary protocol	http://www.identecsolutions.com
Syris Xtive	User tracking Asset tracking	Propietary protocol	http://xtive.com.tw
UWB			
Ubisense	User tracking assisted living apps	UWB - (TDOA) and (AOA) techniques	http://www.ubisense.net/en/ http://www.ubisense.net/en/resources/case-studies/assisted-living.html
Bluetooth			
Topaz	User tracking	RSSi techniques	http://www.tadlys.co.il/pages/Product_content.asp?iGlobalId=2
IPCS	User tracking asset tracking	Bt low energy RSSi techniques	http://www.9solutions.com/ipcs-insight/products

Zigbee			
Nanotron products	asset tracking	RSSi techniques	http://www.nanotron.com/EN/PR_products.php
IDC zigbee tracking system	Asset tracking	RSSi techniques	http://www.zig-bee.co.uk/tabid/1026/Itemid/10/default.aspx
Netvox	Location – home automation	RSSi techniques	http://www.netvox.com.tw/
WiFi			
Hugs Infant Protection	User tracking	WiFi Tag -RSSi techniques	http://www.stanleyhealthcare.com/solutions/patient-security/hugs-infant-protection
Passport Patient Protection	User tracking	WiFi Tag - RSSi techniques	http://www.stanleyhealthcare.com/solutions/patient-security/passport-patient-protection
Petz Pediatric	User tracking	WiFi Tag - RSSi	http://www.stanleyheal

Protection		techniques	thcare.com/solutions/patient-security/pedz-pediatric-protection
RoamAlert	User tracking	WiFi Tag - RSSi techniques	http://www.stanleyhealthcare.com/solutions/patient-security/wander-management/roamalert
Aeroscout	Asset tracking – location – sensoring	WiFi Tag – WiFi network - RSSi techniques	http://aeroscout.com/healthcare
Ekahau	User tracking – Asset tracking	WiFi Tag – WiFi network - RSSi techniques	http://www.ekahau.com/products/products-overview.html
Infra-red			
HiBall Tracking System	User tracking	RSSi techniques	http://www.3rdtech.com/HiBall.htm

Table 20.2: Commercial Indoor localization solutions

Similarly, passive RFID tags and a portable reader have been used in pervasive computing to detect what the user is actually touching[3], which can intuitively associated with the services.

3 MIT Home of the Future, 2003, http://architecture.mit.edu/house_n/

Passive tags must be less than 50 cm away from the reader, depending on the technology (active tags can operate within a few meters distance). Hence, their sequence of activation may be correlated with the user's ADL or associated to a certain activity (Philippose, 2003)(Tran et al, 2010) (Wren, 2006). Other researchers have also conducted similar studies using domotics networks deployed around the house (presence and motion detection, touch sensors, switches, videocameras, etc …)(Alwan et al, 2003)(Virone et al, 2008) or worn by the user instead (Himberg et all, 2001)(Lee & Mase, 2002). The main advantage of passive RFID-based systems is that only one reader per user is needed and cheap sticker-like tags can be distributed around the environment with no need for battery replacement nor installation. Unfortunately, commercial readers are still too bulky to wear them comfortably and there are some problems regarding antenna orientation, interferences with materials, etc, so this hardware technology is still under development.

Once a person is localized with respect to his environment, captured data can be contextualized and modeled into knowledge. Context data can be roughly split into general models, domain-specific models and no models (Bellavista et al., 2012). The main problem with knowledge-extraction in this field is that there is no general model of human activity: instead, each person has different ADL depending on his preferred environment distribution and state, circumstances, functional profile and likings. Hence, most AmI applications focus on learning an activity profile of their target user and estimating the importance of deviations from the acquired profile. AmI systems usually mine sequential patterns to detect habits and repetitive actions, since interactions of a person with devices in a smart house as part of his routine can be considered as a sequence of events (episode), with some inherent pattern of recurrence (Agrawal and Srikant, 1995). There are several techniques to detect these sequences, like the Episode Detection (ED) algorithm in (Heierman and Cook, 2003), Bayesian networks (Chen et al. 2012), Markov Models (Kautz et all, 2003) or location-clustering (Youssef and Agrawala, 2008). The sequence set for a given person conforms his profile and the system can use it to predict his actions, release some system response, detect abnormal behaviors or trigger alarms.

20.4 Sensors and actuators

Ambient intelligence integrates different computational paradigms, as well as many devices that must coexist as seamlessly as possible. Integration is always a challenge, specially when full ad-hoc design is unfeasible because not every part of the system is going to be developed by its designers. The safest way to achieve compatibility is to comply with existing standards.

AmI sensor and actuator networks are typically based on the same standards than traditional domotics and, hence, they present similar advantages and drawbacks. It is important to know them in advance when we decide what technology to use in our system. Table 20.3 briefs the best known standards in the field and its applications.

The first issue to consider is whether the standard is open or not. For example, well known standards like *Lonworks* or *ligthwaveRF* are proprietary standards, meaning that every device inserted in the network must be purchased from their associated companies and interoperability with other networks is very limited or null. This might seem a minor concern, but, in fact, it is very constraining, because some standards do not support some devices. For example, X10 is not reliable, so it does not support alarm devices (fire, smoke, flood, etc). The only way to include them in an X10 based installation would be to have a two parallel networks in the house. In this sense, open protocols are preferable, since any manufacturer can actually built a standard compliant device, incorporate a standard-compliant interface to an existing device or simply tap into the network(s) to extract all required information and forwards ir to the local processing unit. Casa Agevole in (Annicchiarico & Cortés, 2010), for example, combines KNX-EIB devices with a Zigbee sensor network and an ultrasonic localization system.

In its simplest form, a standard could be simply defined at link/network level in the OSI stack, so any compliant device would be fully compatible with OSI compliant devices and protocols as well (e.g. WiFi or IP cameras), but isolated devices are usually much more expensive and harder to find.

A second issue is whether the chosen standard requires specialized installation. For example, some standards like KNX-EIB require licensed staff for installation and maintenance. This implies an additional cost in terms of money and time, as well as a dependency or third parties. It also needs to be noted that wired installations not only require structural changes in the house, but also additional elements of support to connect to the local bus, feed the different devices, etc. In contrast, a completely wireless mesh architecture, like Zigbee working in zero-configuration mode, ideally requires only a gateway into the local processing unit to be fully operative.

It could be assumed that wireless systems are always preferable but, in fact, this is not totally true. Even low power consumption standards like Zigbee work on batteries that need to be replaced from time to time. In mesh networks where not all elements spend the same time active, each sensor and actuator would consume its battery in its own time, so, in practice, one would spent much time replacing them. Actually, wireless device that need to send a mild amount of information with some regularity may be wireless in terms of communication but plugged to the electric supply. This arrangement obviously does not require specialized installation. However, it can be observed in Table 20.3 that only a few standards support all kind of devices. This brings us to the third consideration in design: cost.

There are major differences between the cost of an installation depending on the chosen standard. Table 20.3 shows tentative prices for the same toy installation with the basics to be completely functional and just one sensor of each kind. Prices may change depending on the provider and the time of installation and it also needs to be taken into account if equipment needs to be imported to obtain the final cost. However, it is immediate to notice that KNX-EIB is 4 times more expensive than BUSing, and 8 times more expensive than X10. As commented, X10 is not reliable enough to support fire smoke detectors, but it is fairly cheap to operate via Internet. All in all, the best option could be to install a heterogeneous network where all devices were integrated after data is exported to the processing unit, so that expensive standards only support critical devices, but it can be noted that the enormous price difference is mostly due to functional elements of the network, like the RTC-EIB and IP gateways. Besides, this approach could imply the need for two different installers, so most systems ultimately choose a unique standard depending on their needs (Cortés et al, 2010).

Standard	Parts	Price
KNX-EIB	RTC EIB Gateway (support) Smoke detector Motion detector (volumetric) Door opening detector Light actuator IP Gateway	~1700 EUR ~170 EUR ~160 EUR ~95 EUR ~150 EUR ~1500 EUR TOTAL: 3775 EUR
BUSing (wireless)	ETHBUS Web Server B-W Wireless Gateway MECing-W adapter	~420 EUR ~50 EUR ~60 EUR

	Smoke detector Motion detector Door opening detector Light actuator	~85 EUR ~105 EUR ~85 EUR ~195 EUR TOTAL: 1000 EUR
X10 (wireless)	WLAN X10 interface Smoke detector Motion detector Door opening detector Light RF actuator	~360 EUR Not manufactured ~62 EUR ~34 EUR ~45 EUR TOTAL: 501 EUR

Table 20.3: Tentative (real) budget for a toy domotics installation for different standards

Name	Type	Uses	URL
Lonworks	Propietary wired domotic protocol	Lighting, energy, HVAC, security, building automation	http://www.echelon.com/technology/lonworks/
Bacnet	Open data communication protocol for building automation and control networks	HVAC, interoperability of domotic networks,	http://www.bacnet.org/
KNX	Open wired/wireless domotic protocol,	HVAC, building automation, Alarm monitoring, Energy management & Electricity/Gas/Water metering, Audio & video distribution	http://www.knx.org/
X10	Propietary wired/wireless domotic protocol	building automation	Www.x10.com
Z-wave	Open wireless domotic protocol,	Gateways, Hospitality, Lighting, Locks, Remote Controllers, Security & Alarm, Sensors, Shade Control, Smart Meters, Thermostats, Window Control	http://www.z-wavealliance.com/
Zigbee	Open wireless communication protocol,	Low power communcations, Building Automation, Health Care, Home Automation, Smart Energy	http://www.zigbee.org/Standards/Overview.aspx
ligthwaveRF	Propietary wireless domotic protocol	Lightning power, heating security, energy , assisted living	http://www.lightwaverf.com/

RFID	Tracking and identification protocols. Open and propietary	Access management, Tracking of goods, persons and animals, Contactless payment, Machine readable information, Massively distributed sensor networks, Authentication	http://rfid.net/
ILLUMRA	Open wireless domotic protocol. Based on ultarlow power consumption protocol EnOcean (ISO/IEC 14543-3-10)	HVAC control, house automation	http://www.illumra.com/Products/index.html
WiFi	Open Wireless communication protocol	Networking, Consumer Electronics, Computing & Peripherals, Handsets, Transportation Management, Medical/Fitness Devices, HVAC, Home Security and Control, Embedded Sensors	http://www.wi-fi.org/
Bluetooth	Open wireless communication protocol	Automotive, Consumer Electronics, Health & Wellness, Mobile Telephony, PC & Peripherals, Sports & Fitness, Smart Home	http://www.bluetooth.com
Continua	Industrial interoperablility standards between Bluetooth and USB devices, enabling them to more easily share information with caregivers and service providers.	healthcare	http://www.continuaalliance.org/index.html

Table 20.4: Standards

20.5 Biometrics sensors

Biometrics sensors are well known in telemedicine applications, but in order to use them at home, they must be easy to adjust and their output must be easy to transmit to a processing unit. Monitorization can either be invasive (e. g. needles, probes, etc.) or non invasive. Even though in extreme cases invasive devices are acceptable (e.g. electromyography based control, glucosemeters...), biometrics sensors are usually non-invasive, specially if users must attach them on their own.

Ideally, biometrics sensors should be wearable, meaning that the person can be constantly monitorized during their daily activity. Wearable sensors must be comfortable, resistant and wireless. Besides, they must be low power consumption devices, so they are based on communication standards that can operate for long time periods without battery replacement.

Most typical commercial sensors matching the commented criteria for non specific conditions include blood pressure, heart rate, frequency rate, blood oxygen saturation and body temperature, ranging from 2000 to 5000 USD. Some researchers have tried to develop their own ad-hoc sensors, e. g. (Mundt et al., 2005), but most systems rely on market solutions because: a) devices must be safe to avoid any user damage (electric shock, interferences with pacemakers, device warming, etc.); ii) they must be compatible with the usage of other medical devices (i.e. pacemakers), but also with everyday devices such as mobile phones and PDAs; iii) devices should be standard-compliant. One of the main issues with commercial sensors is to obtain their raw readings for processing, as many of them just show processed data in their own displays. As commented in previous section, the best option is to offer data flows via a well known, popular standard, like Bluetooth. However, it is necessary to take into account the bandwidths of the signals to be transmitted if communication is supposed to go live rather than off-line: for example, an ECG data flow is on the limit of what BT can actually transmit safely, whereas electromyography data would exceed BT bandwidth. Nevertheless, most systems try to achieve compatibility with smartphone supported protocols so received signals can be broadcasted using

GPRS or 3G when there is no LAN available (e.g. MOBIHEALTH**).**

Table 20.5 shows a list of current biometrics devices on the market that present all commented features.

Name	Company	Notes	URL
ECG			
BT12	Corscience	Bluetooth communication, 12 channels	http://www.corscience.de/en/medical-engineering/products/ecg/bt12-device.html
Pulse-oximetry			
4100 Bluetooth Pulse Oximeter	Nonin	Bluetooth	http://www.nonin.com/
Blood-pressure			
Boso-Medicus Prestige	Corscience	Bluetooth	ttp://www.corscience.de/en/medical-engineering/products/blood-pressure/boso-medicus-prestige-bt-device.html
EEG and EMG			
NeXus EEG cap	MindMedia	21 channels	http://www.mindmedia.nl/CMS/en/products/eegaccesories/item/186-nb-eegcap-s/m/l.html
KMS (Kine	KINE	Wireless	http://kine.is/Products/MMS/

Measurement System)		EMG	
Galvanic skin response (GSR)			
Skin Conductance Sensor	Thought Technologies		http://www.thoughttechnology.com/
Body and skin temperature			
Temperature Sensor	Thought Technologies		http://www.thoughttechnology.com/
Heart Rate			
HR - 210	Omron	Strapless HR monitor	http://www.omronwebstore.com/detail/OMR+HR-210
Blood-pressure			
Upper Arm Blood Pressure Monitor 767PBT	A&D	Bluetooth, continua compliant	http://www.andonline.com/medical/products/details.php?catname=&product_num=UA-767PBT-C
Respiratory rate			
Respiratory belt transducer	ADInstruments	DIN or BNC connector	http://www.adinstruments.com/products/mlt1132#overview

Table 20.5: Commercial biometrics sensors

It needs to be noted that most chronic patients require supervision of several biometrics parameters at the same time. Since solo devices are still quite bulky, most systems actually rely on multiparametric sensors, that can capture several magnitudes at a time. Most these devices are built around body belts, where capture devices can be plugged in on a need basis. Table 20.6 briefs current commercial multiparametric sensors and the parameters they provide.

Device	Company	Parameters	url
NIBP2010/ChipOx	Corscience	blood pressure, oxygen saturation (SpO2) and pulse rate	http://www.corscience.de/en/medical-engineering/products/multiparameter/nibp2010chipox-board.html
ProComp Infinity	Thought Technology Ltd	8 channels for: ECG, EEG, EMG, blood volume pulse (BVP), heart rate, GSR, respiration or skin temperature	http://www.thoughttechnology.com/
Nexus-10 MKII	MindMedia	4 single channel inputs, 2 dual channel inputs, 1 oximetry input and 1	http://www.mindmedia.nl/CMS/products/nexus-systems/item/175-nexus10mkii.html

		digital multichannel input muscle tension, brainwaves, heart rate, relative blood flow, skin conductance, respiration, temperature, oximetry	
Equivital	Hidalgo	ECG, Respiratory, Tri Axis Accelerometer and temperature, Core Body Temperature, Galvanic Skin Response, Oxygen Saturation	http://www.equivital.co.uk/
Sensium Life Platform TZ2050	Toumaz	HR, ECG, accelerometer, temperature	http://www.toumaz.com/uploadsv3/wysiwyg_editor/files/TZ205000-MPB%20Product%20brief%20Sensium%20Life%20Platform%20V1_1.pdf#search=%27sensium%27

Table 20.6: Commercial multiparametric sensors

20.6 Interfaces and ergonomics

Originally, most interfaces in AAL used to consist of switches and/or a PC based interface. In these cases, it was assumed that users would need to cope with the system interface and, hence, much effort has focused on ergonomics. There are many questionnaires to evaluate usability in human/computer interfaces. One of the best known general ones is NASA TLX (Hart,1988), but there are several specific ones for persons with disabilities coping with assistive technology, like QUEST (Quebec User Evaluation of Satisfaction with assistive Technology) (Gelderblom et al. 2002), PIADS (Psychosocial Impact of Assistive Devices Scale) (Jutai and Bortolussi, 2003), ATDs (Assistive Technology Devices) (Scherer et al., 2007) or MPT (Matching Person and Technology) (Gatti et al., 2004). Systems meant to be operated by persons with potential physical and/or cognitive disabilities should be piloted first to obtain an estimation of usability and, if possible, evaluated by associations of users and caregivers (Annicchiarico and Cortés, 2010). Voice control clearly shows the need for these studies. Although voice can be complemented by other physical interfaces, it seems natural that a person can send commands to a smart environment by means of a simple micro, e. g. (Garate et al., 2005) (Noyes et al., 1989). Regarding usability, it is important to note that mild disabilities may affect significantly the vocal skills of the user, so most frequent voice databases are rendered useless for these people. In some cases, their condition may even change in time, so voice based systems may require learning capabilities to be useful for these people.

The main problem with voice-based interfaces is how to present information to the user. Simple sentences and status reports are easy enough to provide via an earplug or area speakers, but more complex data is easier to present in a visual format. Visual information was first provided by means of PDA (Personal Digital Assistant) (Favela et al., 2004)(Rodríguez-Losada et al., 2005), (Tapia and Corchado, 2009) but these devices have been replaced by the latests generation of affordable tablets and smartphones in the market.

Some persons, though, have strong impairments and, consequently, can not work with the usual controllers. Other physical interfaces can be controlled by head, feet, chin, shoulder switches, etc, which are fairly common, yet quite expensive in the field of assistive technologies. These interfaces are not as comfortable as the aforementioned ones but, in some cases, there may be no other choice for the user to exert some control on his environment. In these cases, it is extremely important to take into account ergonomics and medical factors. For example, some headtrackers might not be advisable for people with spinal cord injury, as they require significant neck motion. Some of these interfaces are presented in Table 20.7. In extreme, interfaces can be designed ad hoc. For example, the Telethesis project (Pino et al., 1998) proposed an on/off switch to choose an option in a screen that is continuously renovated to fit the needs of a patient affected by Amyotrophic Lateral Sclerosis (ALS).

Finally, if mobility is completely out of question, there are less intuitive other mechanisms for control. Eye tracking, for example, can be based on tracking the cornea, which is outlined through focal illumination (Li et al., 2007) or on using electrodes to measure the Electro-Oculographic Potential (EOG), which corresponds to the angle of the eyes in the head (Yanco, 1998) (Wei et al., 2010). Brain Computer Interface (BCI) has also offered promising results, despite its poor signal to noise ratio. Some BCI interfaces quantify potential commands into reduced number of bins (mental states) to choose among a limited number of options (Millán et al., 2004). However, this approach requires the user to be continuously focused to operate the system. Alternatively, other systems rely on the P300 evoked potential, a natural, involuntary response of the brain to infrequent stimuli: if a sequence of stimuli is presented, but only one of which interests the subject, approximately 300ms after the target flashes, there is a positive potential peak in the EEG signal, which can be reliably detected (Rebsamen et al., 2007). Table 20.7 briefs all mentioned commercial devices, with a tentative list of manufacturers are price ranges.

Type	Physical skill required	Invasiveness	Manufacturers	Price range (orientative)
Touch screen	Pointing & clicking	None	CINTIQ, TERN, Honeywell, JUNG	350-1500 USD
Tablet	Pointing & clicking	None	Apple, Samsung, Asus, ...	150-500 USD
Smartphones	Pointing & clicking	None	Apple, Samsung, Sony, Nokia, LG …	80-500 USD
Switches (for disabled users)	Button pressing	None	ASL	2800 USD
Speech recognition	Speaking	Low	Kempf, Dragon NaturallySpeaking, IBM Viavoice	500-1600 USD
Head tracker	Head motion	Low-medium	APT Tech. Inc, Peachtree, Magitek	990 USD
Head mouse	Head motion	Low-medium	Smartnav, Tracker-Pro, EagleEyes	500-900 USD
Chin sensor, breath actuators	Partial muscle motion	Medium	Dynamic DX, Systems, Sunrise Medical, Dynamics DX, PG Omni+	1200-1700 USD
Eye tracker	Eye motion	Low	ASL, Eyelink	45000 USD
EOG	Eye motion	Low-medium	Adinstruments Inc, Biocontrol Systems	1000 USD
BCI	None	Medium	Cyberlink/Brainfingers, Emotiv	2100-3500 USD

Table 20.7: Control devices for persons with disabilities

20.7 Robotic Companions

Assistant robots are typically autonomous mobile robots that help the user with minor tasks, like carrying food, drinks and medication (Hagras et al., 2004)(Cesta et al., 2005)(Saffiotti and Broxvall, 2005). In this kind of systems, robots are typically connected to the environment and make decisions depending not only on their onboard sensors, but also on the input instance of all sensors in the system as well as any knowledge acquired by the environment sensors. In order to conciliate the behaviors of all the system components, agent architectures are often used. A common requirement in homes equipped with robots is to know the locations of all robots and users, so localization is usually of key importance.

A special category in assistant robots are *socialization robots* (Cauchi et al., 2012) (Tiberio et al., 2012) (Granata et al., 2012). These mobile robots do not have manipulation capabilities. Instead, their goal is to promote social inclusion by linking users to people and events outside their homes. Socialization robots typically hold a monitor to provide easy access to online services. These services may range from videoconference or participation in social networks to cognitive reminders or activity monitoring (telemonitorization and telepresence). It needs to be noted that these robots usually act as a mobile gateway, but do not engage the user themselves in any activity: there must be another person on the other extreme, although many of these robots use voice-based interfaces for usability.

Assistive robots are mostly used for physical support for mobility, basically in the shape of walkers or power wheelchairs. Robotic walkers usually improve balance and assist direction

(Nejatbakhsh and Kosuge, 2005)(Rentscheler et al., 2007)(Rodríguez-Losada et al., 2005) (Wasson et al., 2007). Their input instance typically consists of the force pair exerted by the user in the handles, a front range sensor to detect obstacles and, often, an accelerometer to detect slope changes. Sometimes, these devices are used to keep a constant pushing force when the user loads the walker or faces a slope, specially for frail elderly. In rehabilitation, they may provide haptic feedback to make the user push more or less in a specific way. Robotic wheelchairs are similar to autonomous robots, regarding input instance (controller, encoders, range sensor) and navigation algorithms. These wheelchairs may carry people from one place to another without any actual input, but, in fact, physicians have stated that lack of practice leads to loss of residual skills, so it is preferable that their intervention level is very high instead. Systems where user and robot have to cooperate fit the so called shared control paradigm. Shared control may range from safeguarded navigation (Miller and Slack, 1995) -the wheelchair stops or takes over in case of danger- to full autonomous navigation. Most commercial systems, though, rely on keeping a basic set of primitives like **AvoidObstacle**, **FollowWall** and **PassDoorway** to assist the person in difficult maneuvers (Connell and Viola, 1990)(Simpson et al., 1998). Alternatively, other systems rely on combining human control and robot output in a continuous way to force the user to practice any residual skill (Urdiales et al, 2009).

A third, more ambitious goal in domestic robotics is to create a *companion* capable of responding emotionally to situations experienced and to interactions with humans (Artificial Emotion). Thus far, there has been limited success in robo-pets like Aibo dogs or Ugobe Pleo and, more specifically the Paro therapeutic robot, mostly based on learnt emotive expression in the behavior of the robot for human-machine interactions. Reported effects on persons affected by dementia include stress reduction and improved interaction and socialization. These robots, however, do not understand emotions or interaction, they simply randomize actions from a set and reinforce those that provoke acceptance according to simple sensor readings (e. g. back touch sensors in ERS-7). There have been many works on categorization of expressions. For example, Velásquez (Velásquez, 1998) proposed to use *Anger, Fear, Distress/Sadness, Enjoyment/Happiness, Disgust, Surprise*, which can be learnt via Artificial Neural Networks (ANN). Further works in the field led to more complex models in robotics. One of the best known ones is probably the MIT robot head KISMET, which focuses on maintaining the proper level of stimulation during social interaction (Breazeal and Scassellati, 1998). KISMET uses computer vision and audio input to determine different simple environment parameters like noise level, color, motion, presence of people in the field of view, etc. The system architecture includes several systems: perception, motivation, attention, behavior and motor. Basically, emotions are triggered by stimuli over a given threshold, but also influenced by the so called drives as well as by other emotions. Drives are partitioned into three regimes -homeostatic, overwhelmed and underwhelmed- and they are used to modulate emotions. KISMET includes four drives -fatigue, social, security and stimulation- five emotions -anger, disgust, fear, happiness and sadness- and up to ten expressive states.

Robots like KISMET aim to prove that emotion plays important functions in social interaction. Ethologists have pointed out that emotional expression have a communicative function and act as releasers for the coordination of social behavior (Mook, 1996).

20.8 Architecture design

When a given system becomes very complex, it goes naturally modular, both in software and hardware aspects. Resulting modules need to communicate in an organized way. This decomposition into modules and their interaction is usually called its architecture. Architectures are defined by their structure, which is the number and nature of the modules they are composed of, and their style, which comprises the communication mechanism employed in their interaction (Coste-Maniere and Simmons, 2000). Whereas structure is intrinsically linked to each system functionality and purpose, style is more general, as it is related to efficient computational paradigms for software interaction between modules. Although there are many valid architectures that have been used in AmI projects and different architectures may coexist in most projects, recent ones use multiagent systems (MAS) as part of their structure and web services as part of their style for integration, since there are already many valid operating third party web services that can be integrated into new systems.

Agents are particularly interesting in applications where there are multiple independent computational threads and a task centered model of computation (Wooldridge, 1995). Agent technology is most likely popular in AmI because it is efficient to cope with pervasive systems and distributed information. AmI Agents can be used as abstractions for devices and functionalities (Amigone et al., 2005) (Misker et al., 2004) to coordinate the activities of the lower level entities (Favela et al., 2004) (Rodríguez et al., 2005) or to interface with users (Cortés et al., 2010). Agent communication usually relies on the CORBA (Common Object Request Broker Architecture) model, whereas many implementations rely on F.I.P.A. JADE

(Java Agent Development Environment).

In general, these agent-based architectures include four basic functionalities: i) decision-making, ii) information gathering and knowledge-extraction; iii) communication between agents; and iv) physical elements. Every agent may yield all four functionalities (e.g. (Cook et al., 2006) or just be specialized in one (Plocher and Kiff, 2003), (Guralnik and Haigh 2002). For example, an iDorm embedded agent (Hagras et at, 2004) receives data from the sensors, learns and stores the user behavior, decides what to do and acts accordingly. ROBOCARE, however, has a dedicated software agent to process camera images, detect users and robots from the background, calculate their 3D localization and identify them, whereas a second agent is in charge of controlling the assisted person's schedule, that should fit his location (Bahadori et al., 2004). I.L.S.A. agents are also specialized in individual behaviors like monitoring medication ingestion, issuing reminders, etc (Plocher and Kiff, 2003) (Guralnik and Haigh 2002). When there might be conflict between agents decisions, an additional coordination (or manager) agent is sometimes required to work seamlessly. In other approaches, agents are used as abstractions, to act on behalf of users, doctors, caregivers and, sometimes, even robots (Muñoz et al., 2003), (Corchado et al., 2008), (Cortés et al, 2010).

20.9 Conclusions

This work has presented a review of Ambient Assistive Living systems, with a special focus on assistive technologies and a tentative taxonomy of current projects depending on their demands and target population. We have reviewed as well the most important technologies and computational paradigms employed in this kind of projects, providing information about off-the-shelf standard-compliant networks and devices and their manufacturers, when possible. We have tried to present a showcase of the most significant ones in each field, since AmI is clearly a multidisciplinary research field and, hence, it usually implies coexistence of many different technologies.

It needs to be noted that major research is being performed at the moment in areas related to AmI, like Augmented Reality, metamaterials, wearables, nanotechnology, etc., but we have tried to focus exclusively in systems that have already been prototyped in smart houses around the world.

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1 Acronyms

AAL JP	Ambient Assisted Living Joint Programme
ADL	Activities of Daily Living
ALS	Amyotrophic Lateral Sclerosis
AmI	Ambient Intelligence
BCI	Brain Computer Interface
BVP	blood volume pulse
DD	Digital Divide
ECG	Electroencephalography
EMG	Electromyography
EOG	Electro-Oculographic Potential
GSR	Galvanic skin response
HCI	Human computer interface
HR	Hearth rate
HVAC	H*eating, Ventilation and Air Conditioning*
ICT	Information and communication technologies
PAN	Personal Area Network
RFID	Radio Frequency IDentification

WAN Wide Area Network