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# Smart kitchen for Ambient Assisted Living

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**PhD THESIS**

# Smart kitchen for Ambient Assisted Living

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*Zaragoza, May 2013*

*To Pilar, for her love, support and understanding*

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# INDEX

# LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 1: INTRODUCTION

*This chapter describes the motivation that has led to the development of this thesis and defines their objectives, framework and work plan. It also exposes the methodology followed across the different phases of the work and finally presents the structure of the thesis.*

## 1.1. MOTIVATION

The ageing of our populations is a well-known problem in developed countries. European Union population projections are alarming; the ratio of people aged 65 years or over will increase from 17.1% to 30.0% in 2060 (from 84.6 million in 2008 to 151.5 million people in 2060) (Giannakouris 2008). Similar figures have been found in the USA, where elderly people will represent 20.2% of the population in 2050, or in Japan, with 35.7% for the same year (U.S. Census bureau 2012, NIPSSR 2002).

Elderly people suffer several physical and/or cognitive impairments which increase with the passing of years. According to the Spanish National Statistics Institute (INE 2012), 13.9% of the population between 65 to 69 years old have some disability; this ratio increases to 29.4% for the age group of 75 to 79; growing exponentially with age. Old age affects sensing, information processing capability, reduces speed and increases timing of precise movements, etc. All these issues increase difficulties of comprehension of complex scenarios which may require multi-tasking or a heightened attention over long periods of time. As a consequence, elderly people progressively lose the capacity to perform autonomously their daily activities. Thus, household appliances, instead of fostering independent living, become a burden that adds to ageing limitations.

Older people are one of the population groups most vulnerable to accidents, particularly at home (Angermann, Bauer et al. 2007). Most domestic injuries are related to works done in the kitchen; most dangerous utensils are knives and kitchen tools, cutlery and tableware followed by the household appliances. As a consequence of these accidents, elderly people lose confidence in their capabilities, decrease their self-esteem and, in many cases consequently decide to move to a nursing home.

According to UK statistics, one in eight people attended by domestic accident in a hospital is over 65 years. The low mobility, coupled with low sensitivity to the smell of burning and smoke makes older people more likely to suffer burns or scalds (four to five times higher than the rest of the population). These demographic changes will lead to strong challenges in the health and pension system and thereby, impacting on workforce. However, this situation will also provide business opportunities for suppliers of innovative technology in the field of ICT applied to the domestic environment or AAL (Ambient Assisted Living). These companies link new technologies and the social environment providing products and services that aim to improve people´s quality of life at their own homes (Van Den Broek, Cavallo et al. 2010).

The smart home concept raises a cost-effective manner of improving care for the elderly and persons with disabilities in a non-intrusive way, improving their independence, health and preventing social isolation (Chan, Campo et al. 2009). It poses an alternative to hospitalization or institutionalization, allowing the elderly and/or disabled to be cared at their own environment thanks to technology.

This thesis aims to go one step further in this direction, emphasizing the use of Ambient Intelligence (AmI) in the kitchen, where the elderly need more support for doing their everyday activities, and creating an AAL ready to be setup at their home.

## 1.2. OBJECTIVES

**The main objective of this thesis is the creation of an AAL environment centred in the kitchen, which supports elderly and/or disabled people in the daily activities more easily and safely. The system will help the person based on their capabilities and context**. This raises the following sub-objectives:

1. **Studying the needs** of the target population in the kitchen
   This study defines the requirements of the smart kitchen taking into consideration all the stakeholders involved. This information is used to define the system functionalities.

2. **Designing and implementing the system architecture** according to the identified needs.
   After identifying the needs of the target population, the system architecture is designed. This architecture must be modular, flexible and able to interconnect all the devices on the AAL, allowing its subsequent deployment.

3. **Designing and implementing the context awareness infrastructure**
   A sensor network is designed and integrated in the environment in order to extract the relevant information from the context. Commercial sensors will be preferably used in order to reduce the system cost. Also household appliances must be connected to the system.

4. **Designing and developing the system intelligence**.
   Various techniques of analysis of information from the context and system are studied. Since it is necessary to interpret a multitude of data for decision-making, different techniques have been raised, for example, decision trees, neural networks, etc.
   The intelligence of the system is responsible for processing information from the environment (sensors, appliances and users) and to respond in every situation. Its main functionality is to assist the user in their daily tasks in the kitchen, simplifying and helping when needed. In addition, it must ensure and improve safety in the kitchen, being able to respond in emergency situations.
   On the other hand, the system should adapt to the user's capabilities, detecting changes in habits that may indicate a deterioration of their abilities. Available information of the context is analysed in order to identify which parameters could be relevant for this purpose.

5. **Designing and analysing the system evaluation** with real users and experts.
   The system is validated with real users and experts from social-health areas. The assessment evaluates the system in three areas: accessibility, functionality and usability. From the conclusions, proposals for future improvement emerge.

## 1.3. THESIS FRAMEWORK

This thesis has been developed within the frame of the research project Easy Line Plus (Easy Line + 2010). The project, funded by the European Commission, has as main objective to develop near to market prototypes of advanced white goods in order to support elderly persons with or without disabilities to carry out a longer independent life which will compensate their loss of physical and/or cognitive abilities.

The consortium of this project is composed for the next companies and institutions:

- **BSH Electrodomésticos España, S.A. (Spain):** Manufacturer of electrical appliances. It is integrated into the European leader group BSH Bosch und Siemens Hausgeräte GmbH, which markets in Spain Bosch, Siemens, Gaggenau, Neff, Ufesa and Balay (BSH 2012)**.**

- **Gis Gera Ident-Systeme GmbH (Germany):** GERA-IDENT is an auto-ID company with its main focus on RFID technology (Gera-Ident 2012).
- **Motive Technology (formerly ADSS) (U.K.):** It is a company on bespoke software development; creating integrated systems, applications and complete end-to-end solutions (Motive Technology 2012).
- **Grupo de Empresas G2V. ISDE Aragón, S.L. (Spain):** It is a service company with its main focus on domotics setup (G2V 2012).
- **C-LAB (Germany):** It is a joint research and development laboratory operated by Atos and the University of Paderborn. It collaborates in the project as accessibility expert (C-Lab 2012).
- **Glyndŵr University (U.K.):** It contributes to the project as expert in new technologies focus on Human Interfaces and software development as well as technological evaluation (Glyndŵr University 2012)
- **Zaragoza University (Spain):** Project coordinator and technical coordinator of the project, the University of Zaragoza contributes to the project as expert in new technologies focused on the software, hardware and firmware as well as technological evaluation (Universidad de Zaragoza 2012).

The system developed in the project is based on appliances that provide functionality for the elderly, with particular emphasis on safety and reliability. It must be "intelligent enough" to interpret the context and to communicate with other devices in the environment such as distributed sensors and user interfaces. In addition, these appliances have to be friendly offering the user an easy interface to understand and operate and some of them should implement specific functionalities; for example, the refrigerator reporting which products has inside or warning when one of them is expired.

The project has been developed from 2007 to 2011 with the effort of the said multidisciplinary teams. Consequently not all the work done in the project falls within the thesis scope. For example, all the work related with the Human Machine Interfaces (HMI) as well as its associated database are excluded of this thesis because they have been performed by Glyndwr University and Motive Technology teams[1].

All the contributions reflected in this thesis have been done by the author under the supervision of his advisors. When the work of third parties is mentioned in order to ease comprehension of the thesis, these contributions are always attributed to their original authors. In every case, this is used to explain my work, remarking the author(s) in text and citing them. This policy has been also followed with the work done by other researchers in my team at the University of Zaragoza.

[1] I had the pleasure to work side by side with these teams for two months in Glyndwr University defining and deploying the communication between the human machine interfaces and the system intelligence. Also, during the integration sessions and in several work sessions in Germany and Spain, I have worked together the Gera-Ident team in order to define the specification of the ZigBee modules communication (protocol, schematic, PCB, etc.) that finally has been used by the RFID readers in the system.

## 1.4. METHODOLOGY

According to the objectives, there are three thematic areas that required different methodologies:

Study of the needs of the target population in the kitchen

This thesis starts with the study of the needs of the target population. This study has been done based on statistical data and using the International Classification of Functionalities Disability and health (ICF) to describe the target population and their interaction with the kitchen appliances. The revision and systematization of this process has finished with the development of a new design methodology which permits the extraction of a specific population's needs. The information obtained using it, has been completed with the stakeholders' opinion using a combination of quantitative (surveys) and qualitative (co-design sessions with experts and discussions) tools.

AAL design and deployment

Design of technical developments has been always done following a top-down approach; from the whole system to the finest details. System architecture has been divided into several functional blocks defining the communication interfaces between them. This way, each block is designed and developed independently assuring its integration in the final solution. An important part of this thesis has been the design of the system architecture considering hardware, communications and software developments. The environmental context has been modelled following the OSGi4AmI (Marco, Casas et al. 2009) ontology and its complement in firmware design in order to assure the interoperability between devices of several manufacturers.

In the case of hardware and firmware, the design process started with the definition of its specifications and with the identification of its block diagrams and corresponding schematics. In the same way, functionalities of the firmware have been identified, defined the flow diagram that characterizes its behaviour, and programing it in a modular strategy. Several prototypes have been manufactured and tested, entering a redesign process that culminated when the device worked correctly.

Since it is necessary to process a multitude of data for reasoning and decision-making, different techniques has been raised. These analysis blocks have been developed and validated, determining which technique is the best in each situation. A gradual process of implementation has been followed, starting with the most basic features until achieving the objectives.

Software implementation starts from the use cases and block diagram of the architecture. Each module has a flow chart to model its behaviour and UML (Unified Modelling Language) diagrams have been used for the design of different building classes. After programming each module, an iterative process for error debugging has been followed.

Assessment with real user

A final assessment of the system with real users and social-health experts has been performed to determine system's strengths and weaknesses and also to indicate which parts of the system should be redesigned. The assessment mainly targeted accessibility, functionality and usability indicators. Again it has been chosen a mixed combination of quantitative (survey) and qualitative (objective observation, interviews, etc.) tools.

Every part of the thesis followed the classical research methodology, analysing the state of the art and studying the advances in the related field.

## 1.5. THESIS STRUCTURE

This thesis is structured in the following chapters:

**Chapter 1: Introduction** describes the motivation that has led to the development of this thesis, defining their objectives, framework and work plan. It also exposes the methodology followed during the different phases of the work to finally present the structure of the thesis.

**Chapter 2: State of the art**. This chapter describes the key technical work related to this thesis. Starting from the concept of Ambient Intelligence that later introduces the Ambient Assisted Living to then delve into the related disciplines of the work presented. Finally, main advances in the kitchen scenario are commented. Specific state of the art in non-technical disciplines, i.e. study of needs and evaluation, is discussed in chapter 3 and 7 respectively.

**Chapter 3: Study of the needs of the target population in the kitchen** presents the methodology designed to detect the needs of a specific collective and their application to the design, in this case, of the Smart Kitchen. This study is completed with the analysis of other data sources (statistics, user surveys and workshops with professional caregivers, family and engineers).

**Chapter 4: Architecture design.** Derived from the study of the needs in order to support elderly people in their daily tasks, it presents the AmI architecture of the smart kitchen; ergo an Ambient Assisted Living in the Kitchen. First, system is described, explaining its interaction with the user and the environment. Next, software architecture is detailed, describing the functionality of its main blocks.

**Chapter 5: Context Interaction.** This chapter contains the contributions made in the context interaction implementation of the system; i.e. the physical deployment of the sensors and actuators network as well as the modifications accomplished in the kitchen appliances to enhance their capabilities.

**Chapter 6: Reasoning** presents the contributions in the design and implementation of the intelligence of the system describing the rationale of the logical rules and software implementation which drive the system operation. Also, contributions in the quality of life evaluation system and in the user modelling are included.

**Chapter 7: Smart kitchen assessment** describes the methodology and the tools developed for the evaluation of the system. This evaluation was conducted simultaneously in two countries: UK and Spain, by multidisciplinary teams from the Glyndŵr University and the University of Zaragoza.

**Chapter 8: Conclusions and future work.** The last chapter presents the conclusions of the work outlined in previous chapters highlighting the most important contributions of this thesis. Likewise, it proposes future lines of research in different related fields.

# CHAPTER 2: STATE OF THE ART

*This chapter describes the key work related to this thesis. Ambient Intelligence and Ambient Assisted Living concepts are introduced to then delve into the related disciplines with the work presented. Finally, main advances in the kitchen scenario are commented. The state of the art related to the work presented in chapters 3 and 7, due to dealing with non-technical issues, it was decided to include them within the same chapters, making them self-contained.*

## 2.1. AMBIENT INTELLIGENCE

In 2007, when I started working on this thesis, it was quite common for people to have available two computers: a desktop and a laptop. The technological developments in consumer electronics has caused that, day by day, smaller and cheaper devices with advanced computing capabilities reach the mass market. Today, in 2012, Smart Phones are usually added to desktop and laptop equipment and, in many cases, laptops are replaced by tablets.

As Cook et al. say (Cook, Augusto et al. 2009), this has been the evolution from the 80's, where a PC was used by several people, to the current situation where it is quite normal that a person uses multiple devices with high capacities (GPS, Smart Phones, laptops, Tablets, etc.) This situation has shifted to other housing appliances such as television or video games, and even kitchen appliances.

Today, it seems that, technologically, we are close to the situation posed by Weiser in the paradigm of ubiquitous computing, where computers are embedded and distributed in the environment and people use them naturally (Weiser 1991). As an evolution of this thought, the concept of Ambient Intelligence (AmI) is born in the late twentieth century as an overview of progress in consumer electronics, telecommunications and computing for the period between 2010 and 2020. Today, AmI is used to refer a multidisciplinary area of knowledge that encompasses several fields of engineering and computing (Aarts, Encarnação 2006).

It is necessary to emphasize the role played by the Information Society and Technologies Advisory Group (ISTAG) in the consolidation of the AmI concept. In its twentieth report of 2001, the ISTAG gives expression to the AmI, which to this moment was just a "vision of the future" (Ducatel, Bogdanowicz et al. 2001). It reinforces the concept and use giving a formal definition of what was considered an AmI and identifies which technologies are relevant to its development (Cook, Augusto et al. 2009, Aarts, Encarnação 2006, Augusto, Nakashima et al. 2010).

But, what is an AmI? An AmI can be defined as a **"sensitive and adaptive electronic environments that respond to the actions of the persons and objects and cater for their needs"** (Aarts, Wichert 2009). That is an intelligent system, customizable, aware of the context, adaptive and anticipatory. This approach includes the entire environment, taking into account each individual object and associating its interaction with humans.

Many times, AmI and AAL terms appear in the literature interchangeably to refer to very similar technological solutions. As already mentioned, AmI is a sensitive environment capable of interacting with the person, ranging from ubiquitous computing to smart interfaces with certain social skills. The fundamental difference lies in their purpose: AAL attempts to prolong the time that a person can live in dignity at home, improving their autonomy and self-confidence, simplifying their daily tasks, monitoring and caring for the elderly, sick or disabled, improving safety and saving resources (Steg, Strese et al. 2006).

That is, AAL uses the AmI as a fundamental tool in each specific context. In fact, some authors (Aarts, Wichert 2009) consider the AAL as an area within the AmI focused on providing an integral solution for supporting the person in the independent living, home care and residential nursing houses.

The European Commission has heavily invested in this direction, creating the "Ambient Assisted Living program”. This research and development program aims to improve the quality of life of older people through the use of the Information and Communication Technologies (ICTs). With a performance period from the 2008 to the 2013, AAL plans to mobilize funds around 600 M€ (AAL ASSOCIATION 2013).

Currently, AAL is being extended to others environments such as the car or the workplace. The AAliance (The European Ambient Assisted Living Innovation Alliance) proposes three macro scenarios for the AAL development (Van Den Broek, Cavallo et al. 2010):

AAL4persons: This domain is focused on person centric applications and it is divided in two subdomains: @home and @mobile. Both with the same purpose “Ageing well for the person”

AAL in the community: This domain is focused on applications which improve the social inclusion of the elderly people, their communications and their participation in the community.

AAL@work: This domain is focused on application which supporting elderly and people with disabilities at work.

Next diagram summarizes the main field of the AAL domains:

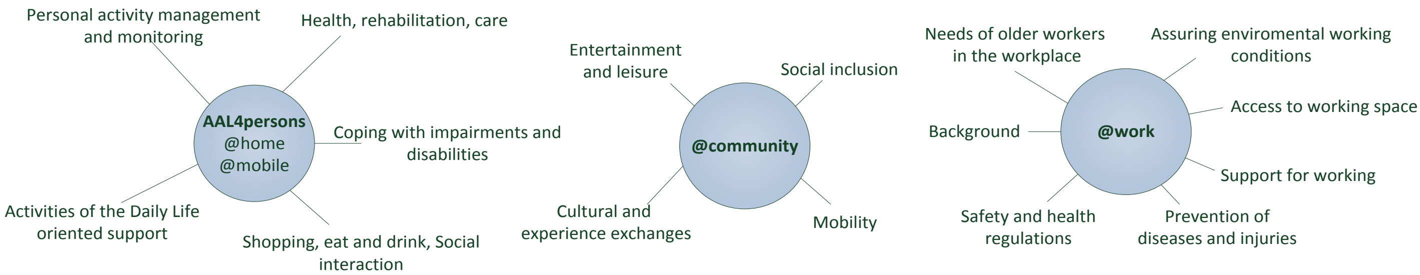


**Figure 1 AAL domains**

Therefore, as O'Grady et al. pose (O’Grady, Muldoon et al. 2010), an ***“Ambient Assisted Living (AAL) is advocated as technological solutions that will enable the elderly population maintain their independence for a longer time than would otherwise be the case”.*** To achieve this goal, the AAL should be aware of context, including in this the person, providing help when needed, detecting abnormal situations and acting accordingly (Andrushevich, Kistler et al. 2009).

To respond to an AAL, it is necessary to involve different fields of knowledge such as Artificial Intelligence (AI), robotics, sensor networks, wireless communications, natural interfaces, among others (Ramos, Augusto et al. 2008). The AAL roadmap (Van Den Broek, Cavallo et al. 2010) clusters these technologies in several fields: related to sensing, reasoning, action, interaction and communication. The following sections focus the state of the art on the fields related to the work presented in this thesis: context interaction, reasoning and system architecture.

### 2.1.1. CONTEXT INTERACTION

Context awareness is very important because it provides information about the people, places, devices and things present in the environment (Hong, Suh et al. 2009). However, there is not a common definition of the context awareness, being possible to find different definitions of context depending on the application domain (Zainol, Nakata 2010).

One of the most broadly accepted (Hong, Suh et al. 2009, Zainol, Nakata 2010, Liu, Li et al. 2011) is the definition proposed by Dey et al. (Dey, Abowd et al. 2001): ***"any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves."***

Most of authors agree in segregating the User or People context from the Environmental or Physical context, proposing more fields conditioned by the application domain. One of the most complete approaches is proposed by Feng et al. (Feng, Apers et al. 2004) that categorizes the world in two different contexts that interact with the AmI system:

**Environmental context:** There are physical environment (e.g. time, location, temperature, noise, etc.), social environment (e.g. traffic jam, surrounding people, etc.) and computational environment (e.g. surrounding devices, communication resources, etc.

**Person-centric context:** The personal context includes background (e.g. interest, habit, preference, etc.), dynamic behaviour (e.g. task, activity, intention, etc.), physiological state (e.g. body temperature, heart rate, etc.) and emotional state (e.g. happiness, sadness, calm, etc.).

Although most of the authors agree on the items present in the context, it is possible to find different clustering of them, producing several categorizations. For example Gu (Gu 2009) proposes, from a user-centric point of view, to divide the context in five areas: the computing, user, physical, time and the social contexts. Same way, Liu (Liu, Li et al. 2011) categorizes the context in three areas: User, Physical and Network contexts.

Context Interaction domain includes the technologies related with extraction of information from the context (sensors, human interfaces, etc.) and acting over it (actuators as devices that can produce changes in the context). Next subsections go over these technologies talking about wireless sensor networks, interoperability and kitchen appliances. Note that Human Interfaces has not been included in this revision of the state of the art because they are not object of this thesis.

*Wireless Sensor Networks*

Distributed sensors are a fundamental part of any AmI. In this field, Wireless Sensor Networks (WSNs) are one of the most powerful tools, thanks to their capacity to access devices embedded in the environment. These platforms enable monitoring of the environment sending information to a base station or to an access point of a fixed infrastructure (as Internet) (Yick, Mukherjee et al. 2008). WSNs are increasingly incorporating smarter devices capable to make certain decisions. These nodes, in many cases, use microcontrollers with embedded operating systems (Bhatti, Carlson et al. 2005) in order to easier the development of new capacities as FreeRTOS (FreeRTOS 2012), Contiki OS (Contiki OS 2012), MICROSAR OS (MICROSAR OS 2012) or Tiny OS (Tiny OS 2012).

As Yick et al. described (Yick, Mukherjee et al. 2008) ***"Smart Sensor nodes are low power devices equipped with one or more sensors, a processor, memory, a power supply, a radio and an actuator[2]."*** Normally, smart sensor nodes use specific sensor-oriented protocols (low transfer rate and very low power consumption) in order to increase the battery life. Standards are essential to provide interoperability among devices, being ZigBee (ZigBee Alliance 2012), Bluetooth (Bluetooth 2012) and EnOcean standard of ultra-low-power (Enocean 2012) the technologies most used. Due to increasing importance of the Internet of Things concept, use of IP-enabled standards such as WiFi (WiFi Alliance 2012) and 6lowPAN (Shelby, Bormann 2009) are also becoming relevant in the field.

WSNs can have a few sensors or hundreds of devices grouped in different topologies depending on the application and communication protocol used. These are typically based on WSN protocols that use routing and MAC layers of specialized transportation for sensors, being the self-organization one of the key features in these communication stacks. This feature allows the nodes to initialize by discovering their neighbours and building local area neighbour tables (Stankovic 2008). Several examples of the use of sensors in an AAL can be found:

> Villacorta et al (Villacorta, Jiménez et al. 2011) present a configurable sensor network with sound sensors (that are based in the radar philosophy tracking objects and detect presence), IP video cameras (to monitor detection and fall detection) and RFID (Radio Frequency IDentification) module (that is used to help the person to identify objects that have been previously labelled with passive RFID labels). Currently, this system is being studied in two scenarios: a nursing home and assistive home.
>
> Vacher et al. (Vacher, Portet et al. 2010) show the possibilities that audio processing could have in an AAL. They propose a scenario with 8 microphones distributed in the house. They raise two tests: in the first one they try to identify the speech, showing the detection distress in this scenario; in the second one, they try to identify daily activities as sleeping, resting, going to the toilets, etc. showing better results. However the main conclusion is that a real scenario includes problems as the discrimination of sounds (several events happen at the same time) introducing a high complexity to the analysis.
>
> Lombardi et al. (Lombardi, Ferri et al. 2009) present a wearable wireless sensor for fall detection based in a MEMS tri-axial accelerometer, ZigBee communication and a FPGA. The device processes sensor information in real time and when a fall is detected sends an alarm through a ZigBee network to the gateway, which is connected to internet. In the same line, Selvabala et al. (Selvabala, Ganesh 2012) propose a wireless sensor with an accelerometer which is complemented with a Passive Infrared sensor (PIR) in order to detect falls.
>
> Jara et al. (Jara, Zamora et al. 2011) propose a system for diabetes therapy. This system is based on a glucometer that uses 6LoWPAN protocol and a RFID reader in order to identify the user. This information is used to adjust the dosage of insulin in a personalized way.
>
> Park and Kautz (Park, Kautz 2008) propose a system that detects several activities as walking or preparing cereals. It is based on a RFID bracelet, which enables the detection of several labelled items, and cameras. Ibarz et al. (Ibarz, Bauer et al. 2008) propose a smart wireless sound sensor that placed in the sink is used to quantify the water flow and to identify the activity related with its consumption.

[2] Actuator in this context is understated as a device that can be used to control the different components of the sensor node (sensor parameters, etc.)

*Interoperability*

Interoperability between devices implies capacity to exchange data and understand the information embedded. Communication standards ensure stack layer's interoperability between devices in the same network sharing the same protocol; i.e. network management and maintenance, security, data exchange, etc. Nevertheless, if application layer is not defined, devices will not understand among them unless they were previously agreed between developers; i.e. information understanding. This is the case of 6lowPAN, WIFI, RFID or 3G.

Bluetooth and ZigBee go one step further in interoperability, defining profiles and device objects within application layer. Bluetooth defines profiles (hands-free, health device, human-interface device, etc.) corresponding to vertical applications. For example, a monitoring infrastructure with Bluetooth microphones streaming audio could be build according to hands-free profile; no matter their manufacturer, any certified host compliant with the profile will play the audio gateway role without any additional programming. ZigBee not only defines vertical profiles (home automation, smart energy, healthcare, etc), also define horizontal clusters to specify how the devices must exchange application data attending their functionality.

For example, every ZigBee compliant temperature sensor must implement "measurement & sensing cluster" and any other device in the network (e.g. a thermostat) would be able to get temperature information as defined in the cluster specification. Additionally, the standard defines how to create virtual bindings among devices allowing instantiation of intelligence in the network; e.g. program automatic triggering of actions between nodes.

| ZigBee Application Profiles | Bluetooth profiles |
|---|---|
| *Released specifications*<br>ZigBee Home Automation<br>ZigBee Smart Energy 1.0<br>ZigBee Telecommunication Services<br>ZigBee Health Care<br>ZigBee RF4CE - Remote Control<br>Etc. | Advanced Audio Distribution Profile (A2DP)<br>Basic Printing Profile (BPP)<br>File Transfer Profile (FTP)<br>Health Device Profile (HDP)<br>Hands-Free Profile (HFP)<br>Human Interface Device Profile (HID)<br>Headset Profile (HSP)<br>SIM Access Profile (SAP, SIM, rSAP)<br>Synchronization Profile (SYNCH)<br>Video Distribution Profile (VDP)<br>Etc. |

**Table 1 Example of ZigBee and Bluetooth profiles**

IEEE1451 (IEEE 1451 2011) is a network-independent specification that uses Transducer Electronic Data Sheet (TEDS) to describe a set of communication interfaces for connecting transducers (sensors or actuators) to microprocessors, instrumentation systems and control/field networks. TEDS is kept in sensor's memory storing its relevant data (identification, calibration, measurement range, etc.). IEEE1451 provide a set of interfaces that enable that a wired or wireless sensor could be accessed. Thus, theoretically is the best suited option to assure interoperability, because it provides independence from the communication protocol. Nevertheless, its penetration in real applications is very limited, with little compatible hardware available and mainly relegating it to the academic and electronic instrumentation field.

*Kitchen appliances*

The kitchen appliances are a cornerstone of the environmental context of the kitchen: person needs to interact with them to carry out any routine activity. Therefore, they could be considered as devices embedding sensors, actuators and simple interfaces inside the kitchen context. When I started working on this thesis, the conventional market did barely have appliances with advanced functions. This situation remains far from changing now, probably conditioned by the economic context. In fact, some advanced smart product lines, such as Serve@Home from BSH have been discontinued (BSH 2007).

However, although these products have not reached the mass market, an evolution in the concept of smart appliance can be found on the websites of various manufacturers. In 2007, an appliance was smart if it had the ability to communicate and be controlled remotely. This concept was closely linked to the conventional home automation. Currently, although the ability to interconnect and remote control are still the basis for all services offered at home, complex solutions could be found.

For example **LG** (LG 2012) presented its smart appliance concept of the future in the International CES in Las Vegas. The main features of these appliances are based on advanced control of energy (Smart THINQ™) and the device-to-device connectivity, highlighting the following services:

- Smart ThinQ™ technology that enables the person to know and to customize flexible ways to control energy use.
- Smart Manager, which offers a complete food management system. With Smart Manager, consumers can use the refrigerator’s LCD panel or their smartphones to check what food is inside, where it’s located and when it will expire.
- Smart Diagnosis™ enables the quick and convenient diagnosis or troubleshooting via smart devices.

The concept of energy management is one of the new features the majority of manufacturers are considering as an option for the future. In addition to LG, others manufacturers as **Samsung**, **Whirlpool** or **BSH** have also incorporated the ability to connect with Smart Grid through PLC (Power Line Communication). **Samsung** is also committed to the communication device-to-device, incorporating WiFi to the appliances and control capability via a smart phone. It has also added a touch screen to its Smart fridge which allows access to a diverse set of apps as well as the social networks, easing tasks as buying on line or making recommendations about how long is good to have the meat in the freezer (Samsung 2012) .

Although it was found that there is emerging interest in incorporating RFID to the various appliances such as washing machine, refrigerator or oven, RFID has not reached the market yet. Probably this is due to the low implantation of RFID labelling in food and clothing (RFID Journal 2003). This feature has a big potential because enables important services, as the food or clothes identification by the appliances.

Other manufacturers such as **Fagor** offer a comprehensive home automation control with fire sensors, actuators, alarm system anti-intruder and kitchen appliance. All the devices are connected by PLC and managed by the voice (Gárate, Herrasti et al. 2005). Likewise, the **BSH** group marketed the Serve@Home, a product consisting of a remote control of your appliances by PLC, allowing its use over the Internet. An identical system is currently marketed by **Miele** Germany (Miele 2012). Majority of manufacturers have selected PLC or WiFi (or both) as communication protocol, but some exception can be found as **Indesit** that is collaborating with Freescale Semiconductor to introduce ZigBee in the range of small appliances (EETimes Europe 2010).

The price difference compared to a conventional appliance of any of these products, plus the fact that, usually these new features are not easy to handle, are major barriers to their arrival in the mainstream market and its use by older people.

### 2.1.2. REASONING

The information from the sensors distributed in the environment provides a "virtual image" of the context. This "image" is composed of multiple inputs that the AmI uses to make decisions. These decisions are transformed into responses, acting on the environment (Figure 2). This process of analysis of the context and decision making is known as **reasoning**.

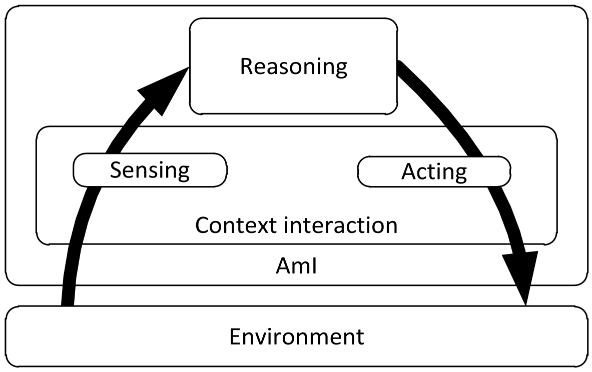


Figure 2 AmI layers and relation with the environment

The process of reasoning can have several layers depending on the complexity of the system implemented. Generically, Aztiria et al. (Aztiria, Izaguirre et al. 2010) propose four main blocks: activity recognition, learning, knowledge and decision making. More specifically, the different Artificial Intelligence techniques within an AmI are focused on (Augusto, Nakashima et al. 2010):

- Learning habits, preferences and needs of the users.
- Correctly diagnosing situations.
- Being aware of where and when the events of interest occur.
- Integrating mobile elements like robots.
- Providing a structured way to analyse, decide and react over that environment.

To meet these needs, different techniques such as Artificial Neural Networks (ANNs), decision trees, statistical methods, Fuzzy Logic rules, etc. can be used. For example some works in AmI in the residential environment:

Bauer et al. (Bauer, Stockinger et al. 2009) propose a Smart Plug Sensor which measures the current consumption of the kitchen appliances identifying what has been used. Zeifman and Roth (Zeifman, Roth 2012) goes a step more in this way using a probabilistic approach based in the Viterbi algorithm in order to disaggregate the home energy consumption reaching an accuracy between 80% and 90%.

Shell and Couplant (Shell, Coupland 2011) propose the use of a method for the production of events from discrete data from a WSN through the use of fuzzy temporal relationships based upon a derivation of Allen’s original algebra, showing a direct application in AAL environments.

Vainio et al. (Vainio, Valtonen et al. 2008) show a system which learns the user’s habits in the domestic light control without actively involving the user in the learning process using Fuzzy Logic. Merico et al. (Merico, Mileo et al. 2009) propose an AAL system called SINDI, which tries to improve the quality of life of people who live mainly at home enhancing their autonomy. The reasoning component is based in Answer Set Programing (ASP), which enable the representation of each problem by a logic program viewer as a description of properties and constraints on the solution.

Chen et al. (Chen, Das et al. 2010) evaluate different machine learning algorithms (a Naïve Bayes Classifier, a Bayes Net Classified, a Neural Network Classifier and a Support Vector Machine) in order to predict the energy consumption of the house based on the residents' habits.

Van Kasteren et al. (Van Kasteren, Englebienne et al. 2010) propose an activity monitoring system for elderly people comparing two techniques: a generative Hidden Markov Model (HMM) and the discriminative Conditional Random Fields (CRF).

### 2.1.3. CONTEXT MODELING AND SYSTEM ARCHITECTURE

Considering the virtual representation of devices and following the Internet of Things (IoT) paradigm, each everyday object will have its virtual representation in the Internet. Thus, standards and ontologies help us modelling the context and obtain virtual representations of the different items present in an AmI (sensors, actuators, interfaces, etc).

Most communication standards include IP (Internet Protocol) as part of their specification; nevertheless this is not enough to ensure interoperability at required IoT application level. Standards such as EEML (Extended Environments Mark-up Language) (EEML 2008), SensorWeb (Botts, Percivall et al. 2008) (including SensorML and TransducerML) or SenseWeb (Grosky, Kansal et al. 2007) use XML based schemes to integrate sensors and actuators with the virtual world. These schemes just express queries and data modelling, lacking of semantics and ontologies that are necessary for complex information processing and support to service composition and adaptation at higher levels of abstraction.

Initiatives such as Sensei project (Presser, Barnaghi et al. 2009), COSE (Wemlinger, Holder 2011), DogOnt (Kofler, Reinisch et al. 2011) and others provide different ontological approaches to model things (sensors, actuators, simple human-machine interfaces, appliances, etc.) in smart environments, associate contained devices through semantic relationships and seamlessly integrate things with web services. It is relevant to point out that most frameworks are OSGi-based (Open Services Gateway Initiative, OSGi) (OSGi Alliance 2012).

The increased use of OSGi in particular on new applications and consumer products, and service-based architectures (SOA, Service Oriented Architectures) in general, is strongly conditioned by the demand for durable and upgradeable technologies. The development of monolithic software applications in this context is just becoming expensive and unsustainable in the medium term. This is where SOA developments allow simple, modular and easily upgradeable developments (OSGi Alliance 2010, Wu, Huang et al. 2008, Li, Zhang 2004).

OSGi proposes a framework where the code is organized in packages (bundles) that can be managed dynamically. These packages are agents for special tasks, which communicate with each other through services published within the framework. This architecture allows to maintain and evolve each of these separate packages independently (stop, start, deploy, update, delete, etc.).

## 2.2. THE KITCHEN SCENARIO

This section takes a tour of the main research lines related to the AmI applied in the kitchen. Although, as shown below, this scenario is not new in this field, it is noteworthy that there are few studies aimed at increasing the autonomy of the person in the kitchen deploying and AAL.

Focusing on activity recognition in the kitchen scenario Kranz (Kranz, Schmidt et al. 2007), propose a non-intrusive environment to detect which ingredient has been cut using a cutting board equipped with 4 load cells and a knife with a force/torque sensor. The kitchen is also equipped with microphones and cameras. Several ingredient cut patterns were successfully identified analysing the sensor data. Also, Lei et al. (Lei, Ren et al.

2012), present a system based only in a RGB-D camera (depth cameras that provide synchronized colour and depth information at high frame rates) which identified activity and tool used (between a selected group of 35 kitchen objects and 25 actions). The system is capable of identifying objects with a 60% accuracy and activities with an accuracy of 82%.

On the other hand, several AmI have been developed to help and guide the user in the cooking process. The Smart Kitchen described by Hashimoto et al. (Hashimoto, Mori et al. 2008) propose a smart and sensitive environment, in which the person can cook without thinking in the system. It identifies the different steps in dish elaboration guiding the user. It is a challenging detection process as the system must recognize the kitchen tool been used, the food and the specific step in the dish elaboration process. To reach this objective, three cameras have been installed covering the worktop and one additional thermic vision camera over the hob. With this distribution, the images are analysed reaching an 85% of successful identification between 5 pre-known situations.

Other example of kitchen assistant is proposed by Siio et al. (Siio, Hamada et al. 2007) that describe a system which can record and play videos about the elaboration of several dishes. It is also possible to contact an expert and follow the process interactively. Schwartze et al. (Schwartze, Feuerstack et al. 2009) present their work in graphical interfaces for Smart Environment with the “4-star Cooking assistant” application which proves the capability to dynamically adapt a graphical user interface to the current context of use.

RFID readers are the key to obtain certain information from the context without requiring direct user interaction. If integrated in the worktop and refrigerator, they can provide help to create automatic shopping lists, interact with other appliances, assist in deciding the menu (Anastasopoulos, Niebuhr et al. 2005, Chen, Chang et al. 2006, Gárate, Herrasti et al. 2005). In this line the Smart Cabinet presented by Pal Amutha et al. (Pal Amutha, Sethukkarasi et al. 2012), has been equipped with RFID readers and weight sensors to know the inventory of the cabinet as well as to preparing the shopping list automatically. The cabinet has been tested in several scenarios with accuracy around the 70% raising some problems identifying little quantities of food (in the weight sensor) and with some kind of food (with the RFID readers).

The Smart Kitchen proposed by Chen et al. (Chen, Das et al. 2010) offers information in real time about the calories, nutritional value and their balance (nutritional & calories). The kitchen has been equipped with three monitors to show this information, weight sensor on the counter and hob and a camera covering the working area. The system detects when a new ingredient appears (it only can be used one by one) and then asks the user about the name of the ingredient in order to update the information of the screens (Wizard of Oz technique has been used in in this last step). The system proposed by Chi, Chen, Chang et al. (Chi, Chen et al. 2007, Chen, Chang et al. 2006) aims to guide the user in the preparation and selection of the food to improve his diet through a screen and speakers installed in the kitchen. They encode the food nutrition information in the RFID tags and use weight sensors and RFID antennas into the refrigerator, cabinets and worktop.

Also, several objects could be easily integrated in an AmI, such as the Intelligent Spoon (Cheng, Bonanni 2006) which is able to measure the temperature, acidity, salinity and thickness of the food or the Chameleon Mug (Selker 2006) which determines the temperature and sugar level of the liquid and, even, the state of the milk.

Only two works related with AAL has been found. The first, the i2Home European project which tries to make appliances and devices easier to understand for people with mild cognitive impairment and elderly using a the Universal Remote Console (URC) as new mainstream user interface standard (Frey, Neßelrath et al. 2011). Although this project is not focused in the kitchen but in the home, they integrate several technologies helpful for the AAL in the kitchen: television (Media Center), white goods with PLC communication (hood, oven, fridge, freezer, dishwasher and air conditioning), touch screen, RFID antenna which implement sensitive surfaces for products equipped with smart labels, blood pressure meter, blood sugar meter and automatic lighting (Neßelrath, Haupert et al. 2011).

The second work is presented by Ficocelli and Nejat (Ficocelli, Nejat 2012) and describes an Assistive Kitchen environment based in three modules: A Speech Recognition and Analysis Module (i), a Visual Interface and Speech Synthesizer Module (ii) and an Automated Cabinet (iii). This system currently is able to help the user to store and find items in the automatic cabinet and to obtaining recipes for meal preparation by speech commands. The cabinet has three automatic shelfs which can go horizontally out and the two top can also adjust their height. This way, when an item is stored, the system registers in a database in which shelf it has been leave and open it when the item is required. This work presents the evaluation of the first prototype, which, in a future, pretends to be an AAL that supports the ADLs in the kitchen by the addition of new features and functionalities.

# CHAPTER 3: STUDY OF THE NEEDS OF THE TARGET POPULATION IN THE KITCHEN

*This chapter presents the methodology designed to detect needs of a specific collective and its application to the design of the Smart Kitchen. This study is completed with the analysis of other data sources (statistics, user surveys and workshops with professional caregivers, family and engineers).*

## 3.1. INTRODUCTION

Elderly people suffer from different physical, sensorial and/or cognitive impairments which get worse along the years. Functionality of sensing organs, information processing capability, reduced speed and accuracy of movements, longer "thinking time" necessary to understand situations, difficulty to carry out two things at once and reduced attention over long periods of time are some age effects. This population composes a heterogeneous group whose needs vary significantly. Understanding these needs is crucial for the success of Independent Living Services (Comyn, Olsson et al. 2006).

User typically requires sensory, motor and cognitive capabilities when interacting with a product. Inclusive Design is a design philosophy that considers the needs and capabilities of the whole population, with the aim of making products functionally accessible to and usable by as many people as reasonably possible (Johnson, Clarkson et al. 2010, Tenneti, Johnson et al. 2012).

Understand user capacities as well as study the interaction between user and product is fundamental to carry out a successful inclusive design (Keates, Clarkson 2003). To address this problem, we have designed a methodology to find needs in a specific population, as the necessary previous step in the design phase of a product. This methodology is born as a result of the systematization of the process followed in an intuitive way in the Easy Line + project. This methodology proposes to study how the target population currently performs the functionalities which will be supported by the new device or system. Target population and interaction characterization is done using the International Classification of Functioning language (ICF) (World Health Organization 2001) and considering the models of the human-machine interaction. The relationships between users' capabilities and activities required to perform the interaction will permit to discover needs indicators. Study of these indicators by a multidisciplinary team leads to a systematic identification of needs related to the interaction between user and product.

Results from this methodology have been used in the design of the smart kitchen for elderly people in order to identify their needs handling the kitchen appliances. In order to have a feedback from the stakeholders, this information has been completed using a mix of qualitative and quantitative tools:

- The users' opinion has been considered analysing user surveys carried out by the University of Zaragoza (Puig, Gracia et al. 2005) in the area of Zaragoza. Section 3.5.1 details the conclusions extracted.
- A 2-days workshop framed in the "Master en Gerontología Social[3]" at the University of Zaragoza has been done. In these sessions, professionals with multidisciplinary profiles (social workers, occupational therapists, nurses and engineers) worked together around the concept of smart kitchen for the elderly. As detailed in section 3.5.2, we worked over the concept of AAL in the kitchen and their suggestions have been considered also as input in the design process.

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[3] http://titulaciones.unizar.es/gerontologia-social/

## 3.2. RELATED WORK

This approach builds on the ICF and the models of the human-machine interaction. This section provides a little background information as well as a summary of the related researches.

### 3.2.1. USER REQUIREMENTS FOR SPECIFIC USERS GROUPS

As mentioned above, knowing the users and understanding their needs and capabilities are fundamental in any design process. User models are a common technique which eases this process. A model is any representation of the potential user, created by or available to the designer, to assist him/her in making predictions about the actual user (Hasdoğan 1996). These models are built on end user data which could be provided from different sources (statistical, capabilities databases, inquiries, surveys, etc.) (Van Isacker, Goranova-Valkova et al. 2008).

It is relevant how the work done in the generation of capabilities databases in the last years is encouraging the development of inclusive design tools (Johnson, Clarkson et al. 2010, Gyi, Sims et al. 2004). For example, HADRIAN (Porter, Case et al. 2004) is a CAD design tool which enables automatic evaluation of the use of a product or service by person of their database; the Exclusion calculator which estimates the number of people who would be excluded from using a particular product (Clarkson, Coleman et al. 2007). Also, USERfit provides a methodology and toolkit for collating design material. USERfit has been designed for improving the design of assistive products, being applicable to the inclusive design (Poulson, Richardson 1998, EDeAN 1999).

Other common design methodologies are applied to understand the capacities of specific users groups as the contextual inquiry (Beyer, Holtzblatt 1997), survey (Mikkonen, Väyrynen et al. 2002, Beecher, Paquet 2005), tasks analysis (Sangelkar, Cowen et al. 2012), focus group (Morgan 1997) or Delphi technique (Martin, Norris et al. 2008).

### 3.2.2. INTERNATIONAL CLASSIFICATION OF FUNCTIONING (ICF)

According to the WHO, the ICF is a framework for measuring health and disability at both individual and population levels that allows the assessment of functioning at the level of the whole human being, in day-to-day life (World Health Organization 2001). The ICF is promoted and officially endorsed by all 191 WHO Member States as the international standard to describe and measure health and disability. This multipurpose tool is used in sectors as diverse as education, health, social policy and general legislation development, statistics or economics.

ICF provides a universal model and taxonomy to describe different levels of functioning and disability, improving the communication across disciplines. By using a universal language, ICF enables comparison of results between, for example, people from different countries, different health systems or studies between population samples. It is a fact that two people with the same level of health (e.g. same Alzheimer stage) may have different functions and disabilities in a specific situation (e.g. operating the television). This evidence prevents the determination of the degree of disability of a person only from the knowledge of the condition being treated.

ICF provides a classification of function and disability itemized into three lists called “Body Functions”, “Body Structures” and “Activity and Participation”. Furthermore, to classify contextual factors, ICF offers another two lists called “Environmental Factors” and “Personal Factors”. Each domain is structured into chapters where each item can have up to four levels of depth. Thus, the ICF offers about 1500 descriptors in its taxonomy.

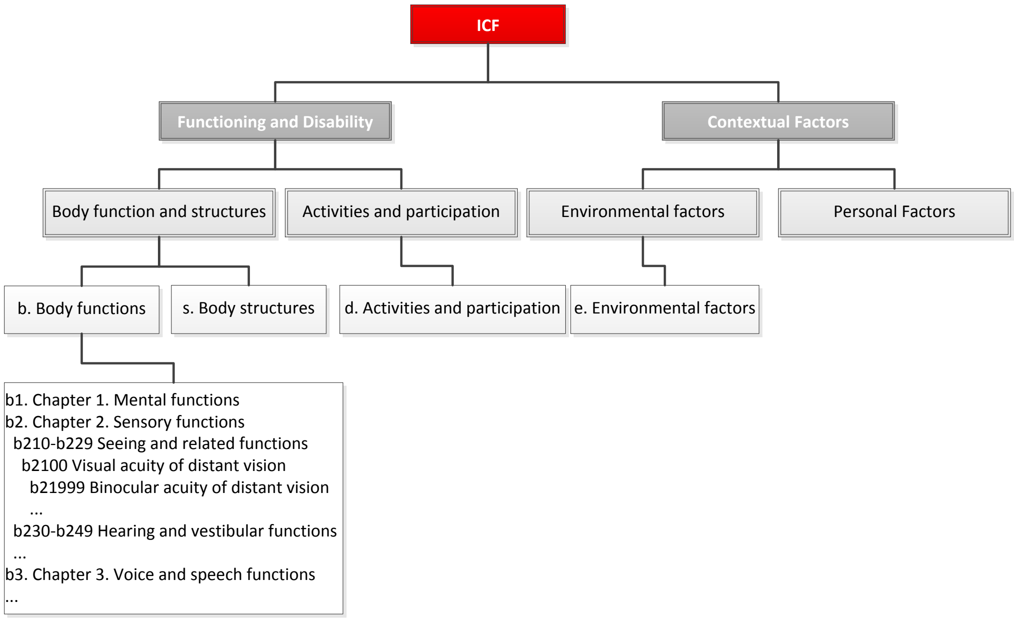



**Figure 3 ICF structure**

This classification is so exhaustive that its daily use usually becomes too complex; thus, many professionals only use a subset of the ICF. Being aware of this fact, WHO has developed several tools to facilitate its use such as the ICF Checklist (World Health Organization 2003). However, it was found that these tools still are too general in some cases. This need has motivated the creation of the ICF Research Branch that develops, evaluates, and disseminates tools and models of functioning and health for different groups of patients and settings (Fayed, Cieza et al. 2011). Besides its main use in the health and rehabilitation sector (Kiltz, van der Heijde et al. 2011, Xu, Kohler et al. 2011), ICF taxonomy has been used for many different uses within Assistive Technology (AT); such as outcome research (Lenker, Paquet 2003), to describe the user activities related to consumer products (Sangelkar, Cowen et al. 2012) or for modelling the selection of AT (Scherer, Jutai et al. 2007).

### 3.2.3. HUMAN DEVICE INTERACTIONS MODELS

Ergonomic (or human factors) is defined by the International Ergonomic Association as the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (International Ergonomics Association 2011). This discipline is strongly related with other younger disciplines as the Human Computer Interaction (HCI) which born in the 1980's as a generalization of the Human Machine Interaction (HMI) due to the increase of research works in the different aspects of the interaction between human and computer (Dix, Finlay et al. 2004). The interaction models used in HCI can be applied in a general way to the study of the interaction between human and devices, understanding device as a product, system or service.

Several authors have modelled this interaction being the Norman's action-circle (Norman 1988) one of the most influents (Dumas, Lalanne et al. 2009, Dix, Finlay et al. 2004). The action-circle defines the interaction in two steps: the execution and the evaluation. The execution involves doing something and the evaluation is the comparison between what really happened and what we wanted to happen in the world by performing the action (our goal). Norman defines seven stages in the interaction:

1. Establishing the goal.
2. Forming the intention.

3. Specifying the action.
4. Executing the action.
5. Perceiving the world state.
6. Interpreting the state of the world.
7. Evaluating the outcome (i.e. the system state with respect to the goals and intentions)

The Interaction Framework proposed by Abowd and Beale (Abowd, Beale et al. 1991) goes one step further in this direction including the system in the model and proposing a more realistic approach. They define four main components in the interaction: the user, the system, the inputs and the outputs. Each one has its own language which is used to express its purpose in the interaction. For Abowd and Beale Input and Output, together, compose the system interface. As Figure 4 shows, there are four steps in the interaction: articulation, observation, performance and presentation. Abowd describes this interactive cycle in his PhD Thesis (Abowd 1991) of this way:

*"User interactive cycle began with the formulation of a goal and task to achieve that goal. The only way the user can manipulate the machine is through the Input, and so the task must be articulated within the input language. The input language is translated into the core language as operations to be performed by the System. The System then transforms itself as described by the operation translated from the Input; the execution phase of the cycle is complete and the evaluation phase now begins. The System is in a new State, which must now be communicated to the User. The current values of system attributes are rendered as concepts or features of the Output. It is then up to the User to observe the Output and assess the results of the interaction relative to the original goal, ending the evaluation phase and, hence, interactive cycle."*

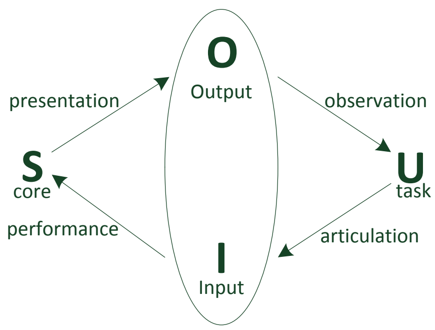



Figure 4. PhD. Abowd extract (Abowd 1991)

This concept has been generalized for multimodal interfaces. For example, Dumas, Lalanne et al. propose a model which takes as starting point the Norman's action circle considering multimodal inputs and outputs (Dumas, Lalanne et al. 2009). Next figure summarize this model:

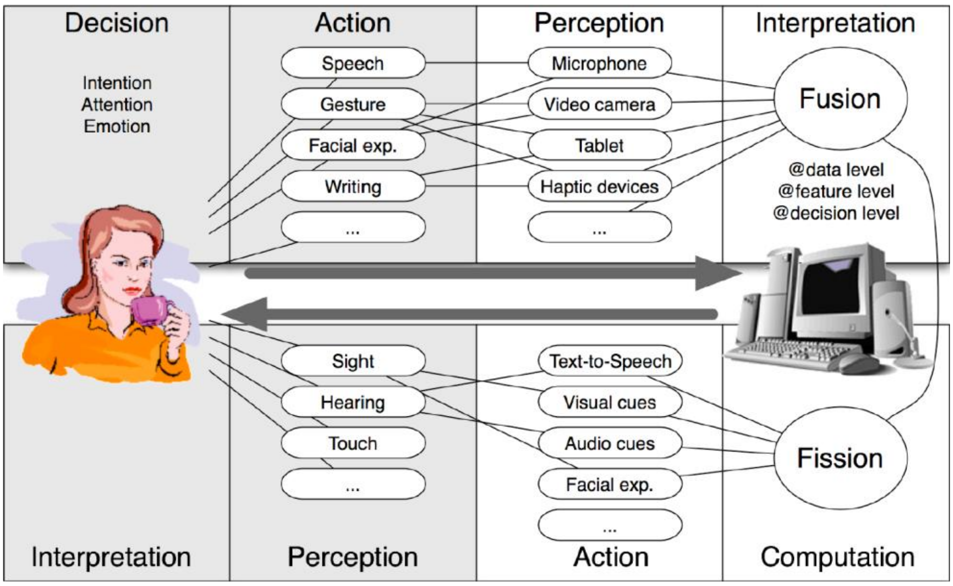



**Figure 5 Multimodal interface interaction example (Dumas, Lalanne et al. 2009)**

Considering the Interaction Framework as starting point, next sections present a methodology which combines the user modelling and tasks study with the ICF lexicon. It provides a new tool to analyse the interaction between user and device which detects the key aspects in order to include the needs of a specific population in the design process.

## 3.3. USERS' NEEDS IDENTIFICATION METHODOLOGY

### 3.3.1. RESEARCH APPROACH

**This methodology offers a systematic way to identify needs in the design of a product or system for a specific collective as elderly or disabled people**. It is based in the study of the potential limitations these users have performing the tasks that will be supported by the new product as currently built, with current technology. To achieve this objective the interaction is studied following the model proposed by Abowd and Beal, and using the ICF language in order to describe human capacities and actions.

As this model shows, both Input and Output, compose the system interface. Focusing in the user point of view of the interaction, we find that, as first step, the user formulates a goal and the tasks to achieve that goal. This implies that **the user has been able to understand the stimuli that perceives, to process the related information and to produce a response according to the context and the interaction objectives**.

Then, the only way that the user has to interact with the system is using one of its inputs (microphone, keypad, touch screen, gesture, etc.). **This step implies that the user has been able to produce a response that the system can perceive (voice, movement, pulsation, etc.).** Once the system responds, the user must be able to perceive and interpret the outputs and assess the results of the interaction versus the original goal; same way than in the first step when the user needed to understand and process the stimuli and to produce a response according to the context and the interaction objectives.

Thus, it is possible to conclude that **the critical user's capacities for the interaction are related with: cognition, sensory, physical (movement, pulsation, etc.) and voice.**

The methodology here presented defines three sequential phases with clearly differentiated objectives:

i. **Users' characterization:** aims to identify which person's capabilities could be typically affected as consequence of belonging to a specific collective. Besides generic aspects, this focus in the critical user's capacities for the interaction.

ii. **User-device interaction characterization:** aims to describe the interaction of the user performing the tasks that will be covered with the new product or system as now done.

iii. **Identification of users' needs:** aims to extract the user needs derived from each task involved in the user-device interaction characterization taking into consideration the users' characterization.

#### 3.3.1.1. USERS' CHARACTERIZATION

Users' characterization is performed in two phases; first, research about the specific capacities and limitations in specialized literature and statistics, provides a general overview of the target population. Many sources are available such as the Survey of Health, Ageing and Retirement in Europe (SHARE), EUROSTAT or any other source (Van Isacker, Goranova-Valkova et al. 2008, Tenneti, Johnson et al. 2012). This research is focused in the skills needed to perform a proper user-device interaction according to framework interaction model: how the person can receive information from the machine through the system output (senses), how the person can command the machine through the system input (hands, voice, gaze, etc.) and how the person can understand the information perceived and reason accordingly (cognitive capacities needed to propose a goal and to evaluate the results of the actions performed).

In the second phase, this research is then embodied using the ICF taxonomy descriptors from the epigraph *b. Body functions classification*. The body functions that influence human-machine interaction and which could be affected as consequence of the elderliness, disease or disability the person might, are described by the ICF the chapters:

> *b1. Mental functions,* which is about the functions of the brain: both global mental functions, such as consciousness, energy and drive, and specific mental functions, such as memory, language and calculation mental functions.
>
> *b2. Sensory functions and pain,* which is about the functions of the senses, seeing, hearing, tasting and so on, as well as the sensation of pain.
>
> *b3. Voice and speech functions,* which is about the functions of producing sounds and speech.
>
> *b7. Neuromusculoskeletal and movement-related functions, which is about the functions of movement and mobility, including functions of joints, bones, reflexes and muscles.*

A set of four tables (one per ICF chapter) indicating cognitive, sensorial, speech and movement-related functions is the outcome of this phase. Each table has two columns: first describing the problems, limitations, capacities of the target population according to literature and second listing the ICF descriptors associated to the items in first column. These descriptors are a set (named C, from characterization) which characterize the body functions which typically could affect to a person included in the target population i.e. $C = \{b_1, \ldots, b_n\}$ being $b_i$ with $i = 1..n$ a descriptor from the *Body functions classification* of the lists previously commented.

> For example, C = { b2100 Visual acuity functions, b2102 Quality of vision,…, b140 Attention functions, b710 Mobility of joint functions, b720 Mobility of bone functions, b730 Muscle power functions }

Users' characterization should be performed by a multidisciplinary group involving social workers, health professionals and other personnel related (caregivers, etc.) who could provide additional information about this characterization.

#### 3.3.1.2. USER-DEVICE INTERACTION CHARACTERIZATION

This characterization is done studying how a person currently performs the tasks which will be supported by the new device or system. In this scope a task is understood as a set of actions to reach a goal. These tasks have been analysed considering the human capacities needed to perform them using the ICF epigraph *d. Activity and participation*. Tasks identification can be done through direct observation, by the study of the process, using flow diagrams or any other systematic technique. However, note that the more rigorous this process is, the better needs identification will be.

As we said earlier, ICF taxonomy is very detailed and not all the chapters within the epigraphs are always applicable. According to the specific objectives of the methodology and the interaction model, we find this relevant:

- *d1. Learning and Applying Knowledge*, which is about cognitive processes required for learning, applying the knowledge that is learned, thinking, solving problems, and making decisions.
- *d2. General tasks and demands*, which is about general aspects of carrying out coordinated actions related to a task; i.e. initiating a task, organizing time, space and materials for a task, pacing task performance, etc.
- *d3. Communication and d4.Mobility*, which are about how the person implements interaction with the device; receiving and producing messages, changing body position, carrying, moving or manipulating objects, etc.

As result of this phase we obtain a set of tasks (named T, from tasks): $T = \{t_1, \dots, t_m\}$ being $t_i$ with $i = 1..m$ the independent tasks which describe the usual interaction between user and device. Additionally, each one of these tasks is in turn described in ICF language, as a set of activities from the *d. Activity and participation* list i.e. $t_1 = \{d_1, \dots, d_p\}$ being $d_i$ with $i = 1..p$ a descriptor from the lists previously commented. Sometimes, it could be useful to break down the task in simple subtasks in order to ease the descriptor identification.

As an example, we will apply this step to the design of a can opener. In this case, the only one task done by a can opener is to "open a can". This process has been broken down in subtasks, taking as starter point the Activity-diagram proposed by Sangelkar (Sangelkar, Cowen et al. 2012) and related with the capabilities required according to ICF:

| Subtask involved | Activity descriptor set |
|---|---|
| Pickup the can opener and hold it in one hand<br>Twist the handle with the other hand<br>Import and position the can to be opened<br>Engage the can opener with the can<br>Remove the lid | d110 Watching<br>d160 Focusing attention<br>d2100 Undertaking a simple task<br>d440 Fine hand use<br>d445 Hand and arm use<br>d449 Carrying, moving and handling objects, other specified and unspecified |

**Table 2 Can opener interaction**

i.e. the tasks set is composed by only one task T={Opening a can} and it could be described according ICF as a set of activities:

Opening a can = {d110 Watching, d160 Focusing attention, d2100 Undertaking a simple task, d440 Fine hand use, d445 Hand and arm use, d449 Carrying, moving and handling objects, other specified and unspecified}

Thus, a user who can perform these activities will be able to perform the task.

Sometimes, when the study is focused on the interaction, the environmental factors could be omitted considering an “ideal” environment which has not influence over it (this is the case of the previous example). However, when the new product or system will work in known and different environments which may condition the interaction, this study should be done in each scenario. In order to assure coherence with the rest of the methodology, these environmental situations should be described using the descriptors provided by the ICF’s *e. Environmental factors* list. Each situation is described by a set of environmental descriptors ($Es_1 = \{e_1, \dots, e_o\}$ being $e_i$ with $i = 1..o$ a descriptor from the lists previously commented). For example, the environmental factors vary if there is not enough light in the room to see.

This phase should be performed by a multidisciplinary group involving technicians (product designer, ergonomics, etc.), social worker and other personnel related (caregivers, etc.) who could provide additional information.

#### 3.3.1.3. IDENTIFICATION OF USERS’ NEEDS

This phase combines the previous phases to thoroughly extract the user needs derived from each task involved in the user-device interaction characterization (3.3.1.2) and taking into consideration the users’ characterization (3.3.1.1).

The needs identification is an iterative process which takes as starting point the set of tasks obtained in the previous step. **For each of these tasks**, the next process follows:

- The task is described as $t_i = \{d_1, \dots, d_p\}$, being $t_i$ the task and $\{d_1, \dots, d_p\}$ the set of ICF descriptors.

  e.g. as it has been commented, a can opener has an only one task characterized by the next descriptors:

  Opening a can = {d110 Watching, d160 Focusing attention, d2100 Undertaking a simple task, d440 Fine hand use, d445 Hand and arm use, d449 Carrying, moving and handling objects, other specified and unspecified}

- Our target population is described by a characterization set ($C = \{b_1, \dots, b_n\}$).

  e.g.

  C = {b2100 Visual acuity functions, b2102 Quality of vision,…, b140 Attention functions, b710 Mobility of joint functions, b720 Mobility of bone functions, b730 Muscle power functions}

  This means that a user included in the target population could have affected any of these functions.

- Then, if there is a relation between a task descriptor and one or more components of the set, it indicates that a need could exist (i.e. if $d_1 = f(b_k, \dots, b_l)$). If environmental factors are considered, they must be also related with the task descriptors for each situation (i.e. if $d_1 = f(b_k, \dots, b_l, e_k, \dots, e_l)$))

e.g. d110 Watching is related with b2100 Visual acuity functions, b2102 Quality of vision. i.e.:

d110 Watching = f(b2100 Visual acuity functions,… , b2102 Quality of vision)

This is called indicator and indicates that the user could have problems to perform this action (d110 Watching) and the need or needs detected will be conditioned by the task.

- Each indicator must be studied in order to detect the need.

e.g. Need detected: People with visual impairments may have troubles positioning the can and the opener and to determine when the can is already open.

When an indicator ($i_n$) is included in several tasks, although the indicator is the same because the relation is independently of the task ($d_i = f(b_k, \dots, b_l)$), the needs detected could be different for each task. Following with the example, each time that a task includes the descriptor *d110 Watching* with the current population objective, an indicator will appear due to the relationship between *d110 Watching* and the descriptors *b2100 Visual acuity functions* and *b2102 Quality of vision*. However the need detected is different for the task *"open a can"* that, for example, "looking for a specific can".

As result, we have a set of indicators ($I_{ti}$) and needs ($N_{ti}$) associated to each tasks ($t_i$) which have been represented in a tabular format. Each table, one per task, has three columns indicating: a) list of descriptor of the activities (according to ICF); b) indicators ($I_{ti}$, relation between activities and body functions implicated according to ICF); c) list of needs detected ($N_{ti}$). These tables provide an extensive and reasoned perspective about the needs to be tackled in the design of the product for the target population of study. They also provide valuable information about the indicators to be used in latter product evaluation.

Following with the study of the can opener for the example target population we would obtain the following table:

| **Task** | | |
|---|---|---|
| **Opening a can** | | |
| **Capabilities required** | **Indicators** | **Needs detected** |
| d110 Watching | d110 related to b2100, b2102 | Although people with visual impairments could use it, they may have troubles positioning the can and the opener and to determine when the can is already open. |
| d160 Focusing attention<br>d2100 Undertaking a simple task | d160, d2100 related to b140 | People with cognitive problems may have troubles following the process (understand the process, injury, etc.) and may require support to do the same. |
| d440 Fine hand use<br>d445 Hand and arm use<br>d449 Carrying, moving and handling objects, other specified and unspecified | d440, d445, d449 related to b720, b730 | Heavy cans can be a problem hindering the use of opener.<br><br>The realization of precise movements and performing hand turns can be a problem. |

**Table 3 Identification of users' needs for the task: "Opening a can"**

This methodology formalizes and systematizes the process of looking for needs' identifiers and must be performed by an expert team in order to set the need; ideally this team should be composed by the professionals in the first and second phases of the process.

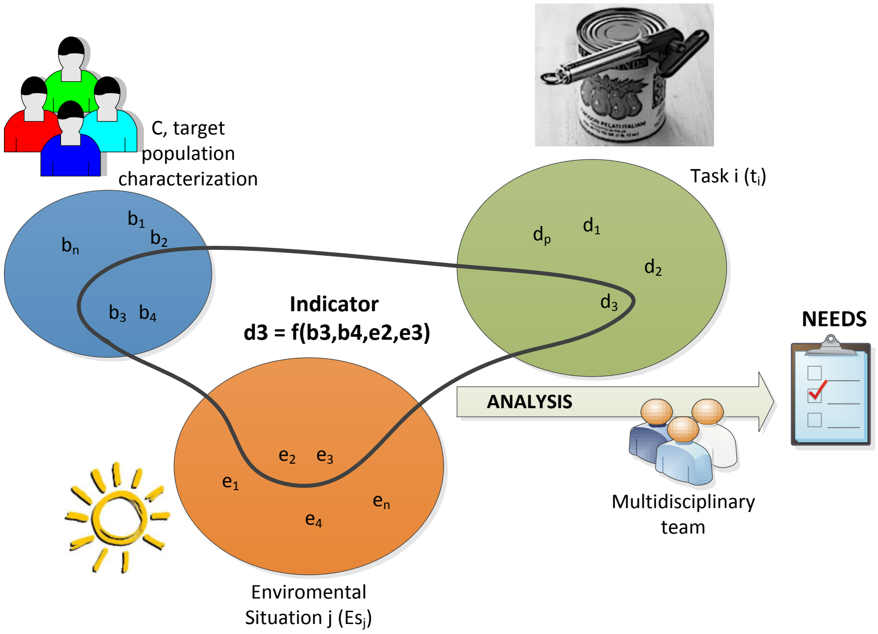



Figure 6 Example of needs identification for one task ($t_i$) in a specific situation scenario ($Es_i$)

## 3.4. LOOKING FOR NEEDS IN THE DESIGN OF AN AAL KITCHEN

### 3.4.1. USERS' CHARACTERIZATION

Characterization of elderly people, target of current study, takes as statistical source the report of the IMSERSO (Agency of the Government of Spain for the management of programs and services for elderly and handicapped people) (IMSERSO 2009). This report presents a thorough analysis of the situation of the elderly people in Spain. It also includes detailed information about the health status of the elderly people, main illness and percentages of people affected.

As said earlier, this characterization is represented in four tables following the epigraphs of the ICF. First column specifies the main illnesses which can affect the elderly people together with the incidence rate over the total of the population. Second column identifies the ICF descriptors that could be affected by the illness. This results in a characterization of the elderly people based in the standard language proposed by the ICF and showing the body functions which could be affected by the ageing.

| | Diseases and conditions common in elderly people | Related ICF descriptors |
|---|---|---|
| **b1.Mental functions** | Around 20% of the population over 65 in Spain has some **cognitive disorder** (IMSERSO 2009, Bartrés-Faz, Clemente et al. 1999, Wikipedia 2013, Casas, Blasco et al. 2009):<br><br>The aging brain is characterized by some degree of natural decline of cognitive functions like memory, visual-spatial skills and speed of information processing.<br><br>Senile dementia is the progressive loss of cognitive functions, because of damage or brain disorders. Typically, this cognitive impairment causes inability to perform activities of daily living. Cognitive deficits can affect any of brain functions, particularly the areas of memory, language (aphasia), attention, visual-constructive skills, the praxis and executive functions as troubleshooting or response inhibition.<br><br>Alzheimer is the most common form of dementia. In the early stages, the most common symptom is difficulty in remembering recent events. As the disease advances, symptoms can include confusion, irritability and aggression, mood swings, trouble with language, and long-term memory loss. As the sufferers decline they often withdraw from family and society. Gradually, bodily functions are lost, ultimately leading to death.<br><br>Parkinson's disease is a chronic neurodegenerative disorder that leads eventually to a progressive disability, produced as a result of destruction of the pigmented neurons of the substantia nigra. Parkinson's disease, as well as movement disorder also triggers alterations in cognitive function in the expression of emotions, speech and autonomic function. | **b114 Orientation functions:** General mental functions of knowing and ascertaining one's relation to self, to others, to time and to one's surroundings.<br><br>**b117 Intellectual functions:** General mental functions, required to understand and constructively integrate the various mental functions, including all cognitive functions and their development over the life span.<br><br>**b140 Attention functions:** Specific mental functions of focusing on an external stimulus or internal experience for the required period of time.<br><br>**b144 Memory functions:** Specific mental functions of registering and storing information and retrieving it as needed.<br><br>**b147 Psychomotor functions:** Specific mental functions of control over both motor and psychological events at the body level.<br><br>**b156 Perceptual functions:** Specific mental functions of recognizing and interpreting sensory stimuli: b1560 (Auditory perception), b1561 (Visual perception), b1562 (Olfactory perception), b1563 (Gustatory perception), b1564 (Tactile perception), b1565 (Visuospatial perception)<br><br>**b160 Thought functions:** Specific mental functions related to the ideational component of the mind.<br><br>**b164 Higher-level cognitive functions:** Specific mental functions especially dependent on the frontal lobes of the brain, including complex goal-directed behaviours such as decision-making, abstract thinking, planning and carrying out plans, mental flexibility, and deciding which behaviours are appropriate under what circumstances; often called executive functions.<br><br>**b167 Mental functions of language:** Specific mental functions of recognizing and using signs, symbols and other components of a language<br><br>**b176 Mental function of sequencing complex movements:** Specific mental functions of sequencing and coordinating complex, purposeful movements. |

**Table 4. Cognitive diseases and conditions common in elderly people**

| | Diseases and conditions common in elderly people | related ICF descriptors |
| --- | --- | --- |
| b2.Sensory functions and pain | **Sensory functions** deteriorate with age, manifesting in impaired vision, hearing, loss of smell, taste, etc. Visual and additive capabilities are the most evident; around the 30% of the elderly people in Spain have some kind of visual disability; increasing to 34% for aural disability. However, though there are evidences that taste, smell, balance or touch capabilities decrease with the ageing there isn't statistics about its impact in the elderly people, due to, usually it is considered a minor problem compared with vision or hearing (IMSERSO 2009, Wikipedia 2013, Paulo, Gac 2000, Casas, Blasco et al. 2009).<br><br>From age 40 onwards, the frequency of presbyopia increases (loss of focusing capability on nearby objects)<br><br>Ageing leads to deterioration of the optical properties of the eyeball (loss of transparency and yellowing), which in turn reduces the sharpness of images on the retina (they become more blurry) and alters them chromatically (the colour green becomes harder to distinguish, while the colour red does not).<br><br>Ageing also leads to deterioration of the nerve mechanisms which respond to variations in light levels (adaptation to changes in the latter becomes slower and it is easier to be temporarily blinded by sharp variations).<br><br>Added to this, ageing also reduces the joint capability of both eyes to combine information, and therefore, to differentiate between short distances, thus reducing hand to eye coordination.<br><br>Certain ophthalmologic illnesses become more frequent: cataracts (opacity of the cornea), glaucoma (increase of intraocular eye pressure) and macular degeneration<br><br>Presbyacusia is the hearing loss brought on by ageing. From age 40 onwards, people loss hearing capabilities symmetric and progressively that affect to the ability to discriminate sounds and usually involve problems related with the speech discrimination.<br><br>With age decreases the secretion of earwax and moisture from the skin, increased dryness, causing the impaction of earwax which may result the plugged up of ear by the earwax and, therefore, affect the person's hearing ability.<br><br>Also, the appearance of tinnitus (perception of sound within the human ear in the absence of corresponding external sound) increases with the ageing. It usually manifests with the perception of a ringing in the ear.<br><br>The capacity of perceive odours and tastes decreases with the ageing. This situation could produce dangerous situations as not perceive the burn smell, the gas smell or the state of the food. | **b210 Seeing functions:** Sensory functions relating to sensing the presence of light and sensing the form, size, shape and colour of the visual stimuli: b2100 (Visual acuity functions), b2102 (Quality of vision)<br><br>**b230 Hearing functions:** Sensory functions relating to sensing the presence of sounds and discriminating the location, pitch, loudness and quality of sounds: b2300 (Sound detection), b2301 (Sound discrimination), b2302 (Localisation of sound source), b2304 (Speech discrimination)<br><br>**b235 Vestibular functions:** Sensory functions of the inner ear related to position, balance and movement.<br><br>**b250 Taste function:** Sensory functions of sensing qualities of bitterness, sweetness, sourness and saltiness.<br><br>**b255 Smell function:** Sensory functions of sensing odours and smells.<br><br>**b265 Touch function:** Sensory functions of sensing surfaces and their texture or quality |

Table 5 Sensorial diseases and conditions common in elderly people

| | Diseases and conditions common in elderly people | related ICF descriptors |
|---|---|---|
| b3.Voice and speech functions | Around the 20% of the elderly people in Spain have some kind of disability related with the **communication** (IMSERSO 2009, Wikipedia 2013, Saludalia 2013, Casas, Blasco et al. 2009):<br><br>Ageing will affect the ability of the individual phonation. When people get older, pulmonary system decreases and expiratory force used in the phonation is coming limited. It also decreases the ability to maintain intraoral pressure during phonation and hence the ability to produce vowel sounds.<br><br>The tone of voice changes, in man the tone increases, the voice becomes more acute by a senile atrophy of the vocal cords. For the woman the tone decreases, the voice becomes deeper due to severe edema of the vocal cords.<br><br>Laryngeal structures also changing to a distinct tissue appearing in the strings, a decrease in mucus production and physiological atrophy of the laryngeal muscles that lead people to what is called "senile voice.<br><br>Parkinson: Diction: At least 50% of patients have slurred speech, whisper, hesitate before speaking, repeating words or speak too fast. | **b310 Voice functions:** Functions of the production of various sounds by the passage of air through the larynx<br><br>**b320 Articulation functions:** Functions of the production of speech sounds.<br><br>**b330 Fluency and rhythm of speech functions:** Functions of the production of flow and tempo of speech. |

**Table 6.Speech diseases and conditions common in elderly people**

| | Diseases and conditions common in elderly people | related ICF descriptors |
|---|---|---|
| **b7.Neuromusculoskeletal and movement-related functions** | Around 71% of the elderly people in Spain have some kind of disability related to the **mobility** (IMSERSO 2009, Wikipedia 2013, MedlinePlus 2013, Casas, Blasco et al. 2009):<br><br>Osteoporosis is a common problem, especially for elderly women. Bones break more easily, and compression fractures of the vertebrae can cause pain and reduce mobility.<br><br>Muscle weakness contributes to fatigue, faintness, and reduced tolerance to activity. Joint problems are quite common, which can range from mild stiffness to debilitating arthritis.<br><br>The risk of injury increases because gait changes, the instability and loss of balance may lead to falls. Some elderly people have reduced reflexes, caused more frequency changes in the muscles and tendons. There may be decreased knee jerk or ankle jerk.<br><br>Involuntary movements (muscle tremors and fine movements called fasciculations) are more common in the elderly. | **b710 Mobility of joint functions:** Functions of the range and ease of movement of a joint.<br><br>**b720 Mobility of bone functions:** Functions of the range and ease of movement of the scapula, pelvis, carpal and tarsal bones<br><br>**b730 Muscle power functions:** Functions related to the force generated by the contraction of a muscle or muscle groups<br><br>**b755 Involuntary movement reaction functions:** Functions of involuntary contractions of large muscles or the whole body induced by body position, balance and threatening stimuli.<br><br>**b760 Control of voluntary movement functions:** Functions associated with control over and coordination of voluntary movements.<br><br>**b765 Involuntary movement functions:** Functions of unintentional, non- or semi-purposive involuntary contractions of a muscle or group of muscles.<br><br>**b770 Gait pattern functions:** Functions of movement patterns associated with walking, running or other whole body movements. |

**Table 7 Mobility diseases and conditions common in elderly people**

### 3.4.2. USER DEVICE INTERACTION CHARACTERIZATION

As it has been commented, this characterization is done studying how a person currently performs the tasks that will be supported by the new device or system. In this case, the tasks which will be covered by the Smart Kitchen, are currently done with standard kitchen appliances; mainly the hob, oven, washing machine, fridge, freezer and microwave. For each one of these appliances, a midrange product has been selected in order to study current interaction.

Additionally, in our case, we have assumed a neutral interaction environment: where environmental factors do not difficult nor facilitate the interaction between user and appliances. Also, these appliances have been grouped by functional areas in order to study the tasks done in the interaction with the user:

- Food management, which groups the tasks related to the fridge and freezer.
- Cooking, which groups the tasks related to the oven, hob and microwave.
- Washing, which groups the tasks related to the washing machine and dishwasher.

Some tasks are similar in several processes and could be considered as "transversal tasks". For example, using the oven, washing machine or refrigerator share the task "Opening and closing the door". Thus, such tasks related with processes that cut across different functional areas are grouped into a new set called "transversal tasks" in order to study them together. Table 8 lists the tasks in each area studied, transversals have been labelled with (Tr).

| Food management tasks | Cooking tasks | Washing tasks |
|---|---|---|
| Food Classification and organization<br><br>Opening and closing the doors (Tr)<br><br>Placing and removing items<br><br>Analysing the state of the food<br><br>Configuring/Programing and monitoring (Tr)<br><br>Maintenance and cleaning (Tr) | Preparation of food to be cooked<br><br>Placing/removing the recipient (over the hotplate or into the oven)<br><br>Opening/closing door (Tr)<br><br>Configuring/Programing and monitoring (Tr)<br><br>Maintenance and cleaning (Tr) | Organization and classification of clothes or crockery<br><br>Opening/closing door (Tr)<br><br>Loading and unloading clothes or crockery<br><br>Measuring and adding detergent, softener and others<br><br>Configuring/Programing and monitoring (Tr)<br><br>Maintenance and cleaning (Tr) |

**Table 8. Tasks by area**

Interaction in the kitchen has been studied by observation, identifying processes and tasks involved in each area. This process is detailed in following points:

### 3.4.2.1. FOOD MANAGEMENT

As reference, in the interaction study, a two doors refrigerator (fridge at top and freezer at bottom) has been selected. The device has simple interface which enables selection of the fridge and freezer temperature, turn on/off and enable/disable the super-freezer option. The interface is located in the centre of the top edge of the refrigerator door.

Fridge has 4 trays and one drawer and 3 shelves for bottles on the door and its interior is illuminated when the door is open. The Freezer has 3 drawers and a little tray for ice cubes. Doorknobs are placed as shows the Figure 7. The refrigerator does not include a door open alarm. Its physical measurements are: 186 cm height, 60 cm width and 65 cm depth.

Figure 7 Refrigerator selected

In order to perform the food management in the kitchen, the user must be able to interact with the refrigerator doing the next tasks:

- Food classification and organization
- Opening and closing the doors
- Placing and removing items
- Analysing the state of the food
- Configuring/Programing and monitoring
- Maintenance and cleaning

Each one of these tasks (excluding transversal tasks which are analysed in the section 3.4.2.4) has been described in ICF language, as a set of activities from the *d. Activity and participation:*

**Food Classification and organization:**

| Task: Food Classification and organization | |
|---|---|
| Food Classification and organization requires the classification of the items depending of the cooling needs and the execution of tasks prior to food storage (remove packaging, etc.). Also, It has been considered to include in this task the transport to the place where the food will be stored. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| Cooling needs food grouping<br>Classify food to be stored<br>Execution of tasks prior to food store (remove packaging, etc.) | d110 Watching<br>d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task<br>d4300 Lifting<br>d4301 Carrying in the hands<br>d440 Fine hand use |

Table 9 Food classification and organization characterization

**Opening and closing the doors:**

(See section 3.4.2.4)

**Placing and removing items:**

| Task: Placing and removing items from the fridge or freezer | |
|---|---|
| This task includes the search process to determine where the item is stored or the planning process to determine where the item will be stored. Also the physical tasks of accessing inside the appliance to put/leave items, etc. Door opening and close has been studied separately. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| To think about the place where the item is stored or where the item will be stored<br>To access inside of the appliance<br>Putting items into the appliance<br>Taking/leaving items into/out of the appliance<br>Looking for space/item inside the appliance | d110 Watching<br>d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task<br>d4101 Squatting<br>d4105 Bending<br>d445 Hand and arm use |

**Table 10 Placing and removing items form the fridge o freezer characterization**

**Analysing the state of the food:**

| Task: Analysing the state of food | |
|---|---|
| Periodically, user checks the status of the food and removes the expired products. This task has only considered the sensorial and cognitive capabilities of the user because the rest of the tasks (open/close door, placing and removing items, etc.) have been studied separately. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| | d110 Watching<br>d120 Other purposeful sensing<br>d160 Focusing attention<br>d177 Making decisions |

**Table 11 Analysing the state of the food characterization**

**Configuring/Programing and monitoring:**

(See section 3.4.2.4)

**Maintenance and cleaning:**

(See section 3.4.2.4)

### 3.4.2.2. COOKING

To study the interaction, next appliances have been chosen:

Figure 8 Oven selected

The oven has three retractable rotary control knobs. The first one, placed on the top-left, is a timer with switch off function, which enables turn off the oven after a maximum of 120 min. The next one is a function selector which sets the type of heating (Top/bottom heating, large grill area, small grill area, bottom heating and oven light). The last one is a temperature selector (50-270°C) or grill power selector (grill power I, II, III, depending on the function selector option). The door has a big handle placed on the top (see Figure 8). Also, it has a front glass that together with the interior light permits to monitor the food state. It has three racks which enable to put the tray or shelf in three different heights. Also the oven could be mounted at different heights in order to simply the access.

Figure 9 Hob selected

The hob has four ceramics fires which are controlled through a touch control (Figure 9). Each fire has associated two buttons and a display which permit to select the power level from 0 (off) to 9 with 11 levels 1, 1., 2, 2., ..., 96. The top left fire has two diameters selected by a specific button. Also the hob has a turn on/off button which handles the four fires. When the hob is off and a fire is hot, the level indicator display an “H” or “h” depending on the temperature (H= high temperature, h=moderately high temperature). Also, it has a block function in order to prevent its use by children and a water warning which turns off the hob when the touch control detects water over it.

Figure 10 Microwave selected

The microwave has a power of 800 W with an interface composed by 2 rotary buttons that enable to select the power and the time, and a push button to open the door. Buttons are located in column at the right as the picture shows (Figure 10).

Focusing in the study of the interaction, it is evident that the preparation of a specific dish can be very complex and different from another. However, leaving aside the use of kitchen tools (knives, bowls, dishes, etc.) to prepare the food to be cooked (remove packaging, slicing, cutting, etc.) and focusing in the interaction between users and white goods, the number of actions the user does is limited (place a recipient, select the fire level, monitor the process, etc.). Also, tasks related with the food management have not been considered due to they are explained in the previous section. Therefore, the user must be able to perform the next tasks in order to interact with the hob, oven and microwave:

- Tasks associated with the food management (see previous section)
- Preparation of food to be cooked
- Placing/removing the recipient (over the hotplate or into the oven)
- Opening/closing door (oven and microwave)
- Configuring/Programing and monitoring (oven, hob and microwave)
- Maintenance and cleaning

Each one of these tasks (excluding transversal which are analysed in the section 3.4.2.4) has been described in ICF language, as a set of activities from the *d. Activity and participation:*

**Preparation of food to be cooked**

| Task: Preparation of food to be cooked | |
|---|---|
| This task includes the different subtasks related with the food preparation in order to be cooked. Note that only has been considered basic subtasks so, in order to elaborate complex recipes, it could be needed to add new ones, increasing consequently the user's capabilities required. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| Removing packaging<br>Adding ingredients to the recipient<br>Cutting<br>Slicing<br>Mixing | d110 Watching<br>d160 Focusing attention<br>d175 Solving problems<br>d177 Making decisions<br>d2202 Undertaking multiple tasks independently<br>d440 Fine hand use<br>d445 Hand and arm use<br>d4154 Maintaining a standing position |

Table 12 Preparation of food to be cooked characterization

**Placing/removing the recipient (over the hotplate or into the oven)**

| Task: Placing/removing the recipient | |
|---|---|
| This task includes the tasks related with the access inside the appliance (oven and microwave) and to put/leave the recipient (hob, oven and microwave) over the hotplate. Door opening and close has been studied separately. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| To access to inside of the appliance<br>To decide where/how to put/leave the recipient<br>Placing/removing the recipient into the oven / on the fire | d110 Watching<br>d177 Making decisions<br>d4101 Squatting<br>d4105 Bending<br>d4300 Lifting<br>d4301 Carrying in the hands<br>d445 Hand and arm use |

Table 13 Placing/removing the recipient characterization

**Opening/closing door (oven and microwave)**

(See section 3.4.2.4)

**Configuring/Programing and monitoring (oven, hob and microwave)**

(See section 3.4.2.4)

**Maintenance and cleaning**

(See section 3.4.2.4)

#### 3.4.2.3. WASHING

The processes of washing clothes and dishes, as discussed below, have several similarities. There are many tasks common for both processes. However, doing the laundry is much more complex from a cognitive point of view due to the large number of possibilities presented in the different steps required for using the washing machine (difficulty in separating the clothes, more programs and settings, etc.) In addition, misuse of the machine can cause the destruction of the clothing being washed while in the dishwasher this situation is unusual.

A frontal load washer has been selected in order to study the user interaction. It has a detergent drawer on the top left, a rotary control knob to select the washing program, three status indicators (start, wash, rinse, spin, end) a flot button which enables to postpone the spin process, a button to select the spin speed (600rpm/1000rpm) and a start button. The door is placed in the middle of the frontal and has a handle placed on the right (see Figure 11).

The dishwasher has an interface placed on the top of the door (see Figure 11). It is composed (from left to the right) for an on/off button, a handle (to open the door) a rotary control to program select with a start button placed in the middle and a set of indicators for salt refill, water supply and rinse refill, dry display and cleaning display.

**Figure 11 Dishwasher and washing machine selected**

Studying the process for washing of the clothes, the user has to organize and classify the laundry, taking into account the type of fabric, colour and recommended washing program. Then, user has to open the washing machine, load the selected clothes inside and close the door. Once the machine is ready, the user has to add detergent and softener; selecting and start the appropriate program. Occasionally, the user can monitor the process to see if the washer has finished. When it finished, user has to open the door and unload it.

For the dishwashing, the user has to prepare (rinse food leftovers), organize and classify the crockery taking in to account that some pieces are not suitable for the dishwasher. Then, the user has to open the door, to load the crockery, add the detergent and close its door. Once the dishwasher is ready, the user has to select a program to start the washing process. Occasionally, the user can monitor the process to see if the washer has finished. When the dishwasher has finished, the user has to open the door and unload the crockery.

Therefore, the user must be able to perform the next tasks in order to interact with the washer and dish washer:

- Organization and classification of clothes or crockery
- Opening/closing door

- Loading and Unloading clothes or crockery
- Measuring and adding detergent, softener and others
- Configuring/Programing and monitor
- Maintenance and cleaning

Each one of these tasks (excluding transversal which are analysed in the section 3.4.2.4) has been described in ICF language, as a set of activities from the *d. Activity and participation:*

**Organization and classification of clothes or crockery:**

| **Task: Organization and classification of clothes or crockery** | |
|---|---|
| This task includes the different subtasks related with the organization and classification of clothes (grouping, classify, unbutton, etc.) and crockery (rinse dishes, etc.) and their handling in order to use the washer and dish washer. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| Grouping of clothing/crockery<br>Classifying clothing/ crockery<br>Execution of tasks prior to loading washing machine/ dishwasher (unbutton, turning trousers inside out, rinse dishes, etc.) | d110 Watching<br>d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task<br>d4300 Lifting<br>d4301 Carrying in the hands<br>d440 Fine hand use |

Table 14 Organization and classification of clothes or crockery characterization

**Opening/closing door:**

(See section 3.4.2.4)

**Loading and Unloading clothes or crockery:**

| **Task: Loading and Unloading clothes or crockery** | |
|---|---|
| This task is focused exclusively on the load and unload of clothes or crockery in the corresponding appliances | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| To access inside of the appliance<br>Putting items into the appliance<br>Taking items out of the appliance | d430 Lifting and carrying objects<br>d4105 Bending<br>d4154 Maintaining a squatting position<br>d445 Hand and arm use |

Table 15 Loading and Unloading clothes or crockery characterization

**Measuring and adding detergent, softener and others:**

| Task: Measuring and adding detergent, softener and others | |
|---|---|
| This task covers all the process of measuring and adding detergent and others products including the physical, cognitive and sensorial processes. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| Opening the tray/detergent dispenser<br>Picking up detergent or other products<br>Measuring and pouring product into tray/detergent dispenser<br>Closing tray/detergent dispenser | d110 Watching<br>d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task<br>d430 Lifting and carrying objects<br>d440 Fine hand use<br>d445 Use of hand and arm |

Table 16 : Measuring and adding detergent, softener and others characterization

**Configuring/Programing and monitoring (oven, hob and microwave)**

(See section 3.4.2.4)

**Maintenance and cleaning**

(See section 3.4.2.4)

#### 3.4.2.4. TRANSVERSAL TASKS

This section includes the analysis of the transversal tasks:

**Opening/closing door:**

| Task: Opening/Closing door | |
|---|---|
| This task studies the opening and closing users' capabilities required for all the appliances studied which have a door (refrigerator, oven, microwave, washer and dish washer). | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| To access to the door<br>Grasping and opening the door<br>Closing the door | d1750 Solving simple problems<br>d440 Fine hand use<br>d445 Use of hand and arm |

Table 17 Door opening and closing characterization

**Configuring/Programing and monitoring:**

| Task: Configuring/Programing and monitoring | |
|---|---|
| This task studies the configuring and programing users' capabilities required for handle refrigerator, hob, oven, microwave, washer and dish washer. | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| Selecting a programme<br>Initiating the programme<br>Monitoring the programme<br>Stopping the programme | d110 Watching<br>d160 Focusing attention<br>d175 Solving problems<br>d177 Making decisions<br>d2202 Undertaking multiple tasks independently<br>d440 Fine hand use<br>d445 Hand and arm use<br>d4154 Maintaining a standing position |

Table 18 Configuring/Programing and monitor characterization

**Maintenance and cleaning:**

| Task: Maintenance and cleaning | |
|---|---|
| This task include maintenance and cleaning of all the appliances studied | |
| **Subtask involved** | **Capabilities required (according to ICF)** |
| | d110 Watching<br>d115 Listening<br>d120 Other purposeful sensing<br>d160 Focusing attention<br>d175 Solving problems<br>d177 Making decisions<br>d2202 Undertaking multiple tasks independently<br>d440 Fine hand use<br>d445 Hand and arm use<br>d4154 Maintaining a standing position |

Table 19 Maintenance and cleaning characterization

### 3.4.3. IDENTIFICATION OF USERS' NEEDS

The needs identification process has been iteratively applied to each task obtained in the user-device interaction characterization following the process described in the section 3.3.1.3. The result has been summarized in the next set of tables, one by task:

**Food Classification and organization:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching | d110 related to b210 | People with visual problems may require **help to recognize the different products or to read information about them.** |
| d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task | d160, d1750, d177, d2100 related to b114, b117, b140, b144, b156, b160, b167 | People with cognitive problems could require help to follow the steps of the process. Additional information about the products may be required to classifying them correctly. |
| d4300 Lifting<br>d4301 Carrying in the hands<br>d440 Fine hand use | d4300, d4301, d440 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | **Removing the package** of some products may require a fine use of the hand. Also, sometimes it is needed to **move heavy loads**. In both cases, people with mobility problems **may require help** to carry out the task. |

Table 20 Needs identification in the 'food classification and organization' task

**Placing and removing items from the fridge or freezer:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching | d110 related to b210 | People with cognitive or visual problems may require **help to find the items and to identify them**. |
| d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task | d160, d1750, d177, d2100 related to b114, b117, b140, b144, b156, b160, b167 | People with cognitive problems could need **help in order to know where is stored each item**. |
| d4101 Squatting<br>d4105 Bending<br>d445 Hand and arm use | d4101, d4105, d445 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | The **highest and lowest locations**, both refrigerator and freezer, **may present access problems for people with mobility problems. Small doors** could **increase the problem**. Picking heavy load up also is problematic. |

Table 21 Needs identification in the 'placing and removing items from the fridge or freezer' task

**Analysing the state of the food:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching<br>d120 Other purposeful sensing | d110 related to b210<br>d120 related to b230, b250, b255, b265 | In general, aging causes degradation in the **senses that may affect a person's ability to detect if the food is in good condition** (presbyopia, presbyacusia, etc.)<br><br>Also people with visual disabilities may require **help to know the expired date of the products.** |
| d160 Focusing attention<br>d177 Making decisions | d160, d177, related to b114, b117, b140, b144, b156, b160, b167 | Similarly, **people with cognitive problems may have troubles to discern safe food to the expired food** (b117, b144, b156). |

Table 22 Needs identification in the 'analysing the state of food' task

**Preparation of food to be cooked:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching | d110 related to b210 | People with visual disability may require **help to handle and to identify some tools and aliments**. |
| d160 Focusing attention<br>d175 Solving problems<br>d177 Making decisions<br>d2202 Undertaking multiple tasks independently | d160, d175, d177, d2202 related to b114, b117, b140, b144, b156, b160, b164, b167 | Usually this task is done concurrently with others and its complexity can change strongly depending on the dish. People with cognitive disability may require **help to follow the correct steps, to remember it and to relate this task with the other**. **Reduce the number of steps and choices may help the users** |
| d440 Fine hand use<br>d445 Hand and arm use<br>d4154 Maintaining a standing position | d440, d445, d4154 related to b147, b176, b710,b720,b730, b755, b760, b765, b770 | Food preparation must not involve stressful motions, heavy weights or unnatural twisting motions affecting joints. However, people with mobility disability may require **help to handle some kitchen tools or to maintain a standing position**. |

Table 23 Needs identification in the 'preparation of food to be cooked' task

**<u>Placing/removing the recipient (over the hotplate or into the oven)</u>**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching | d110 related to b210 | People with visual disabilities could also have identification problems**.** This situation could also be dangerous for the user. |
| d177 Making decisions | d177 related to b114, b117, b140, b144, b156, b164 | People with cognitive disabilities may require **help to understand that hotplates are turned on in the hob**. |
| d4101 Squatting<br>d4105 Bending<br>d4300 Lifting<br>d4301 Carrying in the hands<br>d445 Hand and arm use | d4101, d4105, d4300, d4301, d445 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | **Minimisation of handling and moving weight** as well as to **place the oven at certain height** could facilitate its accessibility. Also a **sliding tray** could be useful for some people. |

**Table24 Needs identification in the 'placing/removing the recipient (over the fire or into the oven)' task**

**<u>Organization and classification of clothes or crockery:</u>**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching | d110 related to b210 | People with visual problems may require **help to** differentiate **clothes and crockery**. |
| d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task | d160, d1750, d177, d2100 related to b114, b117, b140, b144, b156, b160, b167 | People with cognitive problems may require **help to follow the steps of the process**. **Additional information about the clothes and crockery** may be required to classifying them correctly |
| d4300 Lifting<br>d4301 Carrying in the hands<br>d440 Fine hand use | d4300, d4301, d440 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | Tasks as **unbutton, unzip or rinse dishes, etc. may require a fine use of the hand**. Also, to **move the laundry** in the case of the washing machine**, or heavy recipients** in the case of the dishwasher, sometimes could be **heavy loads**. In both cases, people with mobility problems **may require help** to carry out the task. |

**Table 25 Needs identification in the 'organization and classification of clothes or crockery' task**

**Loading and Unloading clothes or crockery:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d430 Lifting and carrying objects<br>d4105 Bending<br>d4154 Maintaining a squatting position<br>d445 Hand and arm use | d430, d4105, d4154,d445 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | **Minimisation of handling and moving weight** could aid to the people with mobility problems. Also, **minimizing the bending or squatting movements and times** in these positions may help to these users. **Door should be sufficiently large** in order to **facilitate the easy access to the appliance**. Also, guarantee that the **edges of appliance are rounded** could prevent knocks. |

Table 26 Needs identification in the 'loading and unloading clothes or crockery' task

**Measuring and adding detergent, softener and others:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching<br><br>d160 Focusing attention<br>d1750 Solving simple problems<br>d177 Making decisions<br>d2100 Undertaking a simple task | d110 related to b210<br><br>d160, d1750, d177, d2100 related to b114, b117, b140, b144, b156, b160, b167 | People with cognitive and visual disabilities may need **help to identify the product, to measure it and to know where must be placed**. |
| d430 Lifting and carrying objects<br>d440 Fine hand use<br>d445 Use of hand and arm | d430, d440, d445 related to b147, b176, b710,b720,b730, b755, b760, b765, b770 | People with mobility disabilities may need **aid to open and to close the detergent/softener/etc. tray or the recipient** where the product is stored. Also these people may have **problems with heavy recipients. Minimizing the number of times it is needed to add detergent/softener/etc. will lead to all these problems decreasing.** |

Table 27 Needs identification in the 'measuring and adding detergent, softener and others' task

**Opening/closing door:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d1750 Solving simple problems | d1750 related to b114, b117, b140, b144, b156, b160, b167 | People with cognitive disabilities may require **help to understand the security mechanism of the washing machine door**. Also, these people might **need help**, in some situation, **to remember that the door of the fridge/freezer or oven is open for long time**. |
| d440 Fine hand use<br><br>d445 Use of hand and arm | d440, d445 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | People with mobility disabilities may need **aid for grasping and open or close the door of the appliances**. **Minimizing the strength and the movement required to handler the door could easy this task**. |

Table 28 Needs identification in the 'door opening and closing' task

**Configuring/Programing and monitoring:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching | d110 related to b210 | People with visual disabilities could have **problems with the interface if the controls are not easy to differentiate**. Usually, touch control could be problematic |
| d160 Focusing attention<br>d175 Solving problems<br>d177 Making decisions<br>d2202 Undertaking multiple tasks independently | d160, d175, d177, d2202 related to b114, b117, b140, b144, b156, b160, b164, b167 | People with cognitive disabilities may require **help to follow several steps and take decisions**. To **guide and feedback the user about the state of the process** as well as to **reduce the number of decisions and to inform** the user **when a mistake is detected could do easier these tasks**. |
| d415 Maintaining a body position<br>d440 Fine hand use<br>d445 Hand and arm use | d415, d440, d445 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | People with mobility disabilities could **need help to access the controls**. Also, if a **fine hand use or strength is required**, these people **could need help**. |

Table 29 Needs identification in the 'configuring/ programing and monitoring' task

**Maintenance and cleaning:**

| Capabilities required (according to ICF) | Indicators | Needs detected |
|---|---|---|
| d110 Watching<br>d115 Listening<br>d120 Other purposeful sensing | d110, d115, d120 related to b210, b230, b250, b255, b265 | People with sensorial disabilities may require **help to detect a breakdown in an appliance**. This could generate a dangerous situation. |
| d160 Focusing attention<br>d175 Solving problems<br>d177 Making decisions<br>d2202 Undertaking multiple tasks independently | d160, d175, d177, d2202 related to b114, b117, b140, b144, b156, b160, b164, b167 | People with cognitive or visual disabilities may require **help to know when the appliance should be cleaned or maintained**. In case of a **breakdown the person may require help to solve the emergency**. This could generate a dangerous situation. Furthermore, the user could need **help for doing some maintenance and cleaning operations which require following several steps**. In addition, **procedures to contact with the technical service could introduce more complexity**. |
| d415 Maintaining a body position<br>d440 Fine hand use<br>d445 Hand and arm use | d415, d440, d445 related to b147, b176, b710, b720, b730, b755, b760, b765, b770 | People with mobility disabilities may require **help to do some usual cleaning and maintenance operations**. Also, if a **breakdown appears, the person could need help to inform about the situation**. |

**Table 30 Needs identification in the 'maintenance and cleaning' task**

## 3.5. OTHER INFORMATION SOURCES

As it is commented in the section 3.1, the information obtained by the analysis of needs has been completed with additional sources of information: User surveys and stakeholders' opinion through a workshop. Next sections introduce this information.

### 3.5.1. USER SURVEYS

A preliminary survey was carried out in the frame of a previous collaboration between BSH and the University of Zaragoza (Puig, Gracia et al. 2005): Easy line project which main objective was the design and development of an accessible washing machine, thus the structure of the survey is conditioned.

That survey was divided in three parts. First, users were asked about personal information (age, disabilities, etc.) in order to have information about the skills of the person. In the second part there was a section for each appliance (dishwasher, freezer and fridge, oven and hob). In this part the person was asked about his/her habits, problems and usual mistakes using each appliance. Also the person was invited to describe his/her "ideal" white goods. The third part was specifically focused in the washing machine, asking in deep about the same subjects.

Forty three surveys were conducted in the area of Zaragoza (rural and urban) within an average age of 71 years old. 35% of the people were female while 65% were male. Besides the obvious old age associated limitations, some users had Parkinson, memory problems, degenerative osteoarthritis, rheumatoid arthritis and osteoporosis. Note that this survey has been used to include the opinion of the Spanish elderly population and, obviously, given the size and location (only Spain) of the sample it does not provide any evidence about the reality in a European context. Thus, inside the Easy Line Plus project, this information was completed with similar surveys carried out in Great Britain (Glyndŵr University) and Germany (C-Lab), whose results are out of the scope of this thesis.

As it can be observed in following sections, needs identified in the surveys are in line with the needs extracted by the application of the proposed methodology.

#### 3.5.1.1. WASHING MACHINE

Users' habits show that 38% of users never separate clothes by colour to make the laundry opposite to 36% that usually do (rest of users polled sometimes separate and others do not). Also, an important part of the people polled, habitually unbutton shirts, turn inside out trousers, etc. before the laundry. Other interesting result is that 37% of the people load the clothes one by one in the washing machine. When the people polled program the washing machine, 23% always use the same program and 25% admit that never use some programs. This situation evidences that the washing machine is not easy to understand and to use by the elderly people.

Focusing in the problems using the washing machine, opening and closing the door is a problem to around 32% of the people polled. Opening and closing the detergent drawer, putting the detergent inside the drum or to recognize and identify detergent and soften are also a problem for several of them. Furthermore, 4% have difficulties to access the controls, 4% have problems handling the controls and 10% have difficulties understanding the program process. After programming the washing machine, 8% are not sure if it is working. Other issue that worries the people polled is maintenance. 37% need help in order to clean the filters of the drawers, 26% have difficulties to access them and 40% do not have enough strength to do it.

#### 3.5.1.2. DISHWASHER

Currently, most of the polled people do not use this appliance. Only 27.3% state that they have one at home. Reviewing the tasks related with the dishwasher, three out of four users say that they usually arrange the crockery in order to put it inside of the appliance. Also, one out of two users rinses the crockery previously.

Among the usability problems detected, some highlights are, in order of importance: problems accessing the trays (bending problems) and security problems related with the closing of the door.

#### 3.5.1.3. FREEZER AND FRIDGE

Around 80% of the polled population have an appliance with two independent doors: one for the fridge and other for the freezer, while the rest have a single door appliance. Among the difficulties of handling and use of this appliance are, in order of importance: forgetting to close the door, noticing expired products, accessing inside of the appliance as well as difficulty related to identification of the food and to know its state.

#### 3.5.1.4. OVEN AND HOB

Most of the people surveyed have the oven under the hob. The most common configuration is a ceramic hob with 4 hotplates, which was selected for safety and cleanliness. The oven is not much used, with an average of 1.5 usages per week. In addition, 39% of the polled population says that also use the microwave.

The most common problems in the use of the oven are, in order of importance: problems to open/close and accessing the interior, burns, strength and balance needed to handle trays and identify the completion status. Relative to the hob, clean, handle the controls and relate the fire with the control. The most common mistake using these appliances is that sometimes food gets burnt.

### 3.5.2. CO-DESIGN SESIONS

After systematic needs and user survey analysis, a workshop framed in the Postgraduate Gerontology course at the University of Zaragoza aimed to gather information from different health and social professionals around the concept of Smart Kitchen. Main focus of the workshop was about elderly person's habits and activities in the kitchen and their relevance in order to detect changes in their daily routines.

Brainstorming, polls and debates were the main tools used to address the needs, concept and functionalities of a Smart Kitchen. The work was articulated in a two-day workshop with a multidisciplinary group of professionals which consisted of social workers, occupational therapists, nurses and engineers; most of them experienced working with elderly people.

First, the concept of AAL was introduced presenting the technological possibilities of a Smart Kitchen focused on help the elderly people in this context. After this presentation, several multidisciplinary groups were formed and worked on the possible system features. Taking as reference a list of proposed features each group worked over the concept proposing and discarding features. They also worked focusing in the selection of the parameters which, in their opinion, are important to assess the person's capabilities to live autonomously.

Next day, the collaborative work was focused in presentation of each group showing its results and a final debate about how the system should help the user and about the usefulness of automatically assessing the evolution of the person's capabilities.

At the end of the workshop, all the people fulfilled a survey to evaluate the results obtained. The survey was structured in two blocks: first block focused in general questions about the system and asking about their opinion regarding the capacities of an intelligent system. Second block made specific questions about person's habits and activities in order to determine which parameters were valid indicators to detect changes in user habits related to the user's ability in the kitchen.

From the qualitative information gathered in discussion sessions about the most relevant parameters to evaluate the cognitive level of an elderly person in the kitchen and the loss of his capabilities, a survey was designed. Responses to the survey were rated between 1 (it is not relevant/not important/not useful) and 5 (it is very relevant/important/useful). 15 surveys were collected and they agreed on the usefulness of a smart system able to evaluate the quality of life of the elderlies (80% between 4 and 5), to adapt the appliances to the user's capabilities (100% between 4 and 5), to detect changes in the relevant habits (73,3% between 4 and 5) and to detect loss of abilities (100% between 4 and 5). Next table summarize some of the parameters polled:

| | |
|---|---|
| Food storage | Type of food that the person eats and persons weight (86,7% between 4 and 5)<br>Excessive purchase of a product (86,7% between 4 and 5)<br>Time that refrigerator (or freezer) is opened without activity (80% between 4 and 5) |
| Washing | Changes in the kind of programs used (86,7% between 4 and 5)<br>Changes in accumulation of dirty dishes (80% between 4 and 5)<br>Change in the kind of clothes that usually washed (60% between 4 and 5) |
| Cooking | Number of times that it is detected smoke / fire in the kitchen (93,3% between 4 and 5)<br>Number of times that it is detected burnt smell (100% between 4 and 5)<br>Change in the number of mistakes (fires lit, open doors, etc.) (86,7% between 4 and 5) |
| Other no specific | Light (or tap) is compulsively turned on and off (80% between 4 and 5)<br>Person erratically goes in and out of the kitchen (73,3% between 4 and 5) |

**Table 31 Relevant parameters to evaluate cognitive level of an elderly person.**

Also, two important conclusions have been extracted from the debates in these working sessions. **First one states that a smart system would be a useful tool for the social workers to complement the information they nowadays use (surveys and personal interviews) to assess the user's quality of life. Main benefits detected would be increasing objectivity, data reliability and amount of data gathered.** Personal interviews are influenced by many factors such as empathy between social worker and elderly (that may modify the person's mood and consequently produce a bias) and also dependency on the person's mood variation through the day, week, etc. (observation in an interview is an isolated event in time which may produce a bias).

Second conclusion shows that **automatic changes in the system's behaviour in order to adapting to the user status are not convenient.** From the point of view of professionals, it will lead to disorientation of the elderly and is better that the system advises a carer upon the data analysis.

## 3.6. CONCLUSIONS

This work presents a methodology which enables the inclusion of the interaction needs of a specific population in the design process. It is based on three steps: (i) a user characterization that determinates which person's capacities could be affected as consequence of being included in a specific population; (ii) an interaction characterization that determinates which actions does the person need to perform in order to have a successful interaction; and (iii) matching both characterizations, the identification of the users' needs. The taxonomy and lexicon proposed by the ICF has been used in all these phases, easing the standardization of the process and the results comparing.

Compared to other methodologies, it offers a systematic way to find indicators that hinders the interaction between the person and the system. It is aimed to ease understanding of the capabilities of the target population and their difficulties performing the functions that are to be supported by the new product.

Identification of users' needs is subject to the analysis of the multidisciplinary group of experts, being this last point one of its strength and weakness because the results can vary greatly depending on the experts' experience. In the end, it is a tool to enhance the multidisciplinary work of the various actors involved in the design process; in our case social workers, care givers and technical people.

In our case, results obtained applying this methodology have been satisfactory providing relevant information to the design of the appliances of the Smart Kitchen. However, it is convenient to complement these data with other sources of information in order to have a complete vision of the problem. We have chosen the user survey and the workshops with stakeholders as complementary tools.

This collection of requirements (results of the user needs analysis, survey and workshops), which reflect the needs and opinion of Spanish users, was added to those provided by C-LAB (German users) and Glyndŵr University (British users) in the EL+ project framework. All these contributions constituted the needs assessment conducted in the Easy Line + project. Based on it, the EL+ consortium determined which features were best suited to meet the needs of the target population[4].

[4] Although as a member of the University of Zaragoza team I participated in all consortium meetings, this selection of features is obviously out of the work covered by this thesis. However, it is interesting its reading for better understanding the following chapters. Therefore, the functional specification and expected impact, extracted from the public deliverable D.1.1. of EL+ project (Casas, Blasco et al. 2009), has been included in Annex I: Functional Specification and expected impact.

# CHAPTER 4: ARCHITECTURE DESIGN

*Chapter 4 presents a deployment proposal for an Ambient Intelligence in the kitchen with the objective of fulfilling the elderly people needs identified in previous chapter; namely an Ambient Assisted Living environment. First, the proposed system is described explaining its interaction with the user and context. Next, software architecture is detailed describing the functionality of its main blocks*[5].

## 4.1. SYSTEM DESCRIPTION

The analysis of the interaction between elderly people and kitchen appliances led to determine that proposed AmI kitchen should provide three new functionalities:

- **To facilitate the use** of household appliances and to provide useful **information and warnings** about the use of household appliances.
- **To detect emergency situations** and to take corrective actions when needed.
- To analyse all the data gathered **to extract relevant information** that could be useful for the user's carers and/or relatives in order to **evaluate the person's quality of life**.

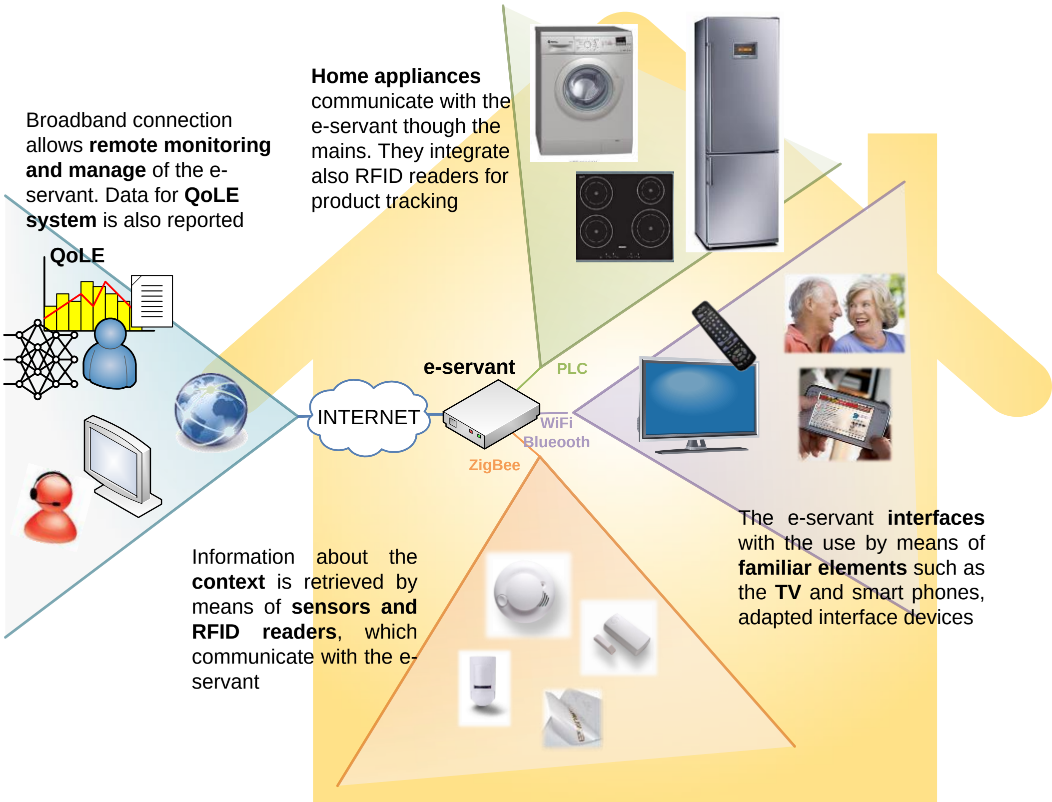



Figure 12 AmI kitchen system

[5] System description (section 4.1.) is included to provide a global vision of the complete system; it is a summary of the deliverable "D.3.2. Design, architecture, development and test of e-servant."(Casas, Blasco et al. 2009). Besides my personal work, this description includes contributions from other project partners. Software architecture (section 4.2.) has been entirely designed within the framework of this PhD thesis work.

In order to cover these functionalities, it is evident that "intelligence" and user interfaces have to be introduced in the kitchen; nevertheless, this doesn't mean that each white good has to be smarter or incorporate new adapted interfaces. Considering the current market and state of the art in kitchen appliances, this would increase their unitary price, complicate their installation (adapting the functionality to the user's particular case requires configuration) and consequently hinder the market penetration. Maybe, in a close future, capacities of the regular smart appliances will enable to develop specific functions without increasing their cost.

Thus, instead of having smart appliances with embedded accessible interfaces, a central intelligence entity has been developed: which has been called "e-Servant". This way, any electrical appliance, user interface or smart device with communication capability can be integrated in the system. As a result, the development and stability of the appliances eases (they don´t change their current way of functioning, they just need to add communication to inform about their status and execute actions). Also, similar to building automation sensors and actuators, a new market sector which reuses the same hardware is identified. Figure 12 shows the proposed system.

### 4.1.1. CONTEXT INTERACTION

In any AmI application, the information from the physical context is essential because it constitutes the input for the logical rules and decision processes that build services. According to Feng, Apers et al. context categorization (Feng, Apers et al. 2004), the world is divided in two different contexts that interact with the AmI system: *environment* (environmental context) and *people* (person-centric context). From this ample taxonomy, **white goods and different sensors are considered as the main context information sources within the kitchen scenario.**

As already mentioned, electrical appliances must be able to report their status and be remotely operated by the system or by the user through the built-in interface. Thus, any appliance with communication capabilities can be integrated in the system. The specific implementation uses BSH's Serve@Home solution to control and monitor the appliances over PLC (Power Line Communications).

RFID technology[6] is increasingly more integrated in our daily lives. It is expected that many goods will store information about their expiry date (food), washing instructions (garments) or dosage (medicines). As conventional white goods do not provide means to retrieve all the information needed, RFID readers with ZigBee communication are integrated to enhance the capacities of the fridge and washing machine. Also, as food is not just stored in the fridge and it is not feasible to put readers in every cupboard, a stand-alone RFID reader to gather information about any specific item is also developed.

Standard security sensors commonly used inside kitchens (gas, fire, smoke, flooding) are also included to detect emergency situations. Additionally, other sensors not so commonly used in this scenario are integrated; for example, magnetic sensors —to detect when the user opens/closes a cupboard or drawer—; light sensors —to detect when the user forgets the lights on—; presence sensors —to detect when the user enters the kitchen—. All these sensors as well as RFID readers use ZigBee as the wireless standard for home control and automation that easily allows adding new devices to the system.

[6] RFID technology has been provided by Gis Gera Ident-Systeme GmbH

### 4.1.2. USER INTERACTION

The purple frame in Figure 12 represents the human-machine interface (HMI) that manages user interaction[7]. HMI devices must be usable and accessible for any kind of user, having the capability of adapting their interfaces according to the user profile. They must have a standard communications interface not needing a powerful processor or large storage capacity. User interfaces are web-based in order to provide interoperability with any IP-enabled device having a browser. There are three different types of devices that can be used to manage the system:

*IP-enabled mobile devices* which allow the user to carry them around the house; we choose smart phones and tablet-PCs as the most suitable according to the user's capabilities and preferences.

*Fixed devices* which act as centralized control; we focused on the digital TV plus infrared remote controller as elderly people accept TV and understand how to use the remote control to send user commands.

*Embedded devices* which may be control panels attached to each of the current appliances. Also digital photo frames are considered as ubiquitous interfaces because they have a large market penetration, they are cheap, they can reproduce images, audio and video, and have wireless communication (Bluetooth or WiFi).

### 4.1.3. INTELLIGENCE (E-SERVANT)

In the architecture proposed, the intelligence is centralized in the e-Servant. It runs in an embedded computer that centralizes the communication with the kitchen appliances, sensors and interfaces as well as acts as a gateway to the outside world. The e-Servant is defined as the central hub of the whole system being the coordinator with whom all the other subsystems communicate over different protocols: PLC, ZigBee, WiFi, Ethernet, Bluetooth, etc. It is aware of the context and user, it enhances the intelligence of the white goods, it is also a learning system able to detect and compensate the behaviour, habit changes and loss of abilities of the user.

The e-Servant helps the user in each interaction with the appliances following operational rules which take into consideration the user capabilities and environmental context. For example, if a person without known disabilities sets the washing machine, the e-Servant would only check that the washing parameters are correct for the detected clothes, providing a warning if they are not. However, if the person has memory problems, the e-Servant would guide the process step by step.

The e-Servant is continuously checking the status of the kitchen appliances, providing warnings through its interfaces if there is any problem or event requiring attention (e.g. the fridge door is open or the cooking has finished). In the same line, e-Servant detects emergency situations in the kitchen (merging the information provided by the sensors previously described) and takes corrective actions if the user does not respond. For example, if the e-Servant detects fire in the kitchen, it could automatically turn off the hob, the oven and provide a warning. Then, if the warning is not attended or no movement is detected, it could send a warning to an emergency service.

[7] HMI has been developed by Glyndŵr University and Motive Technology

The e-Servant manages records with the relevant events that have occurred in the kitchen gathered from the context (sensors, kitchen appliances) and user interaction. This data is processed and analysed using artificial intelligence methods in order to extract findings about the cognitive level of the person that could be useful to the carers and/or relatives. For example, some people are absent–minded and usually forget about closing the fridge's door. This doesn't indicate low cognitive level, but if a person that formerly never forgets about it starts to forget closing the door, he/she might be starting to experience cognitive problems.

This information is forwarded via e-mail to the user's carers or relatives to report about the user habits in four areas of daily living in the kitchen: food management, cooking, doing laundry and other activities; same areas than those identified in the user needs analysis in chapter 3. This report is also aimed for the carers to suggest changes in the system's user profile; user profile defines the level of support that the system provides the user and its update is always done with human supervision (described in detail in section 6.3).

### 4.1.4. REMOTE SERVICES

The blue region in Figure 12 shows the services that the e-Servant provides through Internet and PSTN connectivity. The system is prepared to send information to carers and relatives about the user condition, establishing a connection to the call centre or the emergency centre when needed, allowing remote maintenance of the system, etc. Also, due to the flexible software architecture implemented, it would easily allow the addition of new services to the system such as on-line shopping if it was needed.

## 4.2. SOFTWARE ARCHITECTURE OF THE AMI KITCHEN

### 4.2.1. BLOCK DIAGRAM

The software architecture of the system is made up by different blocks that interoperate among them to provide the required functionality; following figure pictures them:

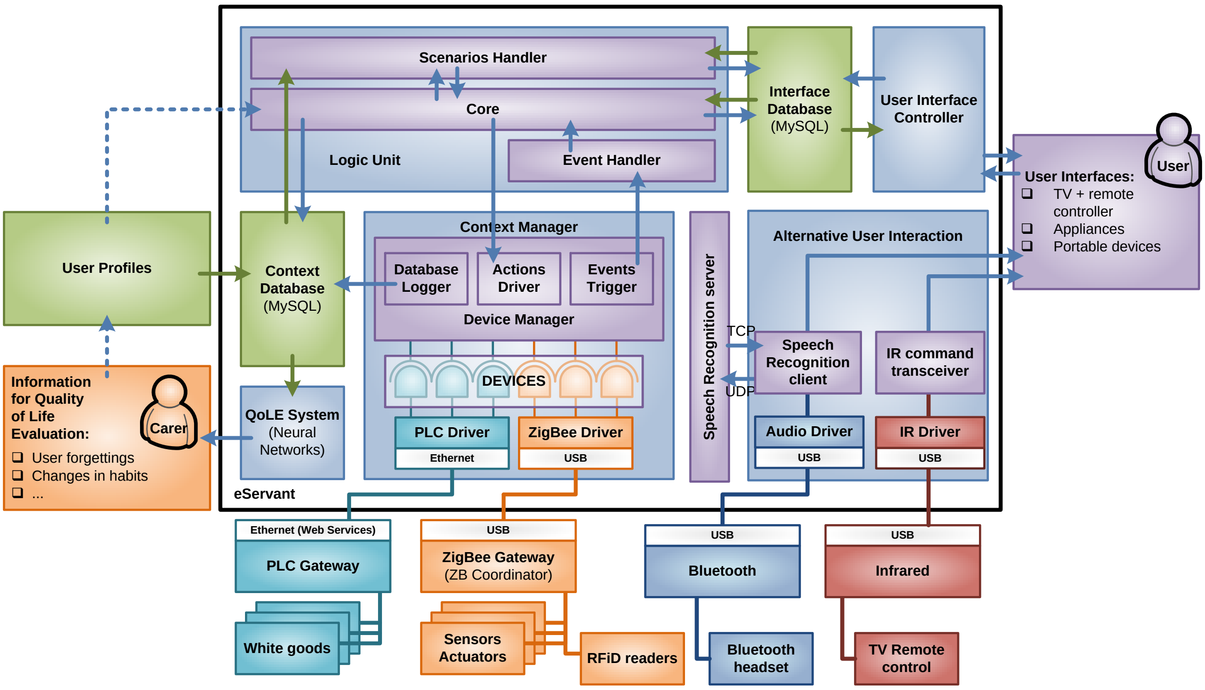



Figure 13 E-Servant software architecture

**Context Manager:** The Context Manager (CM) is the interface between the virtual and the real world. The information about the status of the appliances, product inventory, user actions or any other event is gathered by the CM and sent to the Logic Unit which will decide whichever operation must be performed (control the appliances, generate remote alarm calls, etc.).

Context manager is the agent responsible for retrieving that information, processing and presenting it in a structured way. It is organized in three levels:

- First level (Drivers Layer) manages the communication with the physical devices carrying out the tasks related with physical channel establishment, device enumeration, network support, device instantiation and messaging service.
- Second level (Device Layer) contains a virtual representation of the physical devices connected to the e-Servant.
- Third layer (Device Manager) is responsible of manipulating and aggregating information from the devices and effectively offering awareness of the context to the upper layers.

Further detail about the different parts that make up the CM can be found in Chapter 5.

**Logic Unit** (LU) is the “brain” of the e-Servant, responsible of three main duties performed by three different services: to process all the information provided by the context manager (Event Handler), to reason through that information and to decide actions in order to support the user (Core), and to cooperate with the User Interface Controller in order to manage the interaction with the user from a logical perspective (Scenarios Handler). Detailed explanation of the different parts that make up the LU can be found in Chapter 6.

The LU continuously analyses the information coming from the CM to detect what is happening in the kitchen. When it detects a situation where the user might need guidance, help or information, it starts a communication procedure with the user; this interaction is called a user-scenario. The LU starts and stops completed user-scenarios through the interface database. Execution of the user-scenario is done by the User Interface Controller that manages the different user interfaces, notifying the result of the interaction back to the LU through the interface database.

For example, if the LU receives a smoke warning form the CM, it will launch the corresponding user-scenario to warn the user. If the user does not answer, the User Controller Interface will notify the LU that will consequently turn off the hob and/or the oven to prevent a possible fire, launch a reminder user-scenario and call the emergency centre to notify the problem.

The problems, oversights or mistakes the user might have as well as the relevant information from the context is recorded in the Context Database to be analysed and forwarded to carers or relatives by the QoLE Systems.

**User Interface Controller** (UIC) periodically polls the database refreshing the information served to the user interfaces that will play the user-scenarios. User-scenarios guide and help the user in his/her interaction within the smart ambient. Each user-scenario embeds the visual and aural information necessary to maintain an interaction with the user. When the interaction with the user ends, the UIC writes the user’s answers in the interfaces database to be parsed back by the Scenarios Handler in the LU.

The UIC serves the information to the user interfaces through an embedded http server. Each user interface employs a small Adobe Flash application that retrieves the information from the UIC and displays the graphic interface as seen in Figure 14.


**Figure 14 Screenshot of the user interface developed by Glyndwr University.**

**Alternative User Interaction (AUI).** This block groups the alternative user interfaces: Speech commands and infrared (IR) commands.

Speech is one of the most natural ways of commanding user interfaces. Implementation entails the problem of limitations and interoperability of the platform used. The client side –the user interface- simply needs a small application called the Speech Recognition Client (SRC) in order to support voice control over the system. This client gets the audio stream from the embedded microphone, packetizes and forwards it through a socket to the Speech Recognition Server (SRS).

The Speech Recognition Server has been designed to allow these devices to use a speech recognition engine. The server analyses the audio stream and replies to the client with the identified command. As a proof-of-concept the speech recognition engine from Microsoft installed where the e-Servant is running has been used with good results. It would be simple to change the service to use any other engine's API such as Dragon Naturally Speaking, Google Voice, etc.

Also, the TV remote control is one of the interfaces most extended and elderly people are usually familiarized with it. A commercial IR to USB transceiver (USB-UIRT 2009) has been used in order to integrate this technology in the e-Servant. IR commands are parsed by the IR command transceiver module and converted in understandable stimuli for the e-Servant interface.

**QoLE System** is a service that periodically analyses the context database looking for changes in the user washing, shopping and cooking habits which could be relevant in order to detect a loss of physical, cognitive or sensorial capabilities. For example, if the user starts going to the fridge at night or if s/he is doing the laundry less and less often. The QoLE System performs an indirect evaluation of the quality of life of the user through the measurement of its capabilities and habits in his/her daily tasks in the kitchen.

It produces an easy to understand report which aims to provide objective information about the everyday life of the user. Designed for the use of non-technical people, it is intended as a tool for social workers to complement the information they typically use (surveys and personal interviews) to assess the user's quality of life.

To illustrate the interaction of the various blocks of the architecture, the following use case shows what would happen in the event of smoke detection.

**Use case: smoke sensors notify the system that there is smoke in the kitchen, oven and hob are on but nobody is in the kitchen.**

The ZigBee smoke sensor (1) warns to the CM (2) that there is smoke in the kitchen. LU (3) is notified and decides to launch a user-scenario to warn to the user. UIC (4) commands the interfaces (5) in order to warn the user about the situation. After a timeout, the interfaces (6) notify to the UIC (7) that the user does interact with them and the LU (3) decides to turn off the PLC hob and the oven (10) through the CM (9).

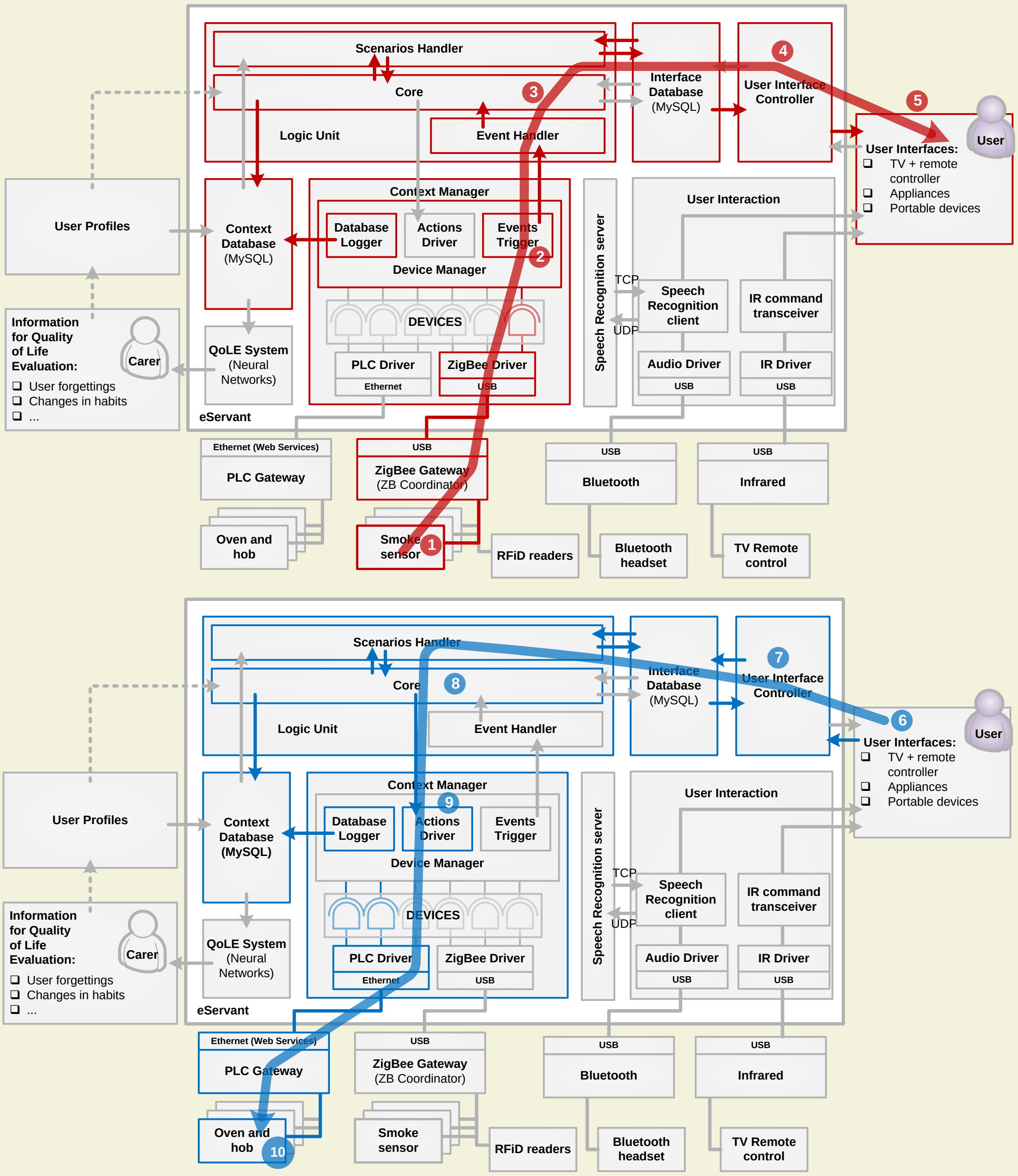



Table 32 Use case: Smoke in the kitchen. Example the interaction between the architecture blocks

### 4.2.2. SOFTWARE PLATFORM

Software platform must be able to integrate several technologies as PCL, ZigBee or RFID and products from different manufacturers. Also, It should permit adding new devices (appliances, sensors, etc.) easily. A Service-Oriented Architecture (SOA) is the most appropriated choice as it enables a modular design, simplifying the programming process and easing the integration of new devices or services.

In this sense, the Open Service Gateway initiative (OSGi), provides a working framework which satisfies the technical needs of the system. In this framework, pieces of code are organized into bundles that can be managed dynamically. OSGi bundles are agents which might be dedicated to specialized tasks, such as handling a serial port, providing a command line interface, collecting, aggregating and analysing data, etc. These bundles communicate and interact with each other by means of services which are published within the framework, and each bundle can acquire and use them (OSGi Alliance 2010).

The main strength of OSGi is that the framework manages these bundles dynamically, allowing them to be upgraded without terminating the full application, as well as enabling the availability of the services to other bundles depending on the situation. A special case of those services are object entities usually related to physical devices. These devices are published by bundles which handle the communication channel between the physical devices and their virtual representation, and have an independent identity in the framework. These features make OSGi one of most powerful tools to implement an ontology that represents the context having bundles as virtual representation of devices. Moreover, as it was noted in Section 2.1.3, most of the standard ontologies choose OSGi as working framework.

Therefore, OSGi has been chosen as the backbone of the e-Servant in order to enhance its capabilities and minimize the installation and maintenance cost in future commercial products (easy update of software packets, addition of new sensors or appliances, etc.).

## 4.3. CONCLUSIONS

This chapter, besides providing a global vision of the system, describes the architecture proposed their different building blocks. Its design has been addressed modularly, identifying the functionalities of each part of the system and its relation. From the beginning, the need to design a system close to the market has spotted essential aspects of the architecture such as the interoperability, flexibility and easy deployment, maintenance and update.

The architecture promotes the interoperability between devices, technologies and manufacturers supporting the integration of devices with any communication technology (we integrated ZigBee and PLC), the interaction with any web based interface, infrared and Bluetooth remote control. Thanks to this modular and flexible design, it is easy to add new appliances or sensors with little changes in the Device Manager (as it is shown next chapter). Also, the OSGi framework chosen to develop the system permits dynamically the remote installation, deployment and update of the services which compose the system.

# CHAPTER 5: CONTEXT INTERACTION

*Context interaction is crucial to any AmI because it provides the data upon which the system will make decisions and act accordingly. This is even more essential when we are designing an AAL environment, where the user might have limited capacities performing actions or be challenged understanding how to manage an appliance or interacting with the system.*

*This chapter contains contributions made in the context interaction implementation of the system. It describes the physical* ***deployment of the sensors and actuators network*** *as well as the modifications accomplished in the kitchen appliances to enhance their capabilities. Also, it details* ***data processing performed to develop devices with advanced features: fall detection and location****. And finally, it explains the* ***architecture and implementation of the Context Manager****, which models the physical devices to provide upper layers a virtual representation of appliances, sensors and actuators in the environment.*

## 5.1. SENSOR-ACTUATOR INFRASTRUCTURE

When considering the interaction between elderly people and kitchen appliances, it is evident that the more information we can extract from the person, the appliance and the environment, the better we can support the user. Regardless this evidence, to build a usable and marketable system, it is necessary to find a compromise between the parameters that must be monitored and those that are technologically feasible in order to have the maximum information.

It has been a PhD requirement to be close to the market, with an actual deployment feasible and acceptable by the user at home. This premise has been taken as a starting point to decide which sensors could be installed in the kitchen assessing their potential impact on the services developed versus the cost, intrusiveness and acceptation issues. However, it was also considered that sensor cost, size or user rejection, which today may suppose a barrier, could change in the future. Thus, the architecture has been designed to allow easily adding new devices or technologies.

A key issue in the deployment of an interactive context in AmI is interoperability. Communication protocols are essential to provide adequate functioning of devices (coverage, data rate, user acceptance, etc.) and use of standards and coexistence of media channels (radio, cable, power line, optical) is also very mandatory in order to provide interoperability and flexibility. Thus, according to the nature of each device and also as PhD requirement, it has been decided to integrate several communication protocols in the deployment of sensors and actuators. Figure 15 shows the connections that currently supports e-Servant with the various elements of the AAL:

- ZigBee as wireless sensor network standard to connect all the sensors distributed in the environment.
- Bluetooth as transport channel for audio streaming in voice recognition and messaging.
- WiFi/Ethernet for IP data exchange between user interfaces, e-Servant, database, etc.
- Infrared (IR) to integrate existing remote controls in the system.
- Power Line Communications as de-facto standard for communication between white goods.

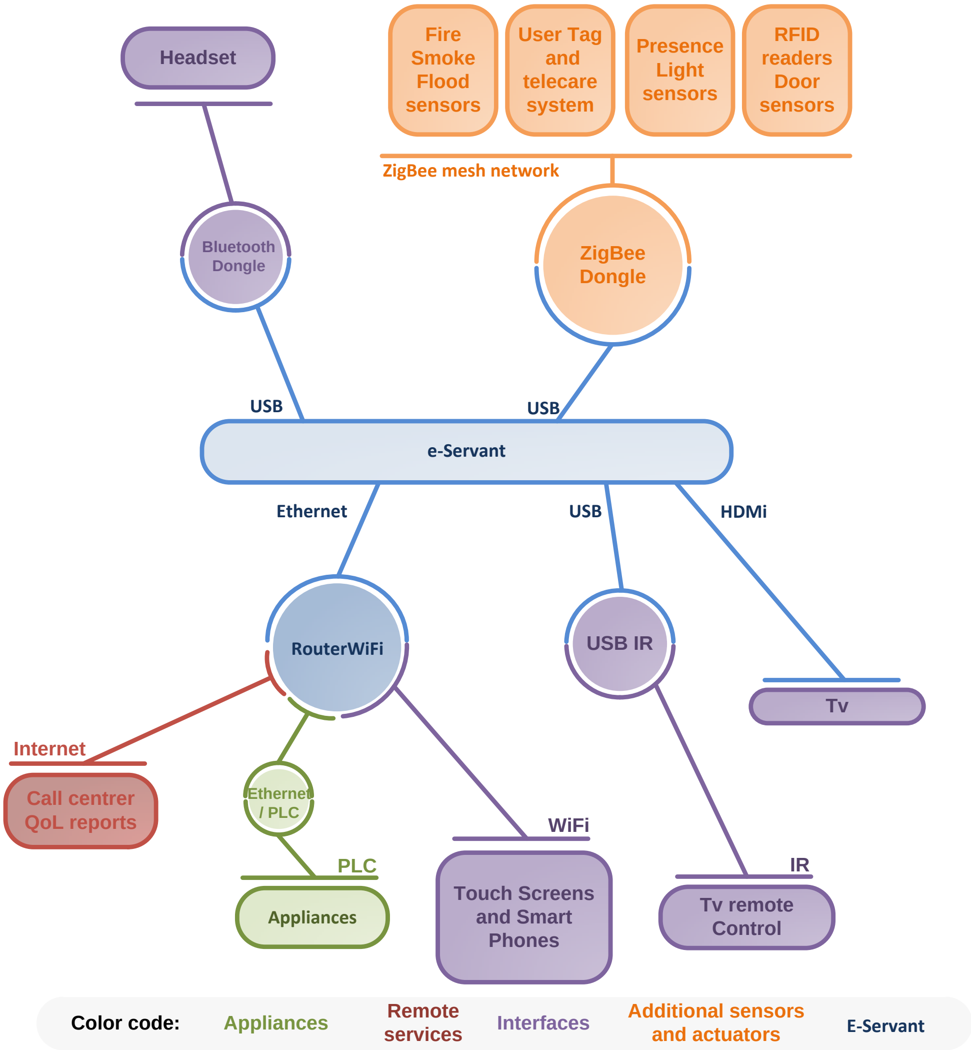



Figure 15 e-Servant physical connexions

This subsection focuses on those devices whose interaction is handled by the Context Manager: appliances, sensors and actuators. CM models them, isolating their functionalities from their respective communications protocol, allowing their use from a high level of abstraction. Devices acting as user interfaces are excluded because they communicate directly with the web server (see section 4.2.1) or through the HDMI connection.

### 5.1.1. ZIGBEE SENSORS AND ACTUATORS

Several ZigBee devices have been developed ad-hoc to be used in the Smart Kitchen to cover specific features or to ease the integration of commercial sensor in the system. The devices described below (except the Multi-sensor) have been fully designed and implemented (component selection, schematic design, PCB design, firmware programming and debug) in the framework of this PhD work.

**ZigBee Tag:** Safety at home is one of the biggest concerns of the elderly and their relatives. User habits, location and detection of critical situations such as falls are important sources of information for AAL systems. Telecare systems based in a panic button are one of the electronic aids most widely used. Tag goes one step further: it aims to identify the user and his/her location and process movement data to infer relevant situations such as fall events and level of movement (see section 5.2). This device, designed to be worn as a neck pendant, is powered by a rechargeable 3.6V Ion-Lithium battery, includes a triaxial accelerometer (Freescale MMA7260Q), two buttons and a ZigBee transceiver (Figure 16. Left).

**ZigBee Carephone:** In order to forward any alarm detected by the system to call centers, a ZigBee Carephone has been designed. It connects to any home care system which allows the generation of external alarms; it was validated with the commercial tele-care system of Caretech (c) (Caretech 2012). By connecting these two devices, it is possible to code up to 4 different alarm events via the ZigBee network and to trigger voice calls or to generate remote events in a call centre (Figure 16**.** Right).

Figure 16 ZigBee Tag (left) and ZigBee Care-phone (right)

**ZigBee Multi-sensor:** When a user interacts with any white good in the kitchen, the system is able to provide information about user habits; for example, how often he/she cooks in the oven. In order to complete this information, ZigBee Multi-sensor (Figure 17) has been designed to get information from the environment. It incorporates a temperature sensor, a luminosity sensor, a PIR (Passive Infrared Sensor), a magnetic contact and up to 5 inputs for external sensors. Depending on the specific requirements (mainly sampling and reporting time) this sensor can be battery or DC bus powered.

This device has been used as luminosity and presence sensor in the kitchen as well as magnetic door sensor. Although refrigerator already includes the function of generating an alarm when the door is open too long time, it was not possible to check its status through PLC. In case of the washing machine, it does not even have a door sensor. This device has been used to integrate a door-status sensor that notifies when any change happens in the doors of refrigerator, freezer and oven. Also, some tests were done placing them in the doors of the kitchen cabinets. However, this configuration was rejected because it was a set-up more akin to an experiment than a real kitchen.

Another use of the ZigBee multi-sensor has been the integration of security sensors; one of the main concerns of older people. The kitchen is one of the most dangerous places of the dwelling where an oversight or misuse could easily cause a fire or flood. To integrate these alarms into the system, commercial sensors typically connected with alarm centre were chosen. Usually, when this kind of sensors detects an alarm situation, open a potential-free contact. They have been connected to the ZigBee Multi-sensor, so that their alarms can be directly routed to the ZigBee network.

Figure 17 ZigBee Multi-sensor.

**ZigBee Bridge:** This device has been designed to create a bridge between ZigBee and any other device which has a 3,3V serial port. It incorporates an 8 bit microcontroller and a ZigBee node. It has been used to connect the RFID readers (described in next section) to the e-Servant (Figure 18).

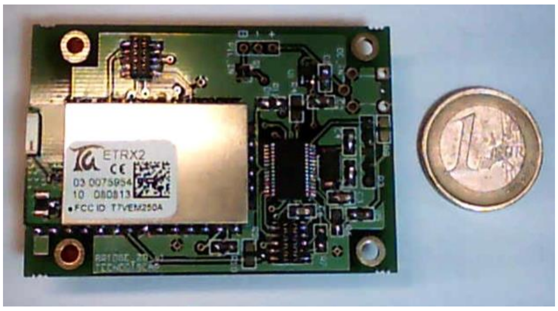


Figure 18. ZigBee Bridge

### 5.1.2. RFID READERS

It is evident that the use of RFID technology provides remarkable added value to the intelligence of a smart system. Tagging every object in the kitchen and placing RFID readers inside all the kitchen cabinets, kitchen door, below the worktop, inside the refrigerator and washing machine, in the kitchen trash or recycling containers, in the food recipients, etc. could retrieve much information about the product handling and person's habits and actions in the kitchen. However, this technological wizardry is not affordable in a real scenario; current cost and complexity reduces it to research field.

Thus, use of RFID technology has been just considered for identifying clothes and food in order to provide information about what is in the washing machine or fridge. As food is not only stored in the fridge —shelves, drawers and cupboards are normally used— and ubiquitous readers are not feasible, a portable stand-alone RFID reader has been developed.

This reader is able to detect any kind of items and it is integrated in the system through the ZigBee Bridge. It allows registering the items bought, checking those needing refrigeration, and assessing the user about how to cook the food read or even directly configure the oven.

#### 5.1.2.1. DATA ENCODING

Given the RFID technological capabilities, there have already been various attempts for the implementation of the Electronic Product Code (EPC); again market adoption is far from being achieved. While demand for these systems is growing in sectors such as logistics, tracking or access control, clothing or food are barely using EPC tags in the mass market. This has created an additional difficulty for the identification of products within the AAL as it has been necessary to determine which information about the clothing and food is needed to be stored and the coding of this information within of RFID tags.

It has to fit into conventional UHF (Ultra High Frequency) chip in order to keep costs to a minimum. At the time this research was done, there was no standard for encoding required data like washing temperature of a garment, expiry date of food, etc. It appears that EPC, the successor of barcode, is becoming the de-facto standard for UHF identification. Coding of data in the RFID chip followed the EPC-standard encoding SGTIN96 Mechanism promoted by Global Standards (GS1 2012). This standard proposes a memory structure in five descriptors: header (8 bits), special field (6 bits), company prefix (24 bits), item reference (20 bits) and serial number (38 bits). Based on this codification, item reference and serial number have been used to encode product information needed by the system. Table 1 show the conversion data stored in a RFID label with the SGTIN.

<table>
<tr><th>SGTIN96</th><th>Number of bits</th><th>Food labels</th><th>Garment labels</th></tr>
<tr><td>Header</td><td>8 bits</td><td>Header</td><td>Header</td></tr>
<tr><td>Filter value</td><td>3 bits</td><td>Filter value</td><td>Filter value</td></tr>
<tr><td>Partition</td><td>3 bits</td><td>Partition</td><td>Partition</td></tr>
<tr><td>Company prefix</td><td>24 bits</td><td>Company prefix</td><td>company prefix</td></tr>
<tr><td>Item reference (20 bits)</td><td rowspan="2">58 bits</td><td rowspan="2">Food Type<br>Weight<br>Expiration date<br>Needs refrigeration<br>Product ID<br>Item ID</td><td rowspan="2">Can be washed in the washing machine?<br>Colour<br>Garment type<br>Temperature<br>Program recommended<br>Bleach<br>Drying<br>Dry cleaning<br>Ironing<br>ClothesID</td></tr>
<tr><td>Serial number (38 bits)</td></tr>
</table>

**Table 33 Information coded in the RFID tags. Item reference and serial number are used to identify and characterize individual items.**

There are some fields of the SGTIN code that should not be altered: The *header* identifies the encoded data as an SGTIN number, the *special field* contains data such as a filter value for pre-selection and partition value that indicates the point where the division between *company prefix* and *item reference* is, *company* specifies the manufacturing company of the object (at the moment it is a decimal number with 7 digits). Serial number and item reference have been used to encode the context information needed. As an example, following the specific definition for the garments obtained from the information already described in the cloth labels:

- Can be washed in the washing machine? (1 bit): only hand washing, true
- Colour (8 bits): 00000000 means not coloured (cannot be washed with coloured garments)
- Garment Type (9 bits): Trousers, socks, T-shirts, etc.
- Washing temperature (2 bits): Cold water, 30 ºC, 60 ºC, 90ºC
- Washing program (3 bits): Normal, delicate, etc.

- Bleach allowed (1 bit): not admitted, admitted
- Drying allowed (3 bits): do not use dryer, drying at moderate temperature, drying over a towel, etc.
- Dry cleaning (2 bits): do not allow dry cleaning, clean just with mineral products, clean with products without trichloride ethylene and clean with all kinds of solvent.
- Ironing (3 bits): do not iron, do not use steam, maximum ironing temperature 110ºC, etc.
- Clothes ID (26 bits)

#### 5.1.2.2. RFID-ENABLED WHITE GOODS

Besides the stand-alone RFID reader, fridge and washing machine have been enhanced with RFID readers. In the case of the fridge, it has been equipped with new hardware consisting on an RFID reader module that can handle four antennae using a multiplexer and a ZigBee module providing communications (ZigBee Bridge). Antennae and RFID reader has been developed by (Gera-Ident 2012). Every time the fridge's door is closed, its content is scanned and sent to the e-Servant that updates the list of tagged food inside the fridge in order to allow the user check it using any user interface (mobile phone, TV, etc.). The antennae (see Figure 19 left) have been placed embedded in the fridge's walls in order to read tags placed in any part of it.

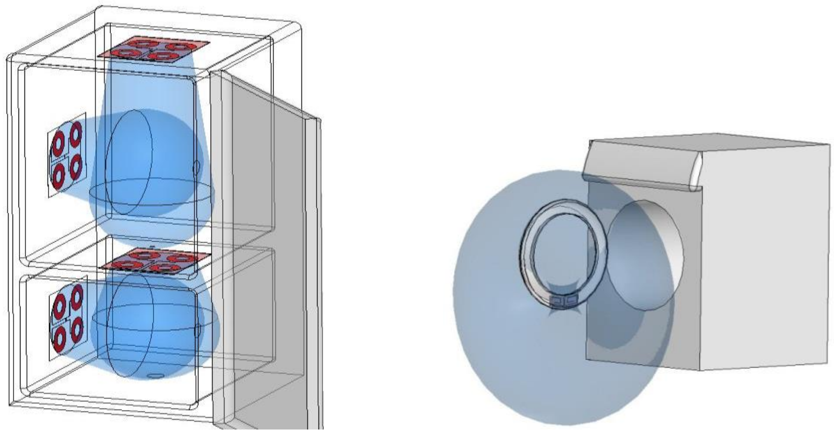


**Figure 19 RFID field inside the fridge (left). RFID field created by the washing machine (right) GERA-Ident©**

Washing machine has been also equipped with the same reader and ZigBee modules; however, in this case, the reader has only one antenna placed in the door frame (Figure 19 right). It reads the clothes as the user introduces them through the washing machine eye. When the washing machine finishes and the door is opened, the clothes are read again.

### 5.1.3. HOUSEHOLD APPLIANCES

Main elements in the kitchen are the appliances. As stated in Chapter 3, the only requirement for the integration of any appliance in the AAL is to have a communications interface able to control and monitor the device. Given that BSH was partner in the consortium, the product range aimed for "home automation" S@H was selected. These appliances can communicate through PLC using a proprietary control protocol based on web services. To access their status and command them from the e-Servant, a Gateway connected to a PLInt (Power Line Interface) which created a bridge between Ethernet and PLC was used (Figure 20).

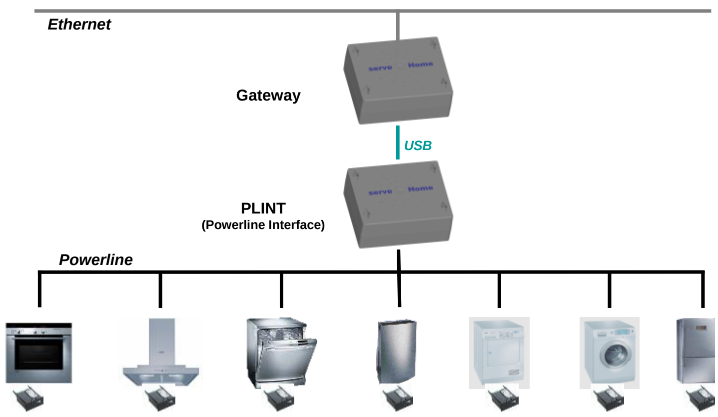



Figure 20. S@H conexión. BSH ©

However, as the appliances did not offer enough information to cover functionalities defined, their capacities were enhanced with additional door status sensors (section 5.1.1) and fridge and washing machine with RFID readers (section 5.1.2) in order to know their content.

## 5.2. DATA PROCESSING

This section presents the low level data analysis that extracts elaborated information to be used in higher layers of the system. ZigBee Tag's radio signal strength and acceleration data are processed to respectively infer location and analyse activity levels and other high level events that feed the Logic Unit.

Using Artificial Neural Networks (ANNs), acceleration data has been studied to validate the use of the ZigBee Tag as a fall detector with satisfactory results. In order to identify who is handling the smart kitchen, an important added value to the AAL is to incorporate the location to the user identification (provided by the Media Access Control (MAC) address of the ZigBee node). It is an initial requirement to do it using the existing ZigBee network avoiding any extra infrastructure deployment. Maximizing location accuracy poses a challenge as network deployments are designed to provide adequate coverage and not to locate; the work done gets satisfactory results.

Finally, use of the ZigBee Tag was discarded in the final system due to a market decisions in the EL+ project since it was considered a tele-care device rather than a kitchen appliance accessory. Assuming that most of the time the system is handled by only one person, the user identification and location service was replaced by a presence service provided by the PIR sensor. As the kitchen use by third persons would be very sporadic and out of the scope of the project, its influence in the parameters registered by the e-Servant would be low and not considered.

Despite this decision, the use of the ZigBee Tag allowed to evaluate fall detection and indoor location through a non-dedicated network. Following the contributions in these fields are briefly described, and also two papers with a full description of this work (Blasco, Casas et al. 2008, Blasco, Marco et al. 2009) have been included as annexes (see annex Annex II Data processing papers).

Artificial Neural Networks propose a mathematical model which enables processing data trying to imitate the biological structure of the brain. These techniques are a powerful tool to resolve problems related mainly with the classification (discriminant analysis), functional regression, time series prediction (forecasting) and data analysis. In general, these systems are especially efficient with processes that for a person are trivial but that are really complicated for a program using algorithms as the speech recognition, food classification, identification of vehicles, etc. (Martín del Brío, Sanz 2006).

The simplest element of a Neural Network is the neuron. As it is shown in Figure 21, a neuron could be modelled as vector of inputs $(p_1, p_2, \ldots, p_n)$ where each one has assigned a weight $(w_{1,1}, w_{1,2}, \ldots, w_{1,n})$ (single row matrix). The neuron has a bias $b$ that is summed to the weighted inputs. This way, the neuron input $n$ is $n = \sum_{i=1}^{i=R} p_i\, w_{1,i} + b$. The output of the neuron $a$ is generated by the transfer function $f$ using $n$ as parameter (Demuth, Beale 2003). Most used transfer functions have been summarized in the Table 34.

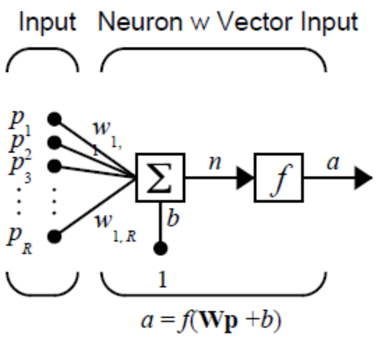



**Figure 21. Single neuron. Source: (Demuth, Beale 2003)**

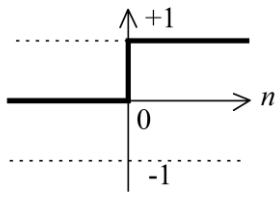
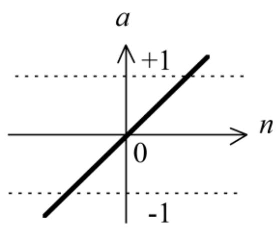
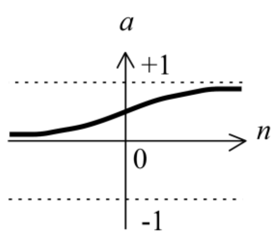
| | Function | Graphic |
|---|---|---|
| **Hard-Limit Transfer Function** | $a = 0\ if\ n < 0$<br>$a = 1\ if\ n \geq 0$ |   |
| **Linear Transfer Function** | $a = n$ |   |
| **Log-Sigmoid Transfer Function** | $a = \text{logsig}(n)$ |   |

**Table 34 Activation functions. Source: (Demuth, Beale 2003)**

Several neurons could be combined making a layer and one or more layers could be combined creating a Neural Network (NN) (see Figure 22). Powerful of these system is that they are processing in parallel, of a distribute way and, also, they are adaptive.

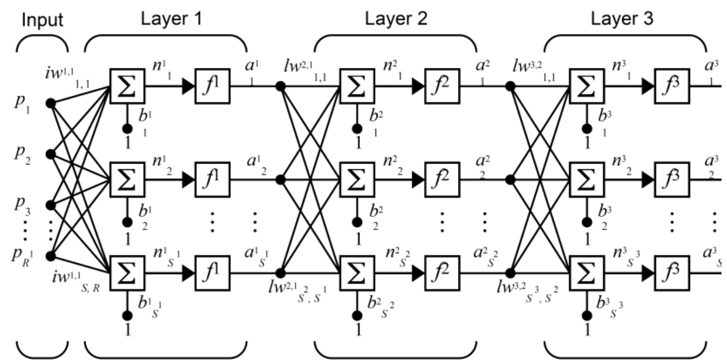



**Figure 22 Three layers Neural Network. Source: (Demuth, Beale 2003)**

There are different learning techniques for Neural Networks. These techniques define how the weights of the neurons which compose the network are tuned to have the desired response. Learning techniques enable to classify the neural networks in four groups:

- Supervised learning: Neural Network is trained from known examples, i.e. using couples of inputs and desired output.
- Unsupervised learning (self-organized): In this case the Neural Network is trained using only the inputs.
- Hybrid learning: These techniques combine supervised and unsupervised training in different layers of the neural network.
- Reinforcement learning: These techniques of learning are based on reward-punishment, this way the Neural Networks learn trying to maximize the number or rewards.

In the next studies, two kind of neural networks have been utilized:

The Multilayer Perceptron (MLP) is a supervised feedforward (neurons model without feedback) Neural Network. The universal approximation capabilities of the multilayer perceptron (Hornik, Stinchcombe et al. 1989) make it a popular choice for modelling nonlinear systems, classification (discriminant analysis) and functional regression. It is composed by three or more neuron layers: The first one provides the input data, the intermediate layers, known as hidden layers, using a non-lineal activation function to process the information, and the output layer, which combines the outputs of the hidden layers proposing a result. It is trained using the backpropagation (BP) algorithm or one of its variants (Levenberg-Mardquardt, Resilent-Backpropagation, Scaled Conjugate Gradient, etc.). BP is a gradient descent algorithm that tries to find the best NN weights in order to minimize the error function between the output and the objective.

The Seft-Organizing Features Map (SOFM), usually known as SOM, is an unsupervised Neural Network structured in two layers: inputs and map (1, 2 or 3 dimensions). SOM are a good tool for the visualization of high-dimensional data. They can convert n-dimensional data into a simple geometric, for example 2-dimensional. They can be used also to produce some kind of abstractions (Kohonen 1990) and they are really useful grouping data with similar characteristics. Its training is based on a competitive method that choses as winner the neuron which has the minimum Euclidian distance between its weight vector and the input vector. The winner neuron and its neighbours update their weight in order to be closer to the input vector. Iteratively, groups of SOM neurons are specialized in a kind of inputs.

## 5.2.1. FALL DETECTION

ZigBee Tag could work as fall detector thanks to the tri-axial accelerometer integrated. Following it is shown how Neural Networks enhances fall detection system in contrast with the traditional threshold-based methods (Chen, Kwong et al. 2006) increasing immunity false falls; events not with similar inertial patterns (e.g. sitting in a sofa abruptly).

Ten people of different ages, weight, height and sex, with the ZigBee Tag hanged around the neck, have imitated the movements of elderly people to create a database of falls. Volunteers were asked to simulate true and false falls situations. In the true fall situations every volunteer falls down 10 times on a straw mat. The fall intensity changed (rough and soft) and the way of falling down too (side, front, backwards), hitting the ground with their back, hip, knees, etc. For the false-fall situations every volunteer flings himself down 5 times on the centre and 5 times on the side of a sofa, stumbles and hits a wall without falling down 5 times and walks around for 2 minutes doing normal movements like sitting up and down in chairs, picking up things, etc.

During the test, the ZigBee Tag continuously samples the three acceleration axes each 32 ms sending them to a PC working as a data logger. In the end, we get a file with all the acceleration samples in axis X, Y and Z for every volunteer. The resulting database consists of 99 samples of true falls and 150 of false falls. This database has been analysed using an acceleration threshold, which was experimentally determined to 2 g in order to detect all the true fall events of the database. This election motivates that some normal movements are above the threshold; being detected as falls, increasing the number of false fall events to 241. Also, based on the stored data, it has been observed that of 800 ms defined the length of any event: time that includes all relevant information about the fall. This time has been increased 160 ms in order to include some preamble data before the acceleration crosses the threshold. Figure 23 represents a fall event.

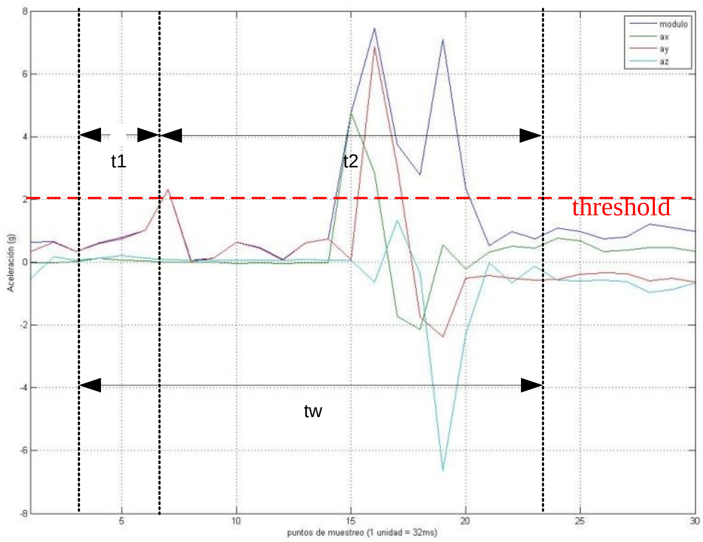



**Figure 23 Fall event**

The "window time" (tw=t1+t2) includes 30 samples to be analysed by the NN. With this window time selected, the number of inputs to the neuronal network is set to 90; 3 axes per 30 samples. In order to reduce the number of network entries —and consequently the network size— a PCA (Principal Component Analysis) has been used. Applying PCA analysis with the 340 events detected with this threshold (99 falls plus 241 false-falls), the number of inputs was reduced from 90 to 55, keeping the 95% of the covariance of the original data.

Different Multi-Layer Perceptron (MLP) architectures 55xMx1 have been trained (being M the number of neurons in the hidden layer, $5 \leq M \leq 35$) using the 80% of the events (randomly selected) for training and 20% for validating. That is to say, from the whole 340 events (99 falls plus 241 false-falls), the validation group had 20 true falls and 48 events that could be confused with falls. In the end, a neural net with 22 hidden neurons was able to classify falls correctly.

The final results using MLP neural networks for fall detection have been quite satisfactory. The application classifies correctly 92% of the validation group falls, achieving a better performance than other detection methods: 80% in (Chen, Kwong et al. 2006). Moreover, the number of false alarms is drastically reduced to 1%, which leads to enhance users trust on the fall detector. Nevertheless, a more extensive study with more users, being also elderly, needs to be conducted to gather more data and confirm the results in order to develop a new service in the AAL.

### 5.2.2. INDOOR LOCATION

The goal to be achieved with this study was to determine whether it is possible to locate, at room level, with a ZigBee network which has not specifically designed for this purpose. This way, with an existing ZigBee infrastructure that provides communication service in the AAL, with the only additional cost of the tag bearing the user, it could be possible to offer new services.

To validate this idea it was defined a test scenario Figure 24; different ZigBee routers (orange triangles in the figure) are distributed in the test environment with the only criteria of ensuring data coverage throughout the test area. Then a person wearing a ZigBee Tag as a pendant around the neck, moved to several positions inside each of the localization area; white circles in figure. For each of these positions, measures were collected with a different user orientation (north, west, south, and east). Each measurement consisted on the Received Signal Strength Indicator (RSSI) with which the tag "sees" its surrounding neighbours. This sequence was repeated in 32 locations, generating a pattern database of RSSI measurements. Information about the location of the beacons was not stored, as only RSSI was used to estimate the location of the Tag.

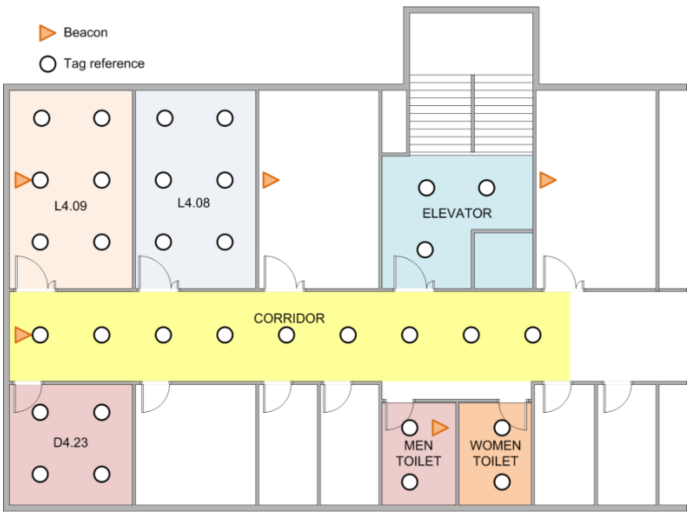



**Figure 24 Scenario map. Fixed devices are denoted by arrow caps, and tag reference locations are represented by circles.**

These data were analysed using a MLP (MultiLayer Perceptron) and SOM (Self Organizing Map), achieving a positioning error of 20% and 18,7% respectively, pointing out that the NN (Neural Network) does not have enough information to locate. Thinking about the physical nature of the problem, at the time this work has been done, localization systems based on ZigBee RSSI, locate targets with accuracy among 3 m and 5 m depending on the density of beacons (or fixed nodes) (ZigBee Alliance 2007). In this case, where a network with a minimum number of beacons has been forced to ensure coverage, it would be logical to think that the accuracy in meters should be 5 meters or more.

Also, in the transition of localization areas without physical separation (doors or walls) the RSSI was very similar. Therefore, if this system provided a location in meters it would not be difficult to provide coordinates and a radius of confidence. When this situation takes place, each time one user is placed less than 5 meters away from the contiguous area, the system will detect the user as being placed in one of the areas located in the radius of confidence within the two areas.

How can this idea be extrapolated to a SOM? If the activation of neurons is studied in detail, it will be observed that there are areas in the map which are activated mainly by stimulus of two areas, i.e. “zone L4.09” (7 activations) and “zone L4.08” (2 activations). If the wining label is considered, in this case “zone L4.09”, when points are set in the “zone L4.08”, which are very close to this area, and the map activates the neuron, the situation is considered as an error. Nevertheless when using any other method, if it is within the radius of confidence, it would be considered as correct.

| Sample Groups | Test error | Validation error |
|---|---|---|
| *Group 1: points where the tag detects at least one beacon.* | *17.20%* | *24.00%* |
| *Group 2: points where the tag detects at least two beacons.* | *12.65%* | *19.59%* |
| *Group 3*: points where the tag detects at least three beacons. | *11.11%* | *18.66%* |

**Table 35 Classification error with SOM using only one label.**

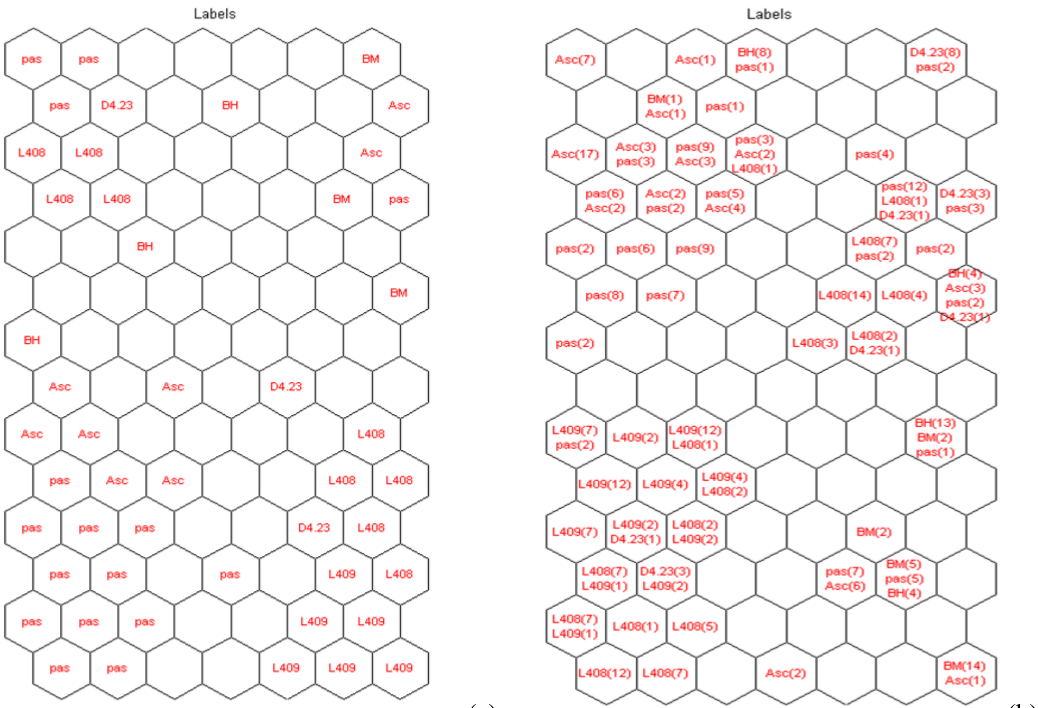



**Figure 25 SOM map for one label (a) and two labels (b) methods**

Therefore, if two labels are considered in those neurons responding to two specific boundaries, it won't be known whether the user is located in the "zone L4.09" or in "zone L4.08", but the area in which the user is located will be known, and probably even the boundary among them. Obviously, it can occur that the neuron is activated by stimulus in the two areas separated by 5 meters, being this unusual situation. In this case only one label will be considered. Taking into account this situation, the error in the localization is cut down to 7.1% for the samples which can see at least 3 beacons. In contrast, in some situations the network feedback is "zone A"-"zone B" instead of one only area (of course, they are adjacent zones). However, this resolution could be enough for many home services.

## 5.3. CONTEXT MANAGER IMPLEMENTATION

Context Manager (CM) is the e-Servant block responsible for managing communications with other devices in the kitchen (sensors, appliances, etc.). It is the most flexible part of the e-Servant, since it must update the context's virtual representation each time a new sensor or appliance is added or removed from the system. In this situation, benefits of using a modular architecture as OSGi against a monolithic application are considerable; incorporating a new range of kitchen appliances or a new sensor technology just involves updating one of the bundles that constructs the application.

The Context Manager is structured in three layers: **Driver Layer**, which manages the communication network with physical devices of the system; **Device Layer**, which contains a logical representation of the physical devices and **Device Manager**, which manages the events of these devices with the rest of the e-Servant. Each driver has been implemented in an OSGi bundle, this way new drivers can be added without making changes to other services. Device Layer and Device manager have been implemented in a unique bundle[8].

The following sections describe in detail each of these layers.

### 5.3.1. DRIVER LAYER

The lowest layer of the context manager is the driver layer, where communication with physical devices and transport services are developed. The tasks carried out by this layer are:

*Physical channel establishment.* The driver layer has the responsibility of creating and opening communication ports with the network gateways. Automatic identification of ports is also performed if possible (i.e. serial port scan for the connected gateway in the ZigBee Network sensors set).

*Device enumeration and network support*. Once the communication channel is up, sensor network management is carried out by the network driver. It deals with network support operations and performs enumeration and registration of the physical devices presenting the network infrastructure.

*Device instantiation and messaging service*. Devices recognized by the driver in the network are instantiated by the driver layer and presented to the context manager, allowing exchange of information between them and their software representation.

Two drivers have been implemented into the context manager architecture for communicating with physical devices:

[8] Note that the Driver layer implementation should not be considered as part of this PhD because it was not part of my personal work within the project. Anyway a short description is included for sake of understanding the Context Manager operation.

*PLC driver to communicate with kitchen appliances*. The PLC driver is connected to a PLC gateway through Ethernet, using web services. The driver checks that the gateway is running, and registers the devices (appliances). For each device, a PLC Device is instantiated and presented to the context manager.

*ZigBee driver to communicate with sensors, actuators, RFID readers and care-phone*. The ZigBee driver establishes the connection with the ZigBee gateway, which also acts as the coordinator of the network, through a USB (serial) port. The driver checks if the network is created and, if so, gets the devices connected in the network. For each device in the network, a ZigBee Device is instantiated and presented to the context manager.

### 5.3.2. DEVICE LAYER

Each of the above described drivers instantiate object devices related to the physical devices connected, or more precisely, controllable by means of the respective driver. These objects correspond to OSGi services, which have an independent identity within the framework.

Device representation allows separating device functionality from the underlying technology and the transport layer. Each one holds data members, properties and methods which model the behaviour of the physical devices they represent. Activation or access to these methods implies the communication with the physical devices through the base driver that has instantiated the device (therefore, the base driver must be active to enable that communication).

The representation of devices start from the OSGi4AmI implementation represented in the Open Source Project embodied in the same name (Marco, Cirujano et al. 2012) and published in (Marco, Casas et al. 2009) as book chapter. This taxonomy proposes three basic devices that are part of any AmI:

**Sensors** are devices which are able to sense physical magnitudes (like temperature, presence, acceleration, etc.).

**Actuators** are devices which are able to change any of the environment characteristics (like switch on/off a plug, dimming a light, close/open a door/window, etc.).

**Simple HMI** (Human-Machine Interface) are devices which are used to input simple data into the system (remote controllers, level controllers, etc.) or are used by the system to provide information to the user in a simple way (LED controllers, buzzer, etc.).

This taxonomy proposes the identification of the common properties inherent to the each device nature. These properties, clustered by functionalities, define the interface of the device. As Figure 26 shows, every device interface extends the base device, and therefore all devices have some common properties. The *BasicDevice Interface*, which is mandatory for all devices, includes the minimum information inherent to the device (Category, description, serial number, provider, etc.) that is needed to recognize it.

Every device has an energy power supply (battery, main power, etc) and a location in the space. However, the virtual device could be aware or not about them and consequently leaving the *power cluster* and the *location cluster* as optional. As a proof of concept, location service presented in section 5.2.2 has been implemented at this level demonstrating its feasibility.

The same philosophy has been applied to the specific devices like sensors and actuators, which may be able to provide different levels of information. Each device category includes mandatory (labelled in orange in the Figure 26) and optional clusters (labelled in violet Figure 26). For example, inherent to its nature, every sensor will be able to provide its measurements. For this reason, the method to retrieve measurements from a sensor belongs to *base sensor cluster*; mandatory for every *sensor device*. Some sensors might be smart to implement measurement analysis and provide alarms when thresholds are exceeded; as this won't be implemented by all sensors, such methods belong to optional *threshold sensor cluster*.

This way, devices with the same functionality, for example two temperature sensors from different manufacturers, should implement the same interface with the same mandatory clusters and corresponding to their capacities optional clusters. Regardless to their implementation, one is a proprietary RF sensor while the other is a ZigBee sensor, both could be used by a "thermostat service" which needs temperature sensors devices (thanks to the BasicDevice) and both can be requested in the same way to provide the temperature value (thanks to the BasicSensor); i.e. implementation of the sensor is decoupled from its logical abstraction.

Additionally each level of abstraction, from the device to the actuator, sensor or simpleHMI, defines a listener interface in order to raise events to registered services.

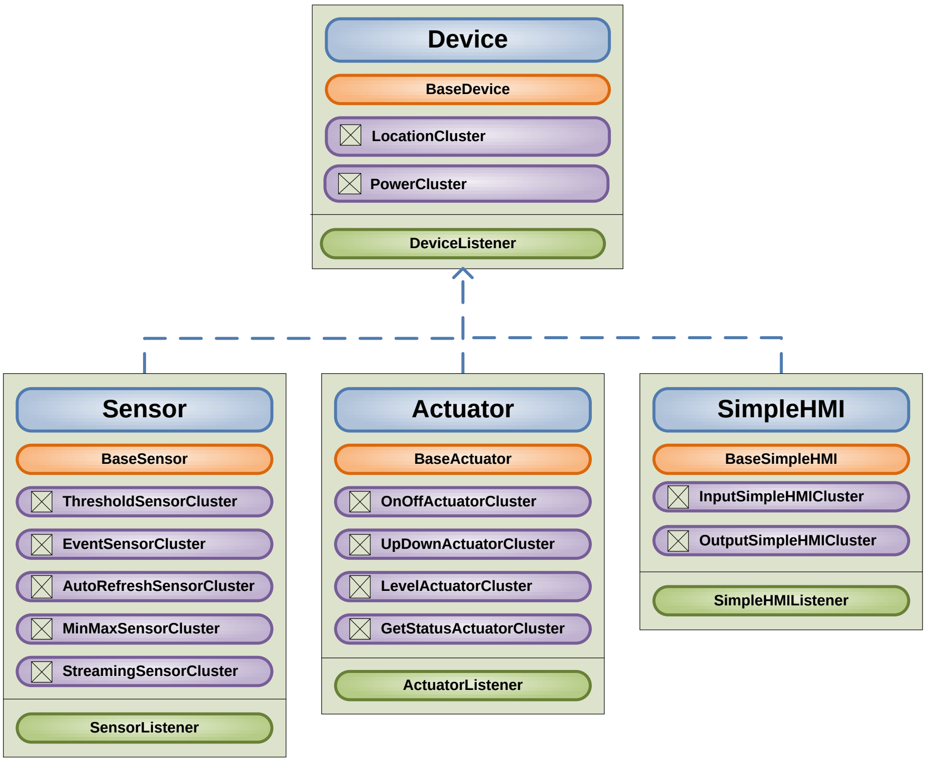



Figure 26 Device categories. Source: (Marco, Casas et al. 2009)

However, although this taxonomy covers the basic elements typical of an AmI, it can be extended to specific contexts. Thus, following the same philosophy, it has been enlarged to include the kitchen appliances. The interface shown in Figure 27, extends from *device* to enable control of the appliances present in this scenario. As shown in this figure, five appliance clusters that allow access to different levels of control are defined:

- ***BaseApplianceCluster*** combines the basic features associated to the appliance as updating their status or setting its refresh time for automatic update.
- ***GetStatusCluster*** allows getting the value of the appliance characteristic state variables.
- ***SetStatusCluster*** allows setting the value of the appliance characteristic state variables.
- ***OnOffApplianceCluster*** allows turning on/off the appliance.

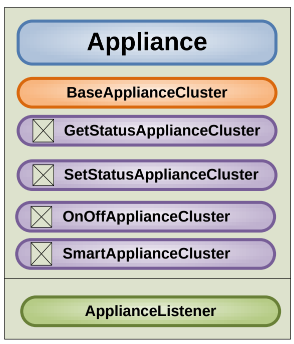



Figure 27 Appliance interface

- ***SmartApplianceCluster*** allows executing a concrete program, to pause it, checking its state or scheduling its execution.

Besides publishing a representation of the basic devices present in the AAL in the OSGi framework, this layer groups some basic devices to build smarter devices that create a virtual representation of the whole; which is called superdevice. For example, in the case of refrigerators, the Device Manager publishes a superdevice called Fridge that is composed by the combination of Refrigerator (PLC), RFID reader (ZigBee) and door sensor (ZigBee).

Figure 28 shows an example of how the Device Layer works. There are two bundles, PLC device discoverer and ZigBee device discoverer, looking for new devices and publishing them as services. Also, the SuperDevice Aggregator bundle is looking for devices which form part of a superdevice, in this case the Fridge.

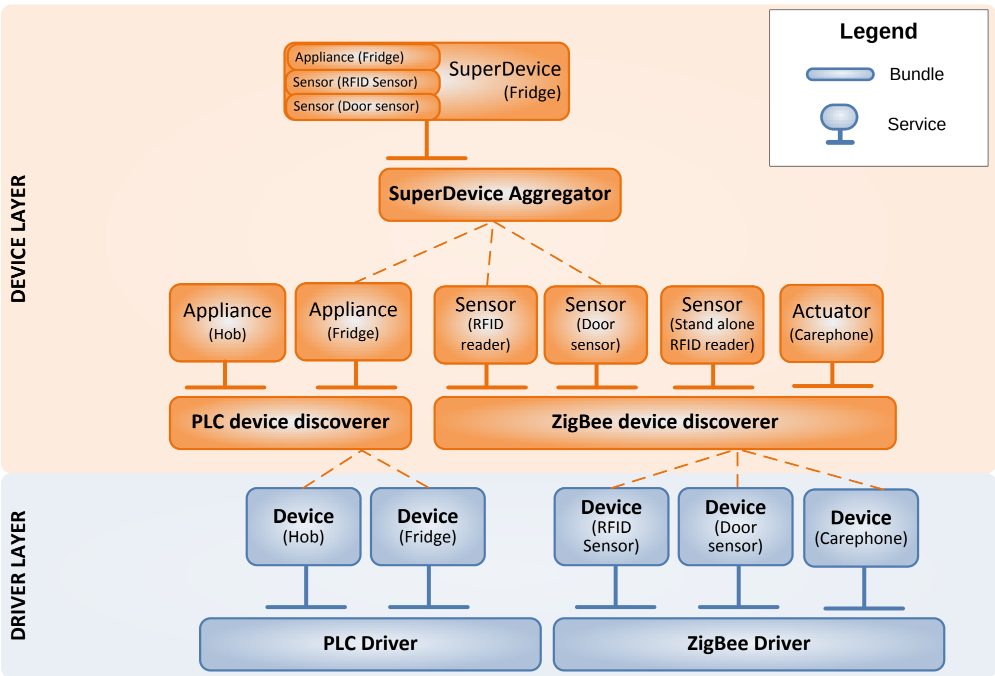



Figure 28. Example of the composition of a superdevice along with the different layers making up the CM

These superdevices have its own identity within the OSGi framework performing Action Driving and Event triggering functions. In addition, they are also independent devices that may require event management or control by the upper layers. Thus, upper bundles work isolated from the technology involved in the sensor, actuator, appliance or Simple HMI. Currently, the Device layer offers the following devices and superdevices:

| Device / Superdevice | Composed by | Functionalities |
|---|---|---|
| **Washing machine** | ZigBee door sensor | This sensor triggers an event when the door of the washing machine is opened or closed. Also, it can be requested to know the current state of the door. |
| | ZigBee RFID reader | This device provides information about the content of the washing machine |
| | PLC washing machine | This device provides properties related to the washing programme being performed and its current phase, the water temperature (target), or the estimated finish time, as well as the operating state and some malfunction and alarm warnings. This device allows also remotely activating or deactivating the programme. |

| | | |
|---|---|---|
| **Fridge** | ZigBee door sensor | This sensor triggers an event when the door of the fridge is opened or closed. Also, it can be requested to know the current state of the door. |
| | ZigBee RFID reader | This device provides information about the content of the fridge |
| | PLC Fridge | Fridge Device exposes properties related to the current and target temperature of both compartments (fridge and freezer), as well as if they are active or not, and SuperFreezing or EcoMode functionality. |
| **Oven** | ZigBee door sensor | This sensor triggers an event when the door of the oven is opened or closed. Also, it can be requested to know the current state of the door. |
| | PLC Oven | Properties accessible by the e-Servant are its state (active or not, failure…), heating mode, current and target temperature, programme duration and absolute end time, child lock state. It is also possible to remotely operate the oven. |
| **Hob** | PLC Hob | This device only provides monitoring of the state of each of the cooking zones in the hob (typically four) and the child lock, because legally it is not allowed to remotely operate this device, and it is only possible to stop the device if an emergency occurs. |
| **Door sensor** | ZigBee door sensor | This device indicates the opening of a door in a cupboard or appliance in the application scenario. |
| **Presence sensor** | ZigBee Presence sensor | This device indicates whether someone is in the sensor area or not. |
| **Temperature sensor** | ZigBee Temperature sensor | Indicates the temperature of the location where the sensor is (maybe outdoors) |
| **Light sensor** | ZigBee light sensor | Indicates if the light is turned on or off, which together with the presence sensor can easily indicate activity or set an alarm. |
| **Smoke sensor** | ZigBee smoke sensor | Indicates the presence/absence of smoke. |
| **Fire sensor** | ZigBee fire sensor | Indicates the presence/absence of fire |
| **Flood sensor** | ZigBee flood sensor | Indicates the presence/absence of water in the area covered by the sensor |
| **RFID reader** | ZigBee RFID reader | Products inventory and tracking will be performed by means of RFiD readers, which provide RFiD code label of devices in range by request. |
| **ZigBee Carephone** | ZigBee Care Phone | This device allows control a commercial telecare system (as the Carephone of the Caretech(c)) generating up to four different alarm codes that can be identified in call centre. It is also capable of establishing a voice call with it. |
| **Light ON/OFF actuator** | ZigBee actuator | This device allows turning on and off the light of the kitchen. |
| **ZigBee Tag** | Base device | Include the basic information about the device (Category, description, end points, clusters supported, etc.) |
| | Accelerometer | Tri-axial accelerometer used to detect falls |
| | Two Buttons | Simple HMI used to generate alarms |

Table 36.Devices supported by the e-Servant

### 5.3.3. DEVICE MANAGER LAYER

Lower layers of the Context Manager gather existing physical devices and present them in a structured way. Device Manager is responsible for manipulating and aggregating information from these devices and effectively offering context awareness to upper layers. Main tasks performed by Device Manager are:

*Context logger.* The information collected about sensors together with the information derived from the context aggregation is logged into the Context Database, which will be used by the Logic Unit (LU) and Quality of Life Evaluation (QoLE) services.

*Action driver.* Through this module, the Context Manager allows the LU to act over the physical devices.

*Event trigger*. The information received from the sensors is stored in the context database, but some external events may require an immediate response by the e-Servant. This module notifies the LU that something is happening.

Figure 29 shows the three bundles that integrate the Device Manager Layer. This layer groups the information of the context and isolates upper layers of the devices management.

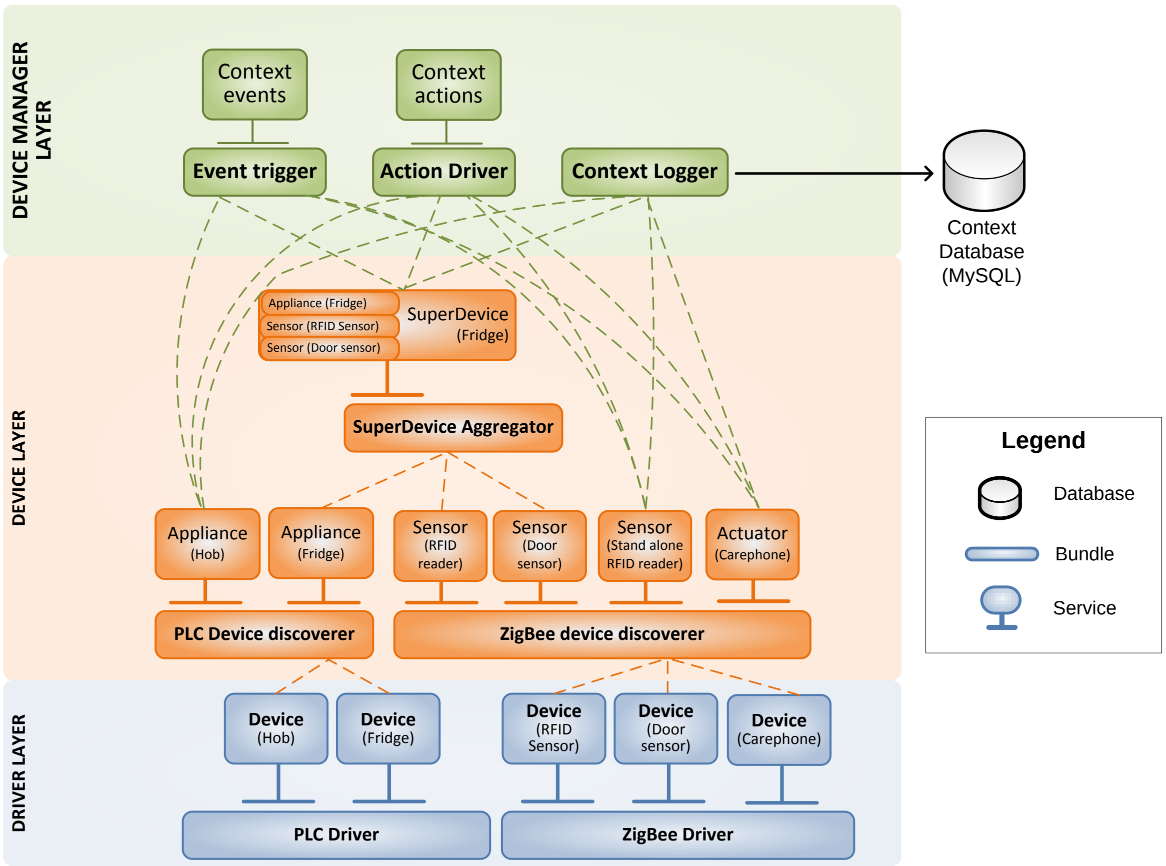



Figure 29 Example of the Context Manager working

## 5.4. CONCLUSIONS

This chapter undertakes the deployment of a heterogeneous sensor-actuator network which enables the communication between the e-Servant and ZigBee, Bluetooth, PLC, WiFi, RFID and IR devices. Specific hardware devices (ZigBee Tag, ZigBee Carephone and ZigBee Bridge) have been designed and developed in order to sense and act over the environment. Also, the encoding of the food and clothes data inside the RFID label as well as the control of the RFID readers has been done.

This technology has enabled the design and test of data algorithms in order to obtain more elaborated information. Fall detection based on NN has been successfully designed and tested obtaining good results in the discrimination between true falls and events quite similar to falls. Also, indoor localization algorithm using the existing ZigBee infrastructure (a non-dedicated ZigBee network) has been designed and validated with a SOM. Acceptable results at room level have been obtained applying the 2 label method.

Finally, the implementation of the Context Manager has been introduced. The OSGi4AmI taxonomy has been used to represent the different devices present in the AmI. This taxonomy has been extended to include the kitchen appliances.

# CHAPTER 6: REASONING

*This chapter presents contributions in the design and implementation of the Logic Unit, describing the logical rules and software implementation which drive the e-Servant operation, the user modelling as well as the contributions in developing the Quality of Life Evaluation System.*

## 6.1. LOGIC UNIT IMPLEMENTATION

Decision making of the e-Servant takes place in the Logic Unit (LU). It is responsible for analysing the stimuli received from the environment through the Context Manager and User Interfaces to provide an adequate response in order to help users to perform their everyday duties in the kitchen.

As Figure 30 shows, the Logic Unit bundles interact with (i) the Device Manager layer of the Context Manager to access to sensor and appliance events and to command appliances; (ii) the Interface Database, to manage the interaction with the user (through the interfaces); and (iii) the Context Database to store high level events to be analysed by the Quality of Life Evaluation System.

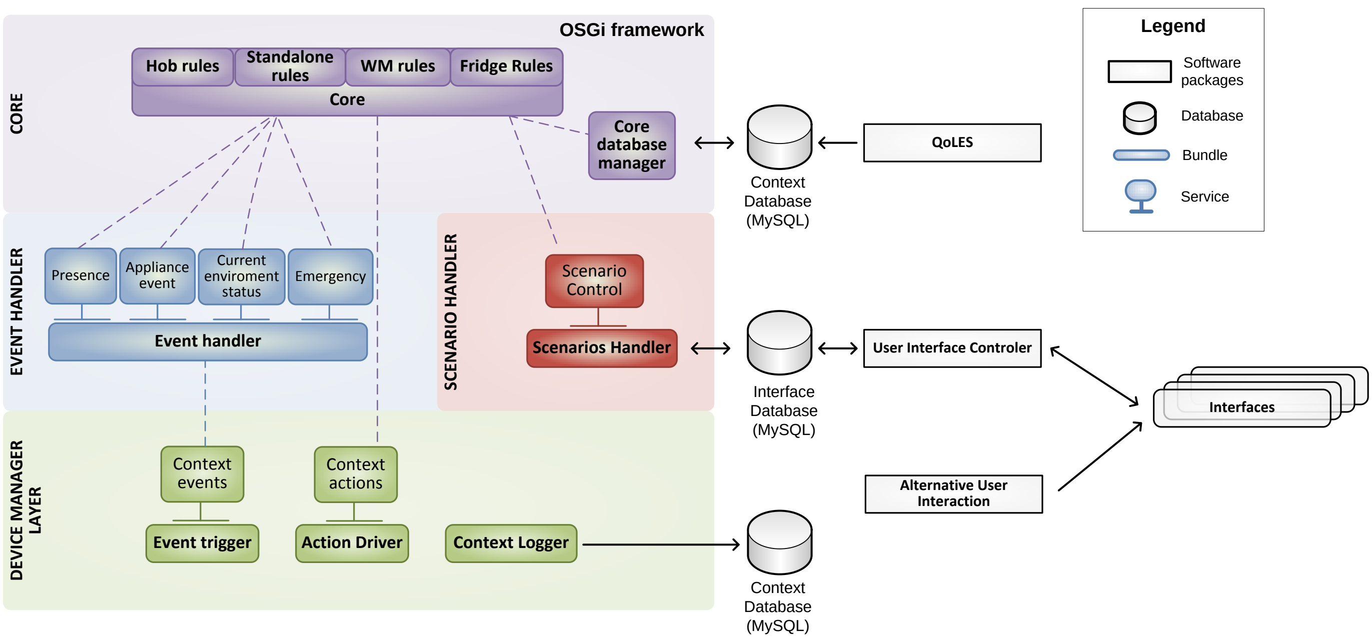



Figure 30 Logic Unit relationship

The Logic Unit (LU) is divided into three layers that are more profusely described in following sections:

- The Event Handler, which makes a first analysis and classification of the context events;
- The Scenario Handler, which offers the methods to control the interaction with the users by mean of the interfaces of the system; and
- The Core, which manages the decision making of the e-Servant.

### 6.1.1. EVENT HANDLER LAYER

The Event Handler is consuming the context event service offered by the Device Manager layer. The Event Handler analyses the events from devices and superdevices published by the Context Manager and notifies the Core when there is a relevant change in a device. This work is done through four services that it implements:

*Presence*: This service informs to the Core about the presence of people in the house aggregating the presence sensors information distributed in the context. It shows the presence status of each sensorized area that could be easily used in the implementation of high level rules. When the event handler does not receive presence events of a concrete area, it changes the area status to indicate that nobody is detected.

*Appliance events*: It informs about all the events related with the appliances. This layer also makes simple statistical operations over the events in order to provide high level information to the Core.

*Current environment status*: This layer stores a snapshot of the environment status which is updated with the events proposed by the Context Manager or by request of the Core.

*Emergency*: This service provides information about the current state of emergency of the house, aggregating the information from all sensors present: fire, smoke and flood as well as statistic about the events happened.

### 6.1.2. SCENARIO HANDLER LAYER

The user interaction is performed by what is called user-scenarios. These user-scenarios contain the visual and aural information to maintain a dialogue with the user in order to help, guide or inform him/her about a given situation. Each scenario has been designed with three levels of complexity (easy, normal and expert). This way, it is possible to select the most suitable interaction depending on the person's user profile (detailed in section 6.3.). The interface also provides information about the content and status of the appliances. Glyndŵr University team has developed the user-scenarios as well as the user interface.

The interfaces management is done by the User Interface Controller (UIC), which sends the information to be displayed. The Logic Unit, through the Interface Database, provides to the UIC the context information (Appliance status, fridge and washing machine content, etc.) and manages the user-scenarios execution. This communication is done using the next tables of the database[9]:

| Table name | Description |
|---|---|
| UI_Scenarios | This table provides a list of valid scenarios that can be invoked by the UI Device Controller |
| UI_OutputMap | This table provides a mechanism to transmit the user - context values back to the Logic Unit. (Scenario information, user interface interaction, etc.) |
| UI_InputMap | This table is used to transmit context information from the Logic Unit to the interfaces |
| UI_Session | The Session table contains records that bind one or more scenarios (i.e. more than one scenario if interrupts happen) to a specific User ID. |
| UI_SesionRequest | This table is used to request call to run a Scenario, which in turn generates a session request ID |

Table 37 Detail of the tables from the Interface Database used in the communication with the UIC. Motive Technology.

[9] UIC and the Interface DataBase were developed by Motive Technology

Therefore the Scenario Handler has two functions: On the one hand it provides the Core with methods to manage the user-scenarios (run, pause, and abort) and, on the other hand it reports about the user-scenario execution state and about the results of the interaction with the user. This work is done thanks to a bidirectional communication established through the Interface Database which is polled in a timely fashion (every second) in order to know which user-scenarios are running, waiting or interrupted. Main tables involved with these tasks are the UI_SesionRequest and the UI_OutputMap.

### 6.1.3. CORE LAYER

The Core is the bundle that takes the decisions that rule the system. These decisions are based on deterministic rules related with the functional areas identified in the kitchen in the chapter 3: food management, cooking and washing. Each one of these rules (detailed in section 6.2) define a specific algorithm for each concrete situation; this way it is possible to know what the e-Servant will do in every situation.

Main functionality of the Core is to manage these logic rules, which can be executed concurrently. It could decide start or stop the execution of a logic rule depending on the whole context: sensor, appliances, user`s profile, interfaces or user scenarios. Also, when a rule decides to act over a device (a rule execution could request turn on/off, configure and command the white goods present in the kitchen; send a notification to a technical support centre when breakdown is detected; forward a warning to a call centre in order to inform about an emergency) or interact with the user (a rule execution could request Interact with the user launching a user-scenario) the Core manages these actions, which must abide the level of priority of the rule.

The Core also performs other tasks such as updating the status of the appliance in the user-interface. When the status of an appliance, food or clothing inventory, etc., changes, the Core updates the information shown in the user interfaces writing the content of the UI_InputMap table in the Interface Database. Also, the Core saves information which could be relevant to study the person’s quality of life: duty performed by the Quality of Life Evaluation System.

## 6.2. LOGIC UNIT RULES

The following section describes the rules implemented in order to validate the actual system with real users. This set of rules aims to show the capabilities of the system, being easily expandable to new situations. These rules have an associated priority level customized for each user, which defines how the actions required in its execution will be done by the Core. There are four levels:

- Disabled: The rule is not used
- Low priority: The actions associated with rules labelled with this level are executed only once a day. An example is the rule R_f1 “There is some food item expired /about to expire” which reminds the user that something is out of date.
- Normal priority. The actions associated with rules labelled with this level are executed in real time and the system could remind the user even some minutes after if no action is detected. It is the usual level for most of the rules.
- High priority: This level is associated by default to the rules which manage the emergency situations such as fire or smoke. When one of these rules requires actuation over a device or communication with the user, the Core stops the execution of any other action, rule or user-scenario, giving priority to it.

**These rules have been designed based on the needs identified in Chapter 3, following the tasks identified for each functional area**.

### 6.2.1. FOOD MANAGEMENT

The design of the rules associated with the food organization and classification have focused on the refrigerator. Many of these rules could be directly extrapolated to a smart cabinet or to the freezer.

**R_f1: There is some food item expired /about to expire**

Once a day, the Core scans the content of the fridge looking for expired products (or about to expire). If it finds something, it will start an interaction with the user in order to notify which products are expired (or about to expire). The Core chooses the user-scenario most suitable to the user's profile.

**R_f2: The fridge's door is open**

When the fridge's door is opened for a long time (more than a defined value) the Core tries to notify the user. If there is no response, a new reminder will start in 5 minutes (optionally a warning could be sent to a call centre). When the door is closed, the rule ends.

**R_f3: The fridge is broken**

This rule is activated when the Core detects that the fridge is not working properly. Then, it will warn the user offering the possibility to call the technical service (if this service is available).

**R_f4: The user wants to change the fridge's settings**

This rule starts when the user wants to change fridge's settings via the user interface. The Core will choose the best user-scenario to help the user depending on the user's profile. If the scenario ends correctly the new settings are sent to the fridge.

### 6.2.2. COOKING

The rules designed for the cooking area focused on oven and hob. However, most of the rules could be directly extrapolated to a smart microwave.

**R_c1: Fire/smoke detected**

When the Core detects that there is fire or smoke in the kitchen, it tries to warn the user. If nobody is present in the house or the user does not answer quickly, the Core turn off the hob and oven and warn to the call centre.

**R_c2: No pan detected**

When the Core detects that the hob is on and there is nothing over it, the Core tries to warn the user. If nobody is present in the house or the user does not answer quickly, the Core could decide to turn off the hob (this rule is only available to induction hob devices).

**R_c3: The Hob/Oven is broken**

This rule is activated when the Core detects that the hob is not working properly. Then, it will warn the user offering the possibility to call the technical service (if this service is available).

**R_c4: The user wants to configure the oven**

When the user wants to turn on/off the oven or change its configuration via the user interface, this rule is activated guiding the person to easily configure the oven. When the interaction ends, the Core checks the data and configures the oven.

### 6.2.3. WASHING

In this case, the logical rules have been focused on the washing process:

**R_w1: Incompatibility of clothes detected and un-washable clothes detected.**
This rule checks the consistency among clothing introduced inside the drum (colours, being washable or not, etc.) with the selected program. It is only available when the user is being guided through the washing process (R_w8) because the clothes need to be introduced inside the drum one by one, enabling the real time detection of the garment.

**R_w2: Load incomplete.**
If the Core detects that the user is loading the washing machine and he/she doesn't end the process, the e-Servant will send a reminder to the user (It is only available when the user is being guided in the washing process (R_w8)).

**R_w3: Program the washing machine.**
The Core can configure or help to configure the washing machine. It is only available when the user is being guided in the washing process (R_w8)).

**R_w4: Washing cycle interrupted**.
The Core sends a warning to the user if the washing process is interrupted.

**R_w5: Washing cycle completed.**
When the washing cycle has finished, the e-Servant notifies the user.

**R_w6: Unload incomplete.**
The Core monitors unload of garments notifying the user if the process takes too much time and no activity is detected.

**R_w7: Washing machine broken down.**
This rule is activated when the Core detects that the washing machine is not working properly. Then, it will warn the user offering (if this service is enabled) the possibility of calling the technical service.

**R_w8: The user needs help to do the washing process.**
When the user cognitive level is low, the Core may decide to guide the user step by step. This process starts with the load process using the "load scenario". If the e-Servant detects that incompatible clothes with the selected program are loaded, the user is warned using the user-scenario: "Incompatibility of clothes detected". The same happens if some un-washable clothes are detected using the "un-washable clothes detected" user-scenario.

When the load is done (the user is reminded), the washing machine could select (or suggest, depending on the user level) the most suitable program for the clothes that are inside the drum. User is notified when the washing process ends and he/she can check its status through the interface in any moment. The Core checks that the discharge of the drum by the user is successful. Otherwise, the user is notified through the user-scenario "Unload incomplete".

### 6.2.4. STAND-ALONE RFID READER

In addition to appliances, rules have also been designed for the stand-alone RFID reader. This device, located in the kitchen, has as main function to provide additional information on those elements carrying an RFID tag. Two rules have been defined:

**R_r1: Display information**

Whenever a labelled object is close to the reader, the information of the object is displayed in the interfaces of the e-Servant. Currently there are two possibilities:

- Food: it is displayed the name of the product and the expiration date (additional information could be added)
- Clothes: it is displayed the name of the product, the colour and the suggested washing mode.

**R_r2: Automatic configuration of the oven**

Additionally, when the tagged item is detected as prepared meal, the interface may suggest an oven configuration and even configuring it if the user desires.

## 6.3. USER'S PROFILES

Each person is represented in the system by his/her user profile. Decisions made by the Logical Unit are conditioned by this profile which mainly determines the person's capabilities at different levels of interaction with the system. To design the user's profiles, interaction between e-Servant and user has been studied using the "persona" concept.

This idea, developed by Alan Copper in his book "The inmates are running the asylum" defines personas as "Personas are not real people, but they represent them throughout the design process. They are hypothetical archetypes of actual users" (Copper 2004). Led by the Glyndŵr University, this idea was applied to the user modelling to define the interface and the user's profile (Casas, Blasco et al. 2008). Ten personas have been defined based on the European statistics randomly assigning age, education, work, family situation, impairments and technology background. As an example next box represents the information about Hannah:

**Hannah, 67 years old, Sweden**

"I am looking for technologies that can bring me closer to my children…"

| | |
|---|---|
| Retired, Ex-secretary in a bank | Suffers from mild impairement |
| Has a less upper secondary education | Suffers from osteoarthritis |
| Widowed, 1 daughter, 2 grandchildren | Owns a computer, no mobile phone. |

Hanna used to work in a bank as the director's secretary. She is a computer literate but never was interested in becoming a power user. Her arthritis started when she was 55 due to the repetitive typing movements on the keyboard.
Hanna was married for 38 years when her husband died a couple of years ago of a lung cancer. She is now living by her own in a quiet residential area in the south of Sweden. She spends most of her time at home doing common household tasks that she hates to do. She enjoys listening to the opera, taking long walks with her dog Bandit, meeting and playing cards with her friends every weekend, cooking and talking for hours on the phone with her daughter Michelle who lives at two hours driving from her. Living alone is not easy, and Hanna likes to get company: her daughter visits with her 2 grandchildren Adam and Erika as often as they can but not as much as Hanna would like.
Hanna wears glasses to correct her visual impairment but she only wears them when she needs to read or do something that requires seeing up close… like playing cards with her friends. Her vision of things at distance is good. She installed a glass magnifier on her computer monitor so she does not have to wear her glasses and she is able to check her emails without any difficulty.

Figure 31.Example of persona. Source: (Casas, Blasco et al. 2008)

While interacting with the e-Servant, it is possible to adjust how and what information is sent to the user. Customizing the physical parameters of the output channels of the system, as volume, pitch, contrast, etc., it is possible to control how the information is send to the user. Also, the e-Servant can increase the help level which is offered to the user as well as the information shown to him/her.

The study of the interaction between “personas” and e-Servant has been used to design a user profile that could provide enough information to the system (LU and user interfaces). User profile aims to consider cognitive and sensorial capabilities of the person within the following categories:

**User level** has four different grades: not possible (0) indicates that the user is not able to use the system; of course it could be a temporary situation. Easy (1), standard (2) and expert (3), indicates the understanding that the user has of the system. This understanding can be due to different reasons: e.g. knowing all the system’s features, having memory losses, etc. From the LU’s point of view, this is the most relevant parameter as it is related with the cognitive capabilities and the technological skill of the person. This parameter determines the interaction with the user (number of options, complexity of menus, etc.).

**Interface** makes reference to how the system will show the information to the user: using icons (0) text (1) or both (2). Besides the user preferences, this also has implicit information about the user’s cognitive level.

**Audio**: Inside audio category, three sub-categories are included: Volume, pitch and voice control. First two can help people with aural disabilities to hear the HMI. Voice control indicates if the user would control the system via voice commands. Of course, this would be helpful for people with visual disabilities, but not only. As voice is the most natural way of communicating (compared with remote controls, keyboards, tactile interfaces, etc.), voice control would be helpful for those people with reduced cognitive capacities or low technological skills.

**Display**: it includes common adjustment controls in screens: contrast, brightness and colour settings (physical parameters). These characteristics, besides adapting to the ambient light and user preferences, together with magnification might help people with visual impairments to interact with the display.

The user profile has been validated setting a different user configuration for each persona. Next we can see Hannah’s case:

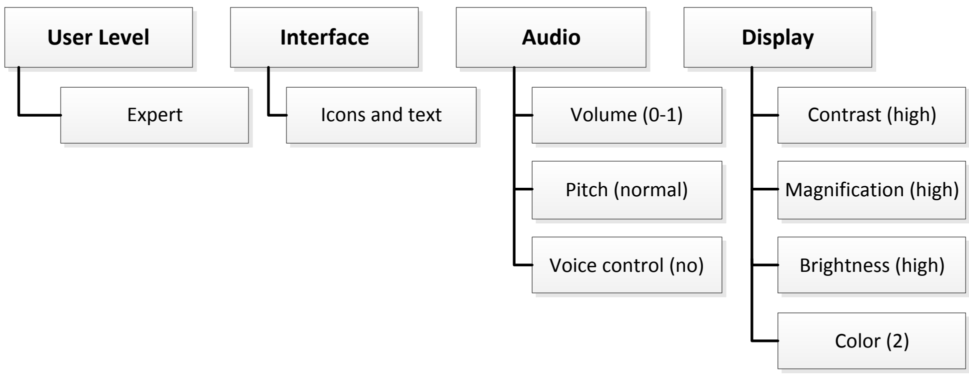



Figure 32. Hannah user profile.

## 6.4. QUALITY OF LIFE EVALUATION SYSTEM (QoLES)

The QoLES is a service that periodically (configurable period) analyses the user`s behaviour looking for changes in his/her habits in the kitchen. These variations could be relevant to detect a loss of physical, cognitive or sensory capabilities. Main objective of this service is to provide objective information about the everyday life of the user.

The first step in the design of the service has been to analyse the data available by the e-Servant which could be more relevant in order to detect changes in the user's habits. Then, the QoLES idea was validated with stakeholders in the co-design session described in the section 3.5.2. In these sessions, participants contributed to the design with new ideas that improved the system. Most relevant contribution was to decide that the system should not automatically change the user level; QoLES service should limit to report the carer with objective data about the person's quality of life, then the carer will take the final decision about the help level of the system.

Finally, according to these information categories, random data were generated to try different algorithms and technics to develop the first version of the QoLE system. This work was carried out by Antonio Bono in his master thesis (Bono Nuez, Roy Yarza 2008). However, to validate this functionality it is needed to evaluate enough number of users during a long period of time (several months). During this time, the user evolution should be contrasted by socio-health professionals who could help to corroborate the QoLES performance; such essay was out of the scope of the research project which framed this PhD and consequently of the PhD.

Next sections show my work regarding **conceptualization and design of the system as well as implementation of the data-retrieving layers**. Implementation of the artificial intelligence layers and its theoretical validation (which was done by Antonio Bono) can be found in the paper: Quality of Life Evaluation of Elderly and Disabled People by Using Self-Organizing Maps (Bono Nuez, Martín del Brío et al. 2009).

### 6.4.1. QoLE SYSTEM DESIGN

It seems evident that changes in HMI's navigation skill or increasing the times the fridge is opened (without picking anything) might be related to changes in the user's cognitive capacity or disorientation. The e-Servant is able to gather a huge amount of data which, if not properly selected and handled, would generate unusable outputs and erroneous conclusions. As the main objective was to create a useful tool for the carers, starting with the analysis performed in chapter 3, engineers have worked closely with health and social professionals to determine the relevant data (see section 3.5.2). Also, design of this tool doesn't restrict to the technology and appliances involved in this AAL (not even to existing technology). This way, the QoLES can be adapted to the technology available and also persist in time. Like in chapter 3, relevant activities in a kitchen are grouped in four areas:

**Food management and storage**: including food storage in cupboards, drawers and fridge, out-of-date food management, cooling interruption of aliments needing refrigeration.

**Cooking:** these activities include from interaction with the hobs, oven and microwaves to actions done in the preparation of the food (following a recipe, cutting, etc.).

**Washing activities:** including washing crockery (dishwasher, sink) and clothes (washing machine).

**Other no specific:** here are included all activities also performed in the kitchen that are not framed by the previous ones. For example, using the water tap, actuating on the lights, interacting with the HMI, throwing the garbage out, etc.

Next tables outline for each area, the high level information that could be useful for the QoLES as well as the data needed to provide it:

| Food storage and management | |
|---|---|
| **High-level information** | **Data needed** |
| Changes in shopping habits | Food tracking in the kitchen (amount, persistency)<br>Time between shopping |
| Habitual food expiration | Expiration date (coded in the RFID labels) |
| Errand behaviour (maybe due to disorientation or bad memory) | Number of times the fridge's door is open without taking/introducing anything<br>Erratic cupboard's door opening (not implemented) |
| Miss-attend the temperature or door alarms | Door and temperature sensor<br>Number of warnings until warning is attended |

**Table 38 Relevant information for the QoLES related with the food storage and management**

| Cooking | |
|---|---|
| **High-level information** | **Data needed** |
| Absence of mind situations (changes may indicate loosing of capacities) | Forget the pan on the fire (e-Servant could warn when more than certain time, if the pan is immediately removed, it could be a forgetting)<br>Wrong stove selection<br>Liquid overflowing when cooking<br>Use the pan void<br>Fire or smoke detected by specific sensors<br>Forget switching the appliances off<br>Number of times the oven and/or microwaves' door is open before ending |

**Table 39 Relevant information for the QoLES related with the cooking activities**

| Washing activities | |
|---|---|
| **High-level information** | **Data needed** |
| Erroneous washing machine operation | Program selected<br>Identification of the clothes inside the washing machine |
| Forgetting taking the crockery/clean clothes out | Number of warnings until crockery/clothing is removed |
| Changes in washing conducts | Time between washings |

**Table 40 Relevant information for the QoLES related with the washing activities**

| Other no specific | |
|---|---|
| **High-level information** | **Data needed** |
| Absence of mind situations (changes may indicate loosing of capacities) | Forget about lights on (presence + light sensor)<br>Erratic movement (position sensors)<br>Forget the water-tap opened (sound sensor) |
| Changes in HMI navigation times | Time needed by the user in each interaction with the HMI |

**Table 41 Other relevant information parameters for the QoLES**

Although all these data sources have been identified as relevant in the workshops, several of them were discarded by its complexity or because the sensor setup needed was not reasonable. Every time the context is evaluated and analysed by the LU, as it is showed in the section 6.1., the information is stored in the context database. Next section shows the information which is stored.

### 6.4.2. QoLES DATA

LU and CM retrieve relevant events and register them in the context database; inside a table called EServant_Events. These registers have the next fields:

**ID**: Auto numeric. This field is used as key.

**Timestamp**: day/month/year Hour:minutes:seconds

**Event**: kind of event (see Table 42)

**Provider**: Name of the bundle which register the event

**Parameters**: Text field where the relevant parameters associated to the event are stored separated by commas (csv format)

CM registers all the changes in the context such as the fridge door open event or the hob fire level selected. This kind of events has been defined as low-level events because they don't require any analysis to be used. LU processes and analyses these events in order to detect more complex situations; defined as high-level events. Next table summarize the high-level events that are used as inputs by the QoLES.

| Event | Description | Parameters | Related technology |
|---|---|---|---|
| F_NewItemDetected | New shop: When a new item or group of items is added to the fridge, the LU registers the event<br>Note that it is only possible when the food is wearing a RFID tag. | New Item list | Fridge (superdevice)<br>Standalone RFID reader |
| F_RemoveTime | Time between the user is informed about an expired product and when it's removed | Time (hours) | Fridge (superdevice) |
| F_FoodOutOfDate | Food out of date | Item list | Fridge (superdevice) |
| F_NumberExpiredProduct | Store the number of expired product in the last month | Month, number of expired products | Fridge (superdevice) |
| F_ErrandBehaviour | Number of times the fridge's door is open without taking/introducing anything in the last month | Month, number of times | Fridge (superdevice) |
| F_DoorOpenWarning | Number of warnings in the last month and average of reminders | Month, number of warnings, average of reminders | Fridge (superdevice) |
| F_ AfterhoursActivity | Fridge afterhours activity detected | - | Fridge (superdevice) |

| | | | |
|---|---|---|---|
| WM_Score | Washing machine score (coherence of washing program-clothing colour-temperature) | 0 = bad selection<br>1 = no appropriate selection<br>2 = suitable selection<br>3 = most suitable selection | Washing Machine (superdevice) |
| WM_Washing | Washing | Content | Washing Machine (superdevice) |
| WM_AfterhoursActivity | Washing machine afterhours activity detected | - | Washing Machine (superdevice) |
| H_LowTimeOn | Number of times that the hob is switched on for less than 10 seconds in a day. Monthly average. | Month, Time (s) | Hob (Appliance) |
| H_ForgottenOn | Number of times that the hob is forgotten on in the last month | Month, Number of times | Hob (Appliance) |
| H_TimeHobOn | Average time that the hob is on in the morning, in the afternoon, in the evening and at night in the last month | Month, morning Avg time on, afternoon average time, evening average time, night average time | Hob (Appliance) |
| H_AfterhoursActivity | Hob afterhours activity detected | - | Hob (Appliance) |
| K_AfterhoursActivity | Activity in the kitchen afterhours detected | - | PIR (Sensor) |
| HMI_times | Average navigation times in the interaction with the HMI for each scenario in the last month | Month, scenarioID, number of executions, avg time of navigation | Communication database analysis |

**Table 42 High-level events relevant to the QoLES**

## 6.5. CONCLUSIONS

Following the same philosophy as in previous chapters, LU has been designed modularly in several bundles, isolating the management of the user scenario or the kitchen events from the core layer which manages the intelligence of the system. This intelligence is based on a set of deterministic rules, designed to cover the users' needs detected in the chapter 3, divided in four areas: food management, cooking, washing and stand-alone RFID reader. Current logic rules have been designed for the assessment of the system with real users. However, thanks to the Core structure which separates the rule management from the rule implementation, it is simple to add/remove rules, even remotely or/and dynamically due OSGi framework's capacities.

Although the first intelligence concept proposed an adaptive system which adjust dynamically the level of help to the capacities of user, this idea was discarded in the co-design sessions (see section 3.5.2). Experts agreed that this feature could disorient the user which detects that, while doing the same things, the behaviour of the system changes. Therefore, deterministic rules assure the same system behaviour to the same user profile, situation and interaction. Thus, carer, relative or social worker is responsible to adjust the user profile and explain the user the changes when required.

Quality of Life Evaluation System has been designed as a support tool in order to provide information to the carer, social worker or relative about the changes in the user's habits which could be related with a loss of capacities of the user. On that score, this chapter shows the work done in the conceptualization and design of the QoLE System as well as implementation of the data-retrieving layers.

# CHAPTER 7: SMART KITCHEN ASSESSMENT

*This chapter describes the methodology and tools developed for the assessment of the Smart Kitchen. This evaluation was conducted simultaneously in two countries: UK and Spain, by multidisciplinary teams from the Glyndŵr University and the University of Zaragoza (Casas, Blasco et al. 2010). Finally, the results obtained are presented.*

## 7.1. INTRODUCTION

When technology is evaluated, it is necessary to consider a range of social, technological, institutional and personal factors (Ballantine, Galliers et al. 1996). Additionally, legal and ethical aspects have mandatory consideration when users are elderly or disabled (Casas, Marco et al. 2006). In this context, there is an interdisciplinary crossing between the technical development of the innovation and its implementation in intervention situations with social assistance which could be considered itself as trans-disciplinary (Nicolescu, Camus et al. 1998).

Literature address this situation from different approaches: about user satisfaction (Demers, Monette et al. 2002), about its psycho-social impact (Day, Jutai et al. 2002), about the person, his environment, the technology and the impact of the period training (Goodman, Luft 2002), about the functional independence (Shone, Ryan et al. 2002), or how they affect the quality of life (Scherer, Laura et al. 2001, Schalock, Verdugo Alonso 2003). Regarding to the evaluation of the Assistive Technology (AT), we can find that the use of interaction models in the assessment is quite usual (Hasdoğan 1996). These models are used mainly for AT outcomes research highlighting the next: Human Activity Assistive Technology (HAAT), Matching Person and Technology (MPT) and the ICF (Lenker, Paquet 2003, Cook, Hussey 2001, Scherer, Craddock 2002). In the end, it is usual to design a specific "tool" in order to obtain evidences about if a particular technological innovation responds or not to the purpose for which it is designed.

Although technology assessment has traditionally followed quantitative techniques based on the accepted convention of their rigor, the prevailing reality shows that qualitative assessments can be equally rigorous. In fact, the prevailing trend tends to combine both (Combessie 1986, Groger, Straker 2002, Howe 1992, Jick 1979, Rossi 1994, Morgan 1997, Teddlie, Tashakkori 2003), minimizing the prejudices of each of these methodologies through the contrast processes. This is the philosophy that has been followed in the design of the system assessment: to combine qualitative tools such as observation or interview with quantitative tools such as surveys and data collection.

## 7.2. ASSESSMENT DESIGN

### 7.2.1. RATIONALE

Although interaction with users and related groups have been considered during the design process, once the Smart Kitchen prototype is available it is necessary to prove its utility. In this sense, the evaluation of the AAL in the kitchen raises three questions: Which people are able to use the system? How easy is to interact with it? Does the Smart Kitchen meet the purpose for which it was designed? Answering these three questions determines the accessibility, usability and functionality of the system.

System assessment follows a methodology in line with the research approach proposed in Chapter 3 to study the needs of the target population. That is, it starts with the study of human-device interaction following the model proposed by Abowd and Beale linking it with the parameters studied (accessibility, usability and functionality). This study is the base of the assessment and it is reflected in specific tools in the section 7.2.3.

As it is raised in Chapter 3, user must be able to understand the stimuli perceived from the machine, to process their related information and to produce a response that the system can understand according to the context and the interaction objectives. Therefore, **the critical user's capacities for the interaction are related with: cognition, sensory, physical (movement, pulsation, etc.) and voice.**

Thus, studying the system interface, it is possible to identify its input and output communication channels; understanding these channels as the different ways a person and device can use to exchange information. In addition, it is needed to consider the cognitive process which governs the stimuli generation depending on the perceived stimuli and the current context. Attending to these processes, the evaluation of the usability, accessibility and functionality has been done as follows:

> **Accessibility** is defined by the ISO 9241-171 and 9241-20 (ISO 9241-171 2008, ISO 20282-1 2006) as "usability of a product, service, environment or facility by people with the widest range of capabilities" i.e. it describes how a system is available to a person. Thinking in the human-device interaction, this assessment has defined it in the next way: A system is accessible for a person if he/she can fully interact with it being able to access all of the functionalities, independently of the communication channel used. This interaction implies the perception and comprehension of the information exchanged. Therefore, in the design of the evaluation it is important to know the perception and comprehension of each channel by the user.
>
> **Usability** is defined by the ISO 9241-11 (ISO 9241-11 1998) as "Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." i.e. it assesses the complexity of handling the input and output channels of the system. This parameter is related with the cognitive, physical and sensorial capacities of the person. To assess this parameter, time and capability to resolve several situations as well as the direct user's opinion will be evaluated.
>
> **Functionality** evaluates if the system accomplishes the initial requirements, this means that the system covers the functions for which it was designed. In this case, main functionalities of the system are:
>
> - To facilitate the use of the household appliances adapting to the disabilities or preferences of the user and using adapted interfaces.
> - To provide useful information and warnings about the use of the household appliances.
> - To detect emergency situations and automatically take some actions: warn the user, switch off some appliances or request for help.

### 7.2.2. ASSESSMENT APPROACH

Evaluating an AAL system as the one developed poses several challenges. First, the system should be evaluated in a situation as close to its real usage as possible. Ideally, the best option would be to install the Smart Kitchen in the actual houses of the users to avoid introducing further complications which contribute to user disorientation. Furthermore, the Smart Kitchen should be tested for a long time (at least one year) in order to evaluate all the features as the QoLE. Additionally, the number of users should be enough to have a representative sample in order to extract significant assessment evidences.

All these factors have been considered inside the Easy Line Plus project as the frame of the development of this thesis. On the one hand, the assessment process was limited in time and number of users. Likewise, existing resources did not allow evaluating the system within the users' houses so assessment was performed under lab conditions. These labs, described in the section 7.3.1, simulate an environment close to a real situation; that is, the users' house. Main drawback of this evaluation design is the associated user disorientation because they are in an unknown kitchen with unknown appliances.

One of the possibilities raised in the University of Zaragoza's lab was to make a "long time" evaluation (one or two weeks) where users had enough time to become familiar with the environment. However, this possibility was discarded due to three reasons: by ethical issues, because the change of location could cause harmful implications in an elderly person (disorientation, loss of capacities, mobility problems in a unknown neighbourhood); by technical reasons, given the time limitation in the evaluation, the number of users involved is drastically limited and therefore, the relevance of their evaluation conclusions; by legal issues caused by any problem or risk that the person could suffer during the assessment.

It was finally decided to perform an evaluation where the user first had a brief period of training in the use of the system and then face four situations that may occur in the kitchen. These situations have been designed in order to allow evaluation of the main system's functionalities studying the interaction between user and system (See Annex III. Functionalities evaluated in each test situation):

> **Situation 1: "Coming home from shopping".** The participant comes home from shopping and he/she is required to store all the items from the shopping bag into the fridge, freezer or cupboards. One of the items is out of date.
>
> **Situation 2: "Making dinner".** The participant is asked to show a frozen pizza to the standalone reader so the interface identifies the item and asks the user if he/she wants to cook it. If yes, it goes to the set_oven_configuration with the needed parameters. Then the participant goes to the living room (maybe to watch TV) and is warned when the food in the oven is finally done cooking.
>
> **Situation 3: "Doing my laundry".** The participant is asked to do a laundry (simulated through the spinning program to avoid long waiting times) using different clothing items.
>
> **Situation 4: "My house is on fire".** The participant is resting and watching TV while the hob is on. The smoke detector is triggered simulating an emergency.

There are three people participating in the assessment whose roles have been defined as follows:

> The **user** is the person who will evaluate the technology.
>
> The test **moderator** leads the sessions being in charge of interacting with the participants and observing them during the testing. The moderator will introduce the session to the participants and realize several short interviews between the different situations tested. During the test he/she should be neutral. However, he/she can decide to help (for example if user is having a bad time in the interaction) and how much to help. Of course, if the test moderator takes part in the test, this situation will be logged.
>
> The test **observer** is watching the different situations evaluated without contact with the user, taking notes about the participants' performance and reactions. The observation notes are considered as "objectives" because they are not influenced by the user. Also, the observer will take note about any failure of the system.

Once the situations and people involved in the assessment are defined, it is necessary to design tools that will be used; tools are described in section 7.2.3. This process is based in the previous experience of the University of Glyndŵr evaluating the interfaces, adapting their concept to the current assessment and linking it with the human-device interaction model. Stages of the test are as following:

**Introduction:** Firstly, the moderator introduces the user (and to his/her carer if it is the case) the general objectives of the project and the assessment, explains the process, the estimated time length and the use of the recollected data. Then, the signature of an informed consent to participate in the evaluation is requested. Although participants have already received a written copy of this information, this step is necessary to ensure the person has really understood the purpose of the test and to verify that he/she agrees to it.

If the person agrees to proceed with the assessment, the moderator interviews the user filling the **Background Interview Questionnaire** (BIQ). This questionnaire has as objective to find and measure the relevant information about the person in order to characterize the user. It has been divided in four sections: Participant Information (gender and age, education level, etc.), household activities experience (use of appliances, autonomy in the household tasks, etc.), user capacities (disabilities, etc.) and technology experience (computer, mobile phone, etc.). This information is needed to perform a user characterization which allows comparing the results of the evaluation based on characteristics of the person. Finally, a brief training is done, in order to familiarize the user with the Smart Kitchen and with the experimentation environment.

**Performing the test.** As it has been mentioned, the user has to face four specific situations during the test. Each situation is explained by the moderator before starting the test. During its performance, the observer is taking notes about the user interaction with system. These notes are done in the **Situation Questionnaire** (SQx, where x takes the value of the number of situation). The observer, who also notes any relevant information happened during the test, fits the next questions: How long did the situation take? How many trials did the user need? Is the user able to perform the interaction(s) successfully? When each situation ends, the moderator interviews the user about the functionalities of the system which has been tested (no more than six questions). This way the users' impression is collected quickly after every situation in order to prevent mistakes and forgets.

**Final interview:** Once the user has completed the different scenarios, the moderator fulfils the **User Questionnaire (UQ)** in order to know the opinion of the user about his experience using the system. This debriefing interview is about asking broad questions, collect preferences and other quantitative data and also follow up on any particular problems that might came up during the experimentation. According to the evaluation objectives, the questions are focused on usability, accessibility and functionality, although other relevant parameters as reliability, satisfaction and future use/outcome are also considered. In the UQ the participants have the opportunity to freely share their remarks and criticisms about the system.

While the user and the moderator are filling the UQ, the observer does the same with the **Observation Form (OF)**. In this form he/she puts his/her impression about the user performance. The parameters evaluated in the OF are directly related with some questions in the UQ. Thus, it is possible to contrast the "objective" information from the OF with the "subjective" from the UQ.

In parallel with this process but the complementarily way, a survey was conducted to professional and family caregivers, in order to know their opinion about the main features of the system. To conduct this survey called **Caregivers Questionnaire (CQ)**, caregivers attended a presentation describing the operation of the system and visualized several videos with examples of use to, finally, proceed to complete the questionnaire.

### 7.2.3. DESIGN OF THE TOOLS

As it was shown, the assessment designed mixes quantitative and qualitative evaluation techniques implemented in four tools: Background Interview Questionnaire, Situation Questionnaires, Observation Form and User Questionnaire. In the next sections the elaboration of these tools is introduced, also a full copy of the tools is included in the Annex IV. Evaluation tools.

#### 7.2.3.1. BACKGROUND INTERVIEW QUESTIONNAIRE

The BIQ has as objective the user characterization to relate each individual to some standard capacities or lacking of such capacities. Categorization of such capacities can be done in different levels of depth and through different instruments such as Mini-Mental State Examination (Tombaugh, McIntyre 1992). Nevertheless, being realistic with the project objectives, it has been decided to take this information relying on individual expression on their own capacities.

As a result, each individual participating in the test would have a characterization vector where the elements would be the variables already defined: age, gender, visual capacity, aural capacity and so on. Each specific value in the variables will, a priori, influence how the interaction of the user with the system is. Nevertheless, due to education, experience or training, people with the same impairment might have completely different ways to cope with their daily tasks or upcoming situations. The background information gathered from the carers is the same but answering about the cared person instead of answering about themselves.

These parameters (except sex and age) have been ranged between 5 and 0 to be graphically represented. Thus, the user's profile can be presented as following:

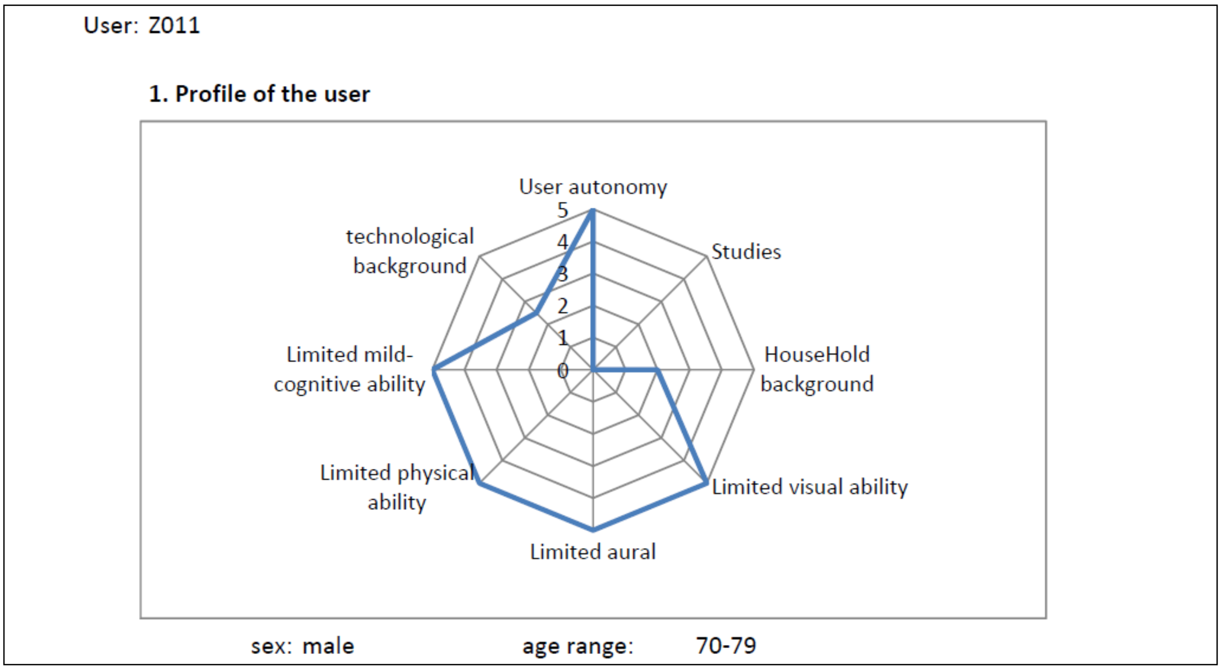



Figure 33 User's background information

Rationale of this graphic is very simple: Full octagon means that the person has all the parameters analysed with the best values. In this example, user Z011 has full autonomy, not any kind of disabilities, no studies, medium-low technological background and medium-low household activities' background. This information is also used to define the user profile in the test.

### 7.2.3.2. SITUATION QUESTIONNAIRES (SQ)

SQs have two purposes: on the one hand they evaluate the usability thanks to the notes of the observer about the interaction between user and system in each situation. This evaluation is based on three parameters: the time needed to complete the situation, the number of trials needed and the success in resolving the situation. In addition to these data, the observer may note any other information considered relevant.

On the other hand, SQ has been designed to evaluate the specific functionalities tested in each situation through a short questionnaire asking to the user. Next table shows an example of the situation 1:

| Situation 1: "Coming home with shopping" | | | |
|---|---|---|---|
| How long did the situation take? | | | |
| How many trials did the user need? | | | |
| Is the user able to perform the interaction(s) successfully? | Yes: ☐ | No: ☐ | Partly: ☐ |
| **Do you find these functionalities useful? (Ask to the user)** | **Yes** | **No** | **Partly** |
| Indication of fridge status | | | |
| Indication of fridge contents | | | |
| Support for configuration of fridge settings: target temperature | | | |
| Advise if the fridge door is left open | | | |
| Advise if the use-by date of food is exceeded | | | |
| Advise if food is approaching the use-by date | | | |

**Table 43 Extract from SQ1**

### 7.2.3.3. OBSERVATION FORM (OF)

OF has been designed in order to evaluate the accessibility, usability and user autonomy from a "realistic" point of view, filtering the impact of the user opinion about his capacities contrasting the information harvested in the UQ. First ten questions are related to the input and output channels of the system to evaluate the interaction between human and machine thinking in the system accessibility. From the user point of view, five communication channels have been identified in the interaction: two input channels (visual and aural) and three output channels (speaking, TV remote control and Touch Screen). Each channel has been evaluated in comprehension and perception. This way, the observer fills two questions about each one. For example, for the visual channel:

- Does the participant see and identify the icons/text?
- Does the participant seem to understand the meaning of written notifications including symbols and icons?

The usability of the system is evaluated through four questions from a global point of view. The objective of these questions is to know the observer's opinion about how the person has learned to handle the product, how complicated has been the interaction with the appliances and his confidence and degree of understanding of the system.

Finally three questions have been included in order to have arguments to check the BIQ information. These questions are related with the capacities of the person to perform task autonomously, to remember pending tasks and to identify different kinds of sounds related with systems notifications.

#### 7.2.3.4. USER QUESTIONNAIRE (UQ)

UQ is divided into six sections, one by parameter evaluated and some of them cross-related with previous forms. First section focuses on usability and through 5 questions user is inquired about the complexity, security and learnability of the interaction with the system. Next section is about accessibility and it is made up by 21 questions. In the same way than the OF, each communication channel is evaluated in perception and comprehension in order to know the user opinion. When the user says that he/she has a problem with one of the channels, complementary questions has been included to have more detailed information for the system designer. For example, in case of the visual channel, question 6 (Q6) is related to the perception and the question 7 (Q7) is inquiring in cause of a perception problem. It is the same for the comprehension of the visual elements where Q8 is related with it and Q9 is inquiring in cause of the problem. Note that the questionnaire can be shortened because questions 7, 8, and 9 do not need to be answered if the user has not used the channel (same for the rest of channels).

**6. Were the element/icons of the screen easy to see and identify?**

| Very difficult | Difficult | Normal | Easy | Very easy | Not used |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

(If you have selected "not used" discard next questions and go to #9)

**7. If you have had any difficulty, please, mark the features that have been a problem.**

| Colours | Contrast | Forms | Extracting form from the global set | Brightness | Size |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**8. Were elements/icons easy to understand?**

| Yes | No | Partially |
|---|---|---|
| ☐ | ☐ | ☐ |

**9. If you have had any difficulty, please, mark the elements that have been a problem.**

| Text | Icons | Other |
|---|---|---|
| ☐ | ☐ | |

Figure 34 Extract of accessibility questions of the UQ

Section three focuses on functionality and through four questions inquires the user opinion about the capacities of the product to increase the independent life of the person, to help the user in the activities of the daily living (ADL) or to increase the quality of life.

Sections four, five and six focus on performance (two questions), satisfaction (three questions) and future use (three questions) respectively. The objective of these sections is to know the user opinion about these relevant factors in order to technically improve it and plan its marketing possibilities. Also, at the end of the interview an open question about how the user thinks that the product could be improved has been added.

#### 7.2.3.5. CAREGIVER QUESTIONNAIRE (CQ)

Caregiver questionnaire has as main objective to have feedback from the carers about the system features. It has been divided in two sections:

i) **Participant information** asks the carer about her/his profile: sex, work place, professional profile, etc.

ii) **System evaluation** asks the carer about the system. Questions from 1 to 8 are general questions (note that the carers does not really handled the system) related with the carer opinion about usability, learnability, system cost, etc. Finally, question 9 is a numeric matrix where the functionalities of the system are evaluated. This last question is very interesting as it permits contrasting the user and caregivers opinions about system functionality.

### 7.2.4. INTERPRETATION OF RESULTS OF EVALUATION

Next table summarizes the content and purpose of the tools.

| Tool | Focused on | To … |
|---|---|---|
| Background Interview Questionnaire | Participant Information<br>Household activities experience<br>User Capacities<br>Technology Experience | Characterize the user |
| Situation Questionnaires | For all situations (Observer):<br>How long did the situation take?<br>How many trials did the user need?<br>Was the user able to perform the interaction(s) successfully?<br>In each situation (User):<br>User opinion about functionalities tested | Evaluate the usability and functionality |
| Observation Form | Observer opinion about the how the user interact with the system | Evaluate accessibility, usability and user autonomy |
| User Questionnaire | User's opinion about usability, accessibility and functionality, reliability, satisfaction and future use/outcome | Evaluate usability, accessibility, functionality and other parameters |
| Caregiver Questionnaire | Caregiver's opinion about generic aspect of the system related with usability, accessibility, reliability, satisfaction and future use/outcome.<br><br>Assessment of the functionalities of the system from the caregiver's point of view | Characterize the caregivers<br><br>Contrast the functionalities assessment from the point of view of the carers |

Table 44 Tools summary

These tools allow characterization of each user and assessment of how usable, accessible, and functional is the system for him/her.

a) Accessibility evaluation

Accessibility is evaluated studying the communication channels between user and system from the information in the UQ (user's perception) and the OF (observer's view). These questions, translated to numerical forms, will determine if the channel is accessible to the person following criteria shown in next table (it should be noted that a channel is accessible if it passes both, perceived and observed criteria:

| System Output Channels | Perceived | Observed | result |
|---|---|---|---|
| Visual perception and comprehension | Q6 and Q7>= 3 | P1 and P2 >=3 | Pass |
| Aural perception and comprehension | Q9 and Q10>= 3 | P3 and P4 >=3 | Pass |

| System Inputs Channels | Perceived | Observed | result |
|---|---|---|---|
| Speaking commands perception and comprehension | Q11 and Q12 >=3 | P5 and P6>=3 | Pass |
| TV remote control perception and comprehension | Q13 and Q14>= 3 | P7 and P8>=3 | Pass |
| Touch Screen perception and comprehension | Q15 and Q16 >= 3 | P9 and P10>=3 | Pass |

| General perception | Perceived | Observed | result |
|---|---|---|---|
| System perception and comprehension | Q17 and Q18 >= 3 | P11 and P12>=3 | Pass |

Table 45 Accessibility evaluation criteria

After evaluating accessibility of each channel, the system is considered accessible for a person when:

- at less one of the criteria of the System Output channels table passes
- at less one of the criteria of the System Input channels table passes
- the criteria of the general perception table passes

b) Usability evaluation

The usability of the system is determined based on the users' feedback, through the UQ and the observer's notes OF. The level of usability of the system is determined for each user by (Q1+Q2+Q3+Q4+Q5)/5 (where Qx are questions from the UQ, see Annex IV. Evaluation tools); that is, the arithmetic mean of the questions concerning usability of UQ. This score, with a value between 1 (not usable) and 5 (very usable) determine whether the system has a good usability for the user or not.

This information is contrasted with the notes taken by the observer in relation to the development time of each situation and the user's ability to carry them out. It is considered that the system is usable for a particular user if the score in usability is greater than or equal to 3 and the user has completed all the tests successfully. When the observer considers the person has taken too long to finish the situations the test is unsuccessful.

c) Functionality evaluation

The overall system functionality is determined based on the user feedback in UQ; given by the arithmetic mean of the questions concerning usability$((Q19+Q20+Q21+Q22)/4)$. A value between 1 (not functional) and 5 (very functional) will determine if the system has a good functionality for the user. This information will be contrasted with the notes taken by the observer who can consider the test is unsuccessful. It is considered that the system is functional for a particular user if the level of usability is greater than or equal to 3. This information has been contrasted with the caregivers' opinion in order to know both points of view.

d) Others parameters

User opinion about performance, satisfaction with the product and future outcome is provided by the information collected in the UQ. In the case of performance, the notes of the observer related with system fails are also considered. In the same way that with the rest of parameters, the system has a good performance/satisfaction/future use if its score is greater than or equal to 3.

Next table summarizes these evaluations:

| Parameter evaluated | User questionnaire | Other related parameters |
|---|---|---|
| Performance | (Q23+Q24)/2 | Notes on the observer about system failures |
| Satisfaction | (Q25+Q26+Q27)/3 | |
| Future use | (Q28+Q29+Q30)/3 | |

Table 46 Performance, satisfaction and future use

## 7.3. EVALUATION RESULTS

### 7.3.1. TEST PLACES

The evaluation of the system was done in two places: Spain and Wales. In Zaragoza, the study took place in a flat owned by the University of Zaragoza and located in a residential area. It was fully furnished and provided with all necessary facilities required to carry out any normal activities in everyday life. The testing environment was exclusively situated at the main entrance of the flat, in the living room (with the TV acting as user interface) and in the kitchen with the full deployment of the AAL.

Figure 35.Evaluation Pilot of the University of Zaragoza

At Glyndŵr University (Wales, U.K.), the study took place in the CAIR usability laboratory. There is a testing room with a one-way mirror to an observation room. The kitchen part of the room consists of a washing machine, an oven, a cooker hob and a fridge with the system.

Figure 36 Usability lab at Glyndŵr University.

## 7.3.2. ASSESSMENT PARTAKERS

### 7.3.2.1. Users

Sixty-three users have participated in the evaluation of the system. As it has been commented, disabled people younger than 59 years old have been recruited to increase the ratio of people with disabilities. A relevant limitation that hinders obtaining conclusions about the ability of the system to cope with specific disabilities is that users usually have more than one disability being very difficult to isolate the effects of each one over the system use. As described in section 7.2.3.1, each user has been parameterized in a radial graphic (Figure 33) simplifying the interpretation of these parameters. Next table describe the population participating in the evaluation[10]:

| | Characteristics | Recruited participants |
|---|---|---|
| **Impairments/Disability** | none: | 26 |
| | visual impairment: | 13 |
| | hearing impairment: | 13 |
| | cognitive impairment: | 12 |
| | motor impairment: | 23 |
| **Age** | <59: | 11 (3 male/8 female) |
| | 60–79: | 45 (17 male/28 female) |
| | 80+: | 7 (3 male/4 female) |
| **Gender** | Female: | 40 |
| | Male: | 23 |
| | **Total:** | **63 participants** |

Table 47 Recruited participants

[10]Note that a person could have more than one disability.

#### 7.3.2.2. Caregivers

Thirty-one caregivers have participated in the assessment of the system. This sample is composed for professionals and family carers from Wales and Spain, next figures show detailed information about their composition:

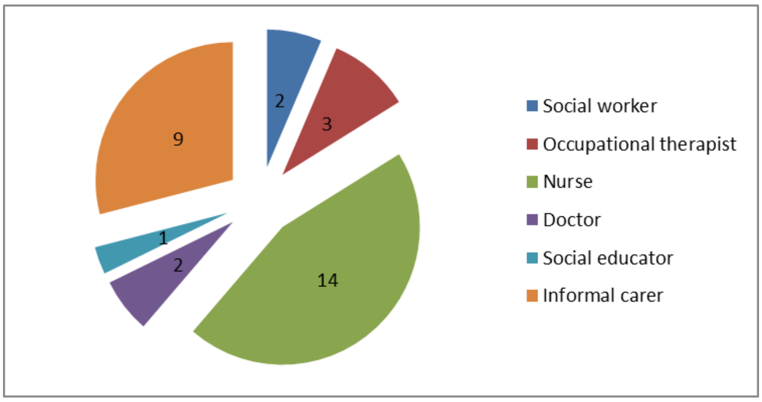



Figure 37 Caregivers' professional skill

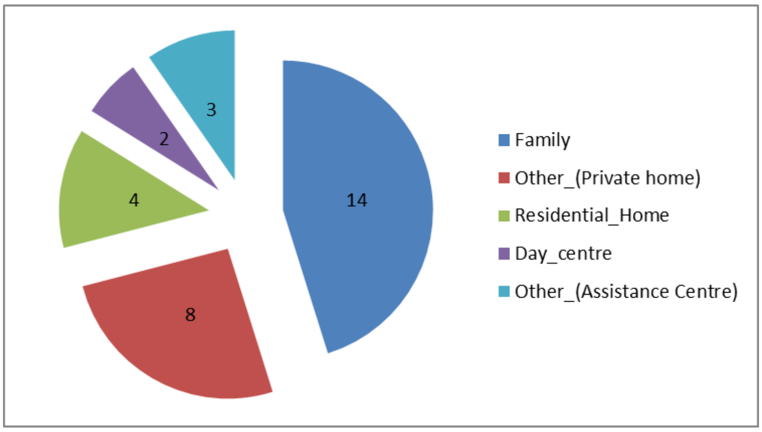



Figure 38 Caregivers' work place

### 7.3.3. SYSTEM DATA RESULTS

Data collected during testing were analysed using the process described in Section 7.2.4. Following, the results of the overall evaluation have been summarized; the detail about individual results of each person can be found in the website of the EL+ Project, in the D.7.2. (Blasco, Casas et al. 2010).

System **usability** perceived by users, shows that management of communication channels is not difficult for most people involved in the evaluation. The average score in usability is **3.85** with a confidence interval (95%) between 3 and 5. Observer annotations agree in this point. However, it should be noted that each user has selected the channel or channels of communication best suited to his/her needs. Following chart shows the selected input channels in the evaluations:

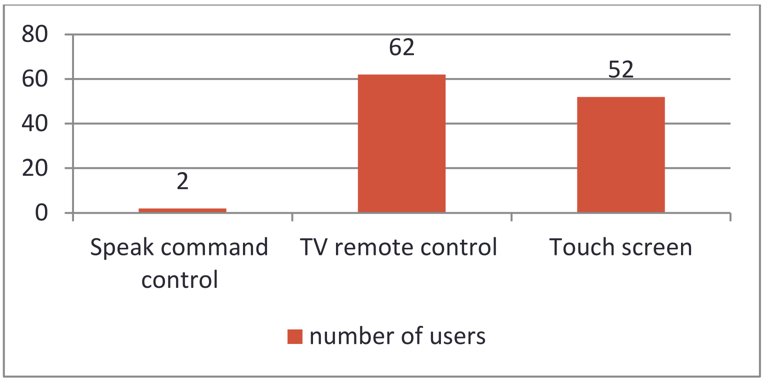



Figure 39 Preferred interfaces for the users

In this regard, note that the majority of users felt more comfortable using the remote control of television as interface, followed by the touch screen which has proven to be quite intuitive. By contrast, the use of voice commands have only been used by those users who really had problems with other interfaces.

Focusing on the system's **accessibility**, input and output channels have been evaluated calculating the average score perceived and observed with a confidence interval of 95%, with the following results:

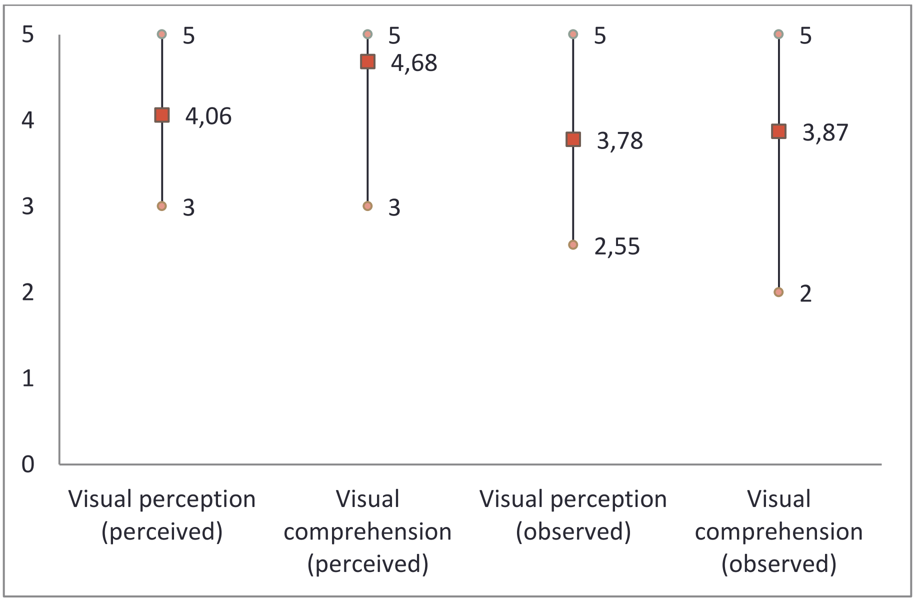



Figure 40 Visual output channel

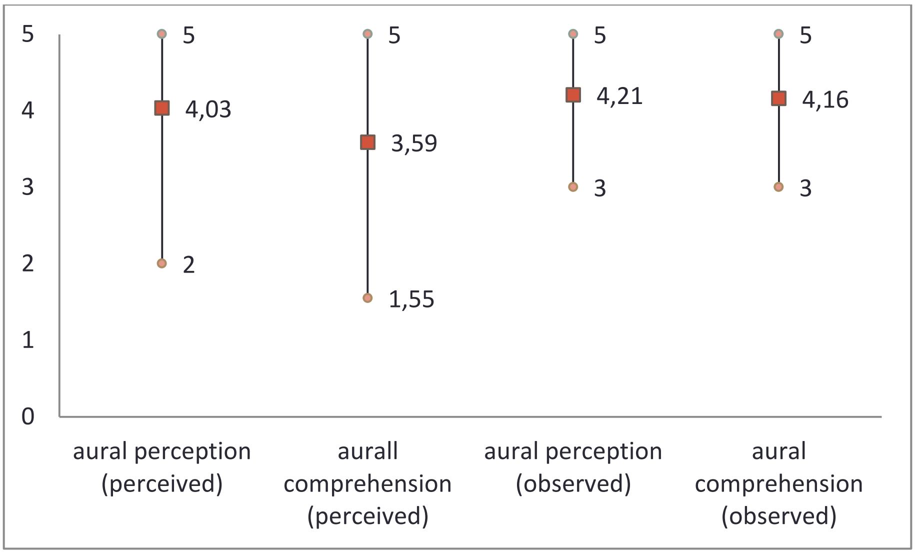



**Figure 41 Aural output channel**

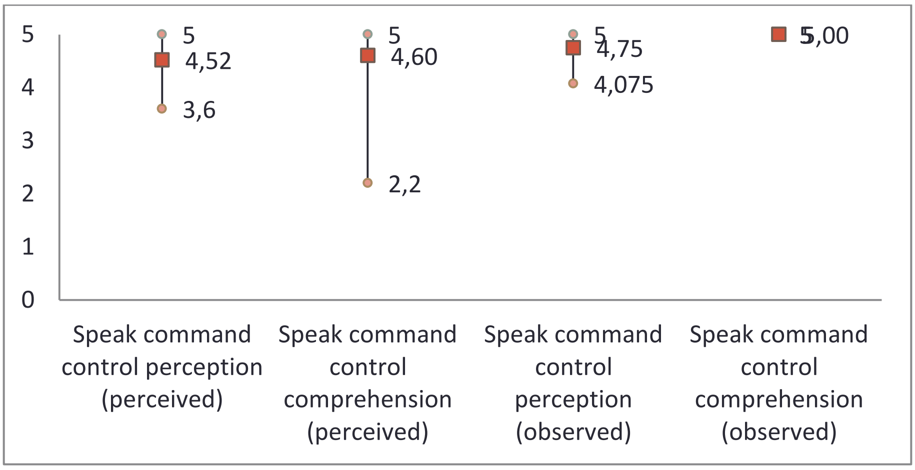



**Figure 42 Speak input channel**

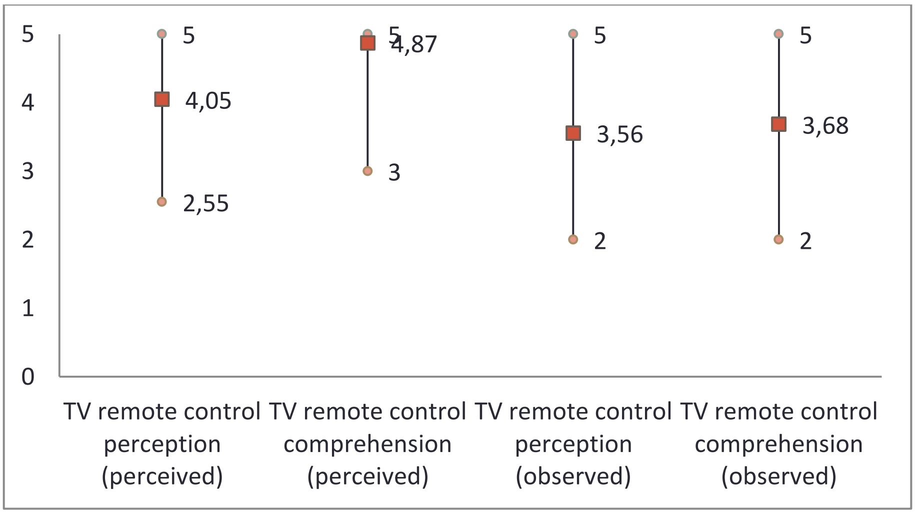



**Figure 43 TV remote control input channel**

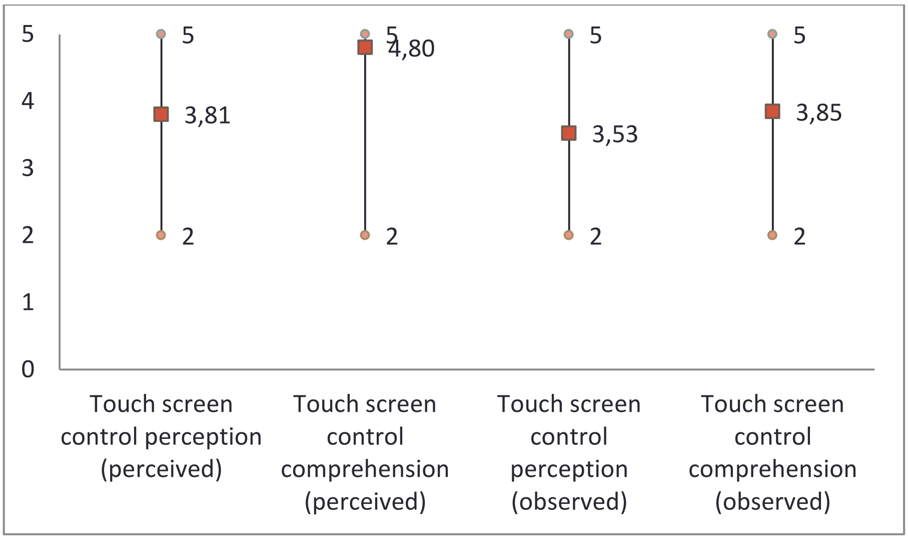



Figure 44 Touch screen control input channel

In general, the perceived accessibility is slightly higher than observed. Recalling the criteria set in the preceding sections, it was considered that the system is accessible to a person "*if s/he can fully interact with it being able to access to all the functionalities, independently of the communication channel used. This interaction implies the perception and comprehension of the information exchanged*". Analysing the results and considering that a channel is accessible for a user if its score is equal or greater than 3, at least one output channel (visual or aural) is accessible for 98,6% of users. Doing the same with the input channels (tactile, TV remote, spoken), one input channel is at least accessible for 92% of users. Therefore, the system is accessible for the people who can perceive and comprehend at least one input channel and one output channel; in this case **the system is accessible for the 90% of the sample**.

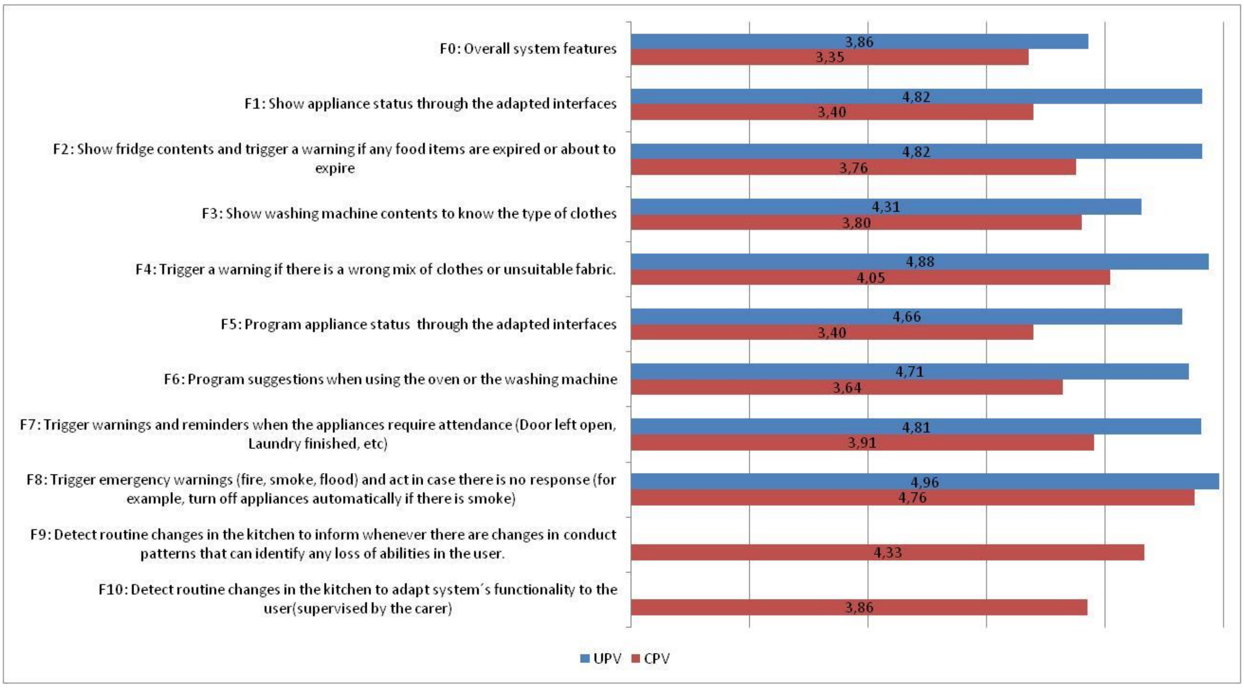



Figure 45 e-Servant functionalities evaluation. User & Carer opinion

In the case of the overall **functionality** of the system, the average score for this parameter is **3.49** with a confidence interval (95%) between 2.38 and 4.86. Contrasting the assessment of the individual features of the system done by the test participants with the opinion of the carers involved, it is possible to see that they agreed on several points. Figure 45 reflects these opinions from the viewpoint of users (UPV) and of caregivers (CPV).

For both, users and carers, “Trigger emergency warnings (fire, smoke, flood) and act in case there is no response” is the functionality rated the highest. For the carers this functionality is followed by “detect routine changes in the kitchen to inform whenever there are changes in conduct patterns that can identify any loss of abilities in the user”. Other functionality with a remarkable evaluation by the user is “Trigger a warning if there is a wrong mix of clothes or unsuitable fabric.”

The Figure 46 summarizes the evaluation of the rest of parameters. Performance of the system has been the parameter with worst score: 3,48 over 5. This data, which can be considered as a good result, has been qualified by the observer and by the technical people. The opinion about the future use of the product as well as satisfaction using it has been very positive with a score average close to 4.

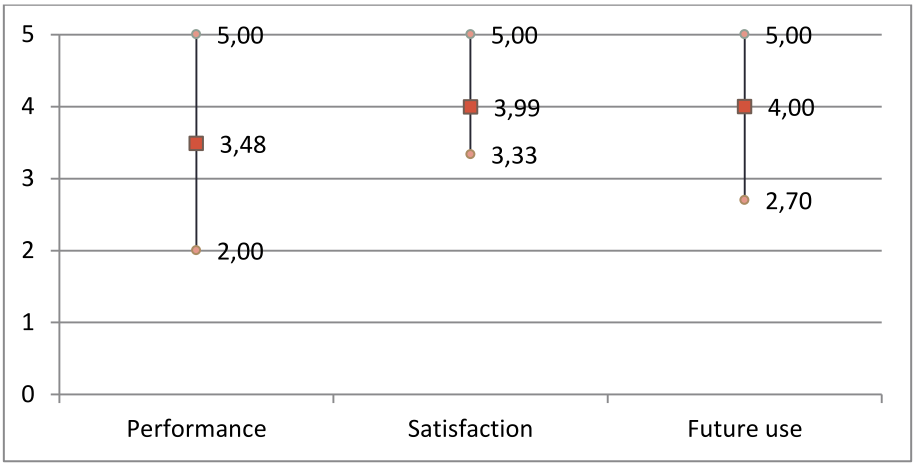



Figure 46 Performance, satisfaction and future use evaluations

### 7.3.4. ENHANCEMENT PROPOSALS OF THE SYSTEM AFTER THE EVALUATION

Users’ evaluation has been very useful to analyse the strengths and weaknesses of the system. Forms and interviews with users have allowed taking a lot of information about the system. Also, having real users handling the system have helped to detect unknown problems. Also, because the system was working continuously for a period longer than a month and interacting with many people, new problems related with the performance appeared.

Next table summarizes the actuations proposed to enhance the system after the user testing. They have been divided in two groups. One group related with the user interface and the intelligence of the system and the other group related with the context awareness:

| | |
|---|---|
| **User interface and intelligence** | To solve reliability problems detected thanks to the long-time user interaction<br>To improve the user feedback about the system status (network connection, etc.)<br>To improve the user feedback about the load/unload process of the washing machine<br>To add configurable interface themes and sounds<br>To display the changes in the content of the fridge in an easier way<br>Added several external communication channels to the system as SMS or e-mail |
| **Context awareness and intelligence** | To solve technical problems detected with RFID:<br>- Reliability problems<br>- Heating problems |

**Table 48 Improvement suggested**

## 7.4. EVALUATION CONCLUSIONS

The prototype of Smart Kitchen for AAL has been evaluated in **real environments** by **63 real end users** in order to spot any accessibility, usability, performance, etc. issues. Data from the evaluation has been analysed and enhancement proposals have been done to improve the system.

From the **accessibility point of view, 90% of the users can perceive and understand at least one input channel** (tactile screen, remote control or voice) and output channel (visual or aural) and 70% have the opinion that the system is accessible. **Usability of the system has been evaluated with a 3.85** over 5. Therefore we can conclude that the system has good usability and physical, sensory and cognitive accessibility. Several suggestions from the users have been taken in account to improve the accessibility and functionality of the system. **User's opinions about the future use (3.98/5) of the product as well as about their satisfaction (3.99/5) have been also very positive.**

Functionalities of the system has ben also assessed by **31 professionals and carers** directly working with end users. It was observed that both for beneficiaries and carers, the highest rated function of the system is security at home: "Trigger emergency warnings (fire, smoke, flood) and act in case there is no response". For the carers, this functionality is closely followed by "Detect routine changes in the kitchen to inform whenever there are changes in conduct patterns that can identify any loss of abilities in the user" as it can strongly improve the tools available to monitor the evolution of the elderly and disabled people. From the point of view of the beneficiaries security functions are followed by the reminder services "Trigger warnings and reminders when the appliances require attendance".

There are clear indicators that the **functionalities of the system have a big potential to support the user in several areas of the Activities of Daily Living (ADLs)**, reducing the dependence level of the person. This situation, consequently, could be useful to increase his/her time of independent life. The system can support the user in the ADLs' areas of carrying out domestic tasks (preparing a meal, doing the shopping and doing laundry/ironing) and making decisions (about domestic tasks). **Early detection of changes in routines would also help to monitor quality of life of the user in some aspects**. For example, it can be detected if the person is washing less often, which might indicate that he/she is wearing dirty clothes.

# CHAPTER 8: CONCLUSIONS AND FUTURE WORK

*Next section summarizes the conclusions of the work described in the thesis; highlights the most important contributions and proposes the future research lines in the different fields addressed. These contributions have been divided in two main areas: methodological with the results of the chapters 3 and 7, and technological, with the advances shown in the chapters 4, 5 and 6.*

## 8.1. INTRODUCTION

Deploying an AAL in the kitchen has a relevant impact increasing the autonomy of the person and their quality of life in their own homes. On the one hand, the kitchen is the place where relevant tasks for the autonomous life take place: cooking, clothes washing or food management. On the other hand, most household accidents happen in the kitchen, being elderly people more likely to suffer them (Angermann, Bauer et al. 2007, Van Den Broek, Cavallo et al. 2010). Therefore, by helping the elderly people in the kitchen it is possible to prevent domestic accident and contribute to increase their autonomy.

As presented in the review of the state of the art in chapter 2, creating and AmI in the kitchen is not a new idea. Several systems recognize user activities (Kranz, Schmidt et al. 2007, Lei, Ren et al. 2012), guide the user in the cooking process (Hashimoto, Mori et al. 2008, Siio, Hamada et al. 2007), guide the user to have a healthier diet (Chi, Chen et al. 2007, Chen, Chang et al. 2006, Chen, Chi et al. 2010), research in innovative user interfaces (Schwartze, Feuerstack et al. 2009), support the user to make the shopping list (Anastasopoulos, Niebuhr et al. 2005, Chen, Chang et al. 2006, Gárate, Herrasti et al. 2005, Pal Amutha, Sethukkarasi et al. 2012), provide cognitive assistance to help users storing and retrieving items in order to complete a recipe (Ficocelli, Nejat 2012) or research in user interfaces for people with disabilities considering the kitchen appliances as a part of the house's smart environment (Neßelrath, Haupert et al. 2011).

All systems present features that are interesting to build an AAL system in the kitchen; however to my best knowledge, none approaches the needs from an integral point of view. This is precisely the area where this PhD thesis makes its **main contribution to the current state of the art: the design and implementation of an innovative AAL architecture, associated context awareness infrastructure and intelligence and the final evaluation of the system with end users**. Main objective of the AAL system is to help elderly and/or disabled people to prolong the time of autonomous life, easing and simplifying their daily tasks in the kitchen while providing domestic accidents' support.

From a methodological perspective, this PhD thesis proposes an innovative methodology for identification of needs in the design of technology. This methodology is based in existing Human-Computer Interaction models and International Classification of Functionalities and derived from the conceptualization, systematization and generalization of the process followed in Easy Line Plus research project. Following the same rationale, the assessment methodology of the Smart Kitchen with real users is also designed and put into practice.

From a technical standpoint, the objective stated in this thesis has been successfully accomplished: the **design and development of an AAL system** that assists the user with his daily activities in the kitchen, simplifying them and helping him/her when necessary, detecting changes in his/her abilities. Also the developed system improves the user security in the kitchen, being able to offer a better answer in emergency situations. This work has been carried out considering market issues such as the need of remote updating and maintenance of the system and keeping costs within reasonable margins.

## 8.2. METHODOLOGICAL CONTRIBUTIONS

### 8.2.1. NEEDS IDENTIFICATION FOR THE DESIGN OF TECHNOLOGY FOR SPECIFIC POPULATION GROUPS

The identification of user needs is a crucial part of the design process of a project as it affects all subsequent development. Inside the research project, this identification was done through different instruments such as surveys and workshops, but without any defined methodology. During the drafting process of this PhD thesis and with the perspective that time provides in the review of a job done years ago, a systematization and a formal structuration of the methodology applied has been defined.

The methodology includes the interaction needs of a specific population in the design process in three steps: a user characterization, interaction characterization and final identification of the users' needs. It is based on the Interaction framework proposed by Abowd and Beale and supported by the International Classification of Functionalities (ICF) taxonomy, considering which factors influence and describe them in a standardized language. The approach facilitates obtaining standardized and comprehensive needs which simplifies definition of functional specifications easing the results comparison.

Use of ICF language in the characterization of the specific population and the subsequent interaction is also a relevant result by itself as can be reused in the design of assessment of the product. It also permits an iterative process of improvement of the interaction with the product or service as new target groups can be included in order to identify further needs.

In addition, as a systematic way to find indicators that hinders the interaction between person and technology, the methodology enhances the multidisciplinary work of the actors involved in the design process. On the one hand, it helps designers and technologists to understand the capabilities of the target population and the difficulties they currently have to perform the functions that are to be covered by the new product. On the other hand, personnel close to the user can understand limitations and possibilities of technology.

### 8.2.2. TECHNOLOGICAL ASSESSEMENT WITH REAL USERS

Evaluation of technology with elderly and disabled people is a discipline by itself. Although there are assessment tools with different levels of standardization, the usual practice is to adapt them according to the needs of the product evaluation. This thesis defines a methodology for the assessment of system's accessibility, functionality and usability. It combines quantitative and qualitative tools —interviews, questionnaires and objective observations— to obtain complete results in the assessment, spot strengths and weaknesses of the system and provide information for future redesigns.

The prototype of Smart Kitchen for AAL has been evaluated in real environments by sixty-three real end users and thirty-one caregivers with good results: the system has been accessible for the 90% of the sample, the usability score has been evaluated with a 3.85 over 5 and its functionalities have been evaluated with a 3.49 over 5. Users and caregivers agree in the system capabilities to support the user in several areas of the Activities of Daily Living (ADLs), reducing the dependence level of the person. Trigger emergency warnings and detect routine changes have been the functionalities better valued.

## 8.3. TECHNICAL CONTRIBUTIONS

### 8.3.1. SYSTEM ARCHITECTURE

The architecture has been one of the main challenges in the system design. It supports interoperability between equipment from different manufacturers and technologies from appliances, sensors or tele-care systems enabling the whole system to work as one device. The OSGi-based Service-Oriented Architecture allows easily adding new ranges of appliances, sensors, user's interfaces, logic rules or new services.

As the system's intelligence is centralized in the e-Servant and the interfaces are not embedded in appliances, independent evolution of each part of the system is enabled and simplified. The appliances only need communication and control capabilities to be integrated in the AAL system, decreasing their cost and allowing that new appliances with new features to be integrated in the system. In order to validate the system concept within the most challenging conditions, as much communication media as possible has been integrated: Power Line Communication (PLC) for the white goods, RFID for item identification, ZigBee as wireless sensor network, infrared for the remote control, Bluetooth for audio streaming and Ethernet (WiFi and cable) for cloud and user interaction. Regarding the system interfaces, as they are based on web server, they can be used in any fixed device, tablet or smartphone with an operating system supporting Flash.

### 8.3.2. CONTEXT AWARENESS AND MODELLING

Gathering information from the user and the environment in a non-intrusive way and at a reasonable cost is one of the current challenges in the development of AmI. In this case, commercial sensors have been introduced to ensure detection of events related to the user safety (fire detectors, smoke and flooding). The user is monitored through infrastructure sensors (presence and light) and also personal sensors (tag) enabling location and user fall detection. Kitchen appliances' capabilities (fridge, washing machine) have been improved through RFID readers.

All these devices, including kitchen appliances, have been modelled following the taxonomy known as OSGi4AmI. Thus, their virtual handling is made based on the nature of the device and its functionalities which have been grouped in several clusters. This design approach together with the flexibility and power of the architecture, allows isolating the device technology from its management. That is, for the high-level layers of e-Servant, it is indifferent that a presence sensor is wired or ZigBee because both will report events using the same methods. This easily allows adding new devices, changing sensor or appliance supplier, standardizing and isolating the application development of the infrastructure deployment.

Furthermore, innovative context awareness services have been tested and evaluated: fall detection and indoor location with non-dedicated ZigBee networks. These services have been proven in real situations, validated their algorithms, and implemented (as an architectural proof of concept) in the system.

### 8.3.3. SYSTEM INTELLIGENCE

The original requirement was to make system's intelligence adaptive to fit the person's capabilities. However, in the system design iterations, social-health professionals pointed out that this feature would confuse users and strongly advised against its implementation. This decision caused that the auto-adaptive capabilities of the system was moved to the analysis of the quality of life evaluation (QoLE) tool. Thus, the carer of the elderly has the responsibility of adjusting the user level according to the QoLE report and his/her opinion. Concept and design of the QoLE system (areas of interaction and relevant information derived from user needs) and implementation of the data-retrieving layers of the system are the contribution of this PhD work.

Following experts recommendations, intelligence of the system was based in deterministic rules which support the users in their activities: for each user level, same context and interaction, the system will always behave the same. These rules have been implemented in the Logic Unit to take decisions depending on the context in order to help the user in his/her activities in the kitchen. The design and implementation of these rules is based in the detailed study of the interaction between the user and each one of the appliances. This analysis, reflected in the needs' identification in chapter 3, is covered by the design of the logic rules present in the chapter 6. These rules also served as indicators which stated that the use of AAL in the kitchen could increase the independent lifetime of the person.

## 8.4. PAPERS AND PATENTS

Next, main publications related with the work done in this thesis are enumerated (5 congress contributions, 1 book chapter and 1 indexed paper) explaining their relation with the same. Also, due to this work is framed in a European Research Project, Easy Line +, where there are industrial interests, part of the results have been embodied in 4 European patent applications.

### 8.4.1. USER AND CONTEXT MODELING

This book chapter presents the OSGi4AmI taxonomy in which definition I worked as member of the University of Zaragoza Team, headed by Alvaro Marco, and that afterwards has been applied and extended in this thesis (section 5.3.2).

- MARCO, A., CASAS, R., BAUER, G., BLASCO, R., ASENSIO, A., JEAN-BART, B. and IBAÑEZ, M., 2009. Common OSGi interface for ambient assisted living scenarios. In: B. GOTTFRIED and H. AGHAJAN, Behaviour Monitoring and Interpretation – BMI - Smart Environment. Netherlands: IOS Press. Doi:10.3233/978-1-60750-048-3-336 (Marco, Casas et al. 2009).

  Abstract:
  Ambient Assisted Living (AAL) is currently being studied by research institutions and industry, and it is expected to become a reality in the near future. One of the main issues in AAL is the heterogeneity of technology, which demands a major effort to allow interoperability of elements operating in a smart environment. Service-oriented frameworks such as OSGi provide beside other interesting facilities an adequate way to handle this heterogeneity and are often used as framework platforms which support smart home environment systems. However, there is also heterogeneity among different AAL projects, as every research team develops its own smart environment. Thus, devices and services definitions usually differ from one project to another. In the following a proposal for a Common OSGi Interface is introduced, which publishes both interfaces for devices and services of AAL related scenarios. By using these interfaces, an AAL application designer will be able to take advantage of existing device and service developments and ensure interoperability with other systems.

Next congress contribution summarizes the user modelling work done in the Easy Line Project in which I worked as member of the University of Zaragoza Team.

- CASAS, R., BLASCO, R., ROBINET, A., DELGADO, A., YARZA, A. and MCGINN, J., 2008. User Modelling in Ambient Intelligence for Elderly and Disabled People. Computers Helping People with Special Needs (pgs.114-122), (10.). (Casas, Blasco et al. 2008)

  Abstract:
  Combining ongoing Ambient Intelligence (AmI) technological developments (e.g. pervasive computing, wearable devices, sensor networks etc.) with user-centred design methods greatly increases the acceptance

of the intelligent system and makes it more capable of providing a better quality of life in a non-intrusive way. Elderly people could clearly benefit from this concept. Thanks to smart environments, they can experience considerable enhancements, giving them an opportunity to live more independently and for longer in their home rather than in a health-care centre. However, to implement such a system, it is essential to know for whom we are designing. In this paper, we present an intelligent system with a monitoring infrastructure that will help mainly elderly users with impairments to overcome their handicap. The purpose of such a system is to create a safe and intuitive environment that will facilitate the achievement of household tasks in order to preserve independence of elderly residents for a while longer. Pursuing this goal, we propose to use the persona concept to help us build a user model based on the personas' aptitudes. The practice of user modelling emphasizes the importance of user-centred techniques in any AmI system development and highlights the potential impacts of AmI for certain targeted groups - in this case, the elderly and people with disabilities.

### 8.4.2. DATA CONTEXT PROCESSING

Next congress contributions collect the results of the fall detector and indoor location techniques presented in the section 5.2

- BLASCO, R., CASAS, R., MARCO, Á., COARASA, V., GARRIDO, Y., FALCÓ, J.L, 2008. Fall Detector Based on Neural Networks, in Proceedings of the International Conference on Bio-inspired Systems and Signal Processing BIOSIGNALS, 2008, pp. 540-545. (Blasco, Casas et al. 2008)

  Abstract:
  Falls are one of the biggest concerns of elderly people. This paper addresses a fall detection system which uses an accelerometer to collect body accelerations, ZigBee to send relevant data when a fall might have happened and a neural network to recognize fall patterns. This method presents improved performance compared to traditional basic-threshold systems. Main advantage is that fall detection ratio is higher on neural network based systems. Another important issue is the high immunity to events not being falls, but with similar patterns (e.g. sitting in a sofa abruptly), usually confused with real falls. Minimization of these occurrences has big influence on the confidence the user has on the system.

- BLASCO, R., MARCO, Á, CASAS, R., IBARZ, A., COARASA, V. and ASENSIO, Á, 2009. Indoor localization based on neural networks for non-dedicated ZigBee networks in AAL. Bio-Inspired Systems: Computational and Ambient Intelligence, pp. 1113-1120.

  Abstract:
  Indoor localization is one of the most appealing technologies in Ambient Assisted Living (AAL) applications, providing support for diverse services such as personal security, guidance or innovative interfaces. Dedicated systems can be deployed to provide that information, but it is possible to gain advantage of available elements to compute a location without requiring additional hardware. In this paper, a ZigBee network designed for a home control application is improved with a localization functionality based on neural networks, achieving room-level accuracy, and non-introducing additional infrastructure constraints to the original application.

### 8.4.3. ARCHITECTURE

The following congress contribution reflects the architecture developed in Easy Line +, which is explained in the section 4.2. It is presented from a conceptual point of view, based on a multi-agent system. This abstraction was done in collaboration with Armando Roy Delgado.

- ROY DELGARDO, A., BLASCO, R., MARCO, A., CIRUJANO, D., CASAS, R., ROY YARZA, A., GROUT, V. and PICKING, R., 2010. Agent-based AmI System Case Study: The Easy Line Project. Advances in Soft Computing: Trends in Practical Applications of Agents and Multiagent Systems. pp. 157-164. (Roy Delgardo, Blasco et al. 2010)

  Abstract:
  Smart environments include context-aware computing to enhance system capabilities which affect user interaction positively. A context-aware application should collect contextual information through different ways depending on technology availability and handle this information adequately to execute actions or warnings, present information or modify the environment. Ambient intelligence (AmI) habitually means system complexity and heterogeneity. This paper describes an AmI system case-study, developed for the Easy Line + project, a decentralized intelligence carefully structured in agents grouped by roles in domains to improve system package interaction and integration.

### 8.4.4. REASONING

The first two patent applications, **Assembly and method for monitoring at least one household appliance** and **Method for monitoring and Assembly a set of household appliances**, protect the developments made in the intelligence of the system, being a direct result of the thesis. The following two patents: **Refrigerator and method for operating a refrigerator** and **Washing machine and Method for operating a washing machine**, include the intelligence associated with each of these appliances, direct contribution of this thesis, and the developments of new sensors (RFID, temperature, magnetic sensor, etc..), in which I have partially contributed.

- AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., COARASA, V., FALCO, J., GROUT, V., HASSAN, R., IBARZ, A., MARCO, A., PICKING, R. and ROY, A., 2011a. Assembly and method for monitoring at least one household appliance. EP 2302312 A1. (Arozarena, Asensio et al. 2011).

  Summary:
  The invention refers to an assembly for monitoring at least one household appliance which comprises a control unit which detects at least one product parameter with respect to goods, e.g. food or laundry, inserted into said household appliance, and/or an operational parameter of said household appliance. Said control unit is linked with a monitoring unit which generates a user profile on the base of the detected parameter. In said user profile said parameter is stored depending on the time, wherein a deviation of user activities relating to said household appliance from said user profile is detectable by said monitoring unit.

- AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., FALCO, J., GROUT, V., IBARZ, A., MARCO, A., PICKING, R. and ROY, A., 2011b. Assembly and method for monitoring a set of household appliances. EP 2302605 A1. (Arozarena, Asensio et al. 2011).

  Summary:
  The invention refers to an assembly for monitoring a set of household appliances each of which comprises a control unit which can detect operational and/or product parameters of the household appliances. According to the invention, the household appliances are linked to a central monitoring unit which generates a user profile on the base of said operational and/or product parameters detected by the control units of the household appliances. In said user profile said parameters are stored depending on the time. Therefore, on the base of said user profile the handling of the household appliances by the user can be simplified.

- AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., FALCO, J., IBARZ, A., MARCO, A., HASSAN, R., NITSCHE, K., KRAHMER, M. and SMIRNOV, A., 2011c. Refrigerator and method for operating a refrigerator. EP 2306129 A1. (Arozarena, Asensio et al. 2011).

  Summary:
  The invention refers to a refrigerator including a refrigerator control which comprises at least one sensor for detecting at least one operational parameter, e.g. cooling compartment temperature, and at least one sensor for detecting at least one product parameter of products introduced into said refrigerator. According to the invention said refrigerator control comprises an analysing unit by which the refrigeration power of said refrigerator can be configured on the basis of a combination of said product and operational parameters. The analysing unit is also able to inform the user about noticeable events such as oversights, relevant product information, refrigerator malfunctioning, relevant changes in product stock and relevant changes in user behaviour.

- AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., MARCO, A., HASSAN, R., NITSCHE, K., KRAHMER, M., SMIRNOV, A., ARTIGAS, J.I. and COARASA, V., 2011d. Washing machine and method for operating a washing machine. EP 2302122 A1. (Arozarena, Asensio et al. 2011).

  Summary:
  The invention refers to a washing machine including a washing machine control which comprises at least one sensor for detecting at least one operational parameter, e.g. status of the appliance door, a washing temperature and/or the rotational speed of the washing drum, and at least one sensor for detecting at least one product parameter of laundry introduced into said washing machine. The washing machine control comprises an analysing unit to which said operational and product parameters (P, SD, TW) are transmitted and which supports the user when selecting the laundry to be introduced into said washing machine. The analysing unit is also able to inform the user about noticeable events such as washing machine malfunctioning, introduced laundry not suitable to be machine washed, incompatibility of introduced laundry with a program selected by the user and/or a bad mix of clothes introduced into said washing machine. It can also warn a career when the user is not using the washing machine as usual.

### 8.4.5. QUALITY OF LIFE EVALUATION SYSTEM

Next congress contribution shows the QoLE System concept and validation based on Artificial Neural Network. It presents the work done in this system, described in the section 6.4, as well as their implementation and validation with pseudo-random data.

- BONO NUEZ, A., MARTÍN DE -BRÍO, B., BLASCO MARÍN, R., CASAS NEBRA, R. and ROY YARZA, A., 2009. Quality of Life Evaluation of Elderly and Disabled People by Using Self-Organizing Maps. Distributed Computing, Artificial Intelligence, Bioinformatics, Soft Computing, and Ambient Assisted Living, pp. 906-913. (Bono Nuez, Martín del Brío et al. 2009).

  Abstract:
  Elderly people usually have some disabilities that get worst with the years. Many times these disabilities difficult the tasks carried out in a normal independent life, as is the case with home tasks. In addition, about one fourth of the household accidents happen in the kitchen. Within the framework of a European project – Easyline plus-, we have developed a tool to evaluate the quality of life of elderly people based on kitchen activity, extracted from data provided by the appliances. Such a tool has found to be very useful for social careers in order to monitor elderly activity, and as an objective support for diagnosis of the evolution of the personal abilities and autonomy of the user.

### 8.4.6. EVALUATION

Although the user interface is beyond the scope of this thesis, little contribution to their evaluation have been done in the course of the Easy Line Plus project. Next indexed paper (Impact factor in 2011, 0.33) shows this evaluation.

- PICKING, R., ROBINET, A., McGINN, J., GROUT, V., CASAS R. and BLASCO, R. The Easyline+ project: evaluation of a user interface developed to enhance independent living of elderly and disabled people. Universal Access In The Information Society. Volume 11, Number 2 (2012), 99-112, DOI: 10.1007/s10209-011-0246-8. ISSN: 1615-5289. (Picking, Robinet et al. 2012).

  Abstract:
  This paper reports the usability evaluation of interfaces developed to enable elderly and disabled people interact remotely with kitchen appliances in the home to enhance their independent living. A number of evaluation exercises were undertaken throughout the project's development, including user-participative workshops and focus groups. This paper focuses on the summative usability evaluation exercise, which comprised a laboratory-based study in a simulated home environment, with a view to determining the appropriateness of employing this approach with potentially vulnerable participants. The study involved 27 participants interacting with the user interface. Their behaviour was observed and recorded, and their interaction with the system was analysed. They were also given a post-session questionnaire, where their opinions of the usability of the interface were solicited. The results of the usability testing were positive, and insight has been gained into how products of this nature can be further improved. The experience of conducting laboratory-based studies with vulnerable users was positive and led to propose in this paper a set of guidelines for future work in evaluating usability for work in this domain.

## 8.5. FUTURE WORKS

This PhD thesis opens several lines of future work. The first one would export the developed system from the kitchen to the entire house supporting all possible activities of daily living. It would be also possible to improve the facilities and services offered by the e-Servant; for example, adding remote services such as online shopping, leisure and interaction between users which can bring new perspectives of use, etc. In this line, fall detection and indoor localization with non-dedicated ZigBee networks could be implemented and validated within the system. In this regard, we are working on getting funding through R&D calls in order to extend the system involving companies that can create a commercial product of it.

Also, the implementation of the OSGi4AmI developed in the firmware of the devices opens the door to the second iteration of OSGi4AmI in order to obtain a virtual representation of these devices which considers the hardware capabilities, embedding it in the same sensor. This way eases the standardization and virtualization of the devices, being closer to the Internet of Things paradigm.

Another open research line with the development of this PhD thesis is the possibility of conducting a study of the quality of life of the person through objective analysis of the user behaviour. Detecting lifestyle changes which could be indicators of capacities loss, opens a world of possibilities to explore. However the case, this line of research should be addressed from a multidisciplinary perspective including social-health professionals. This would allow comparing the results obtained with the support of technology with those obtained with conventional methods and therefore to assess their efficiency and usefulness.

Finally, it is considered to extend the detection of needs' methodology and its associated principles to the evaluation. Final objective would be developing a tool for the design and evaluation of technology for specific populations methodologically consistent.

## REFERENCES


AAL ASSOCIATION, 22/2/2013, 2013-last update, AAL European Program. Available: http://www.aal-europe.eu/.

AARTS, E. and ENCARNAÇÃO, J.L., 2006. Into Ambient Intelligence. *True Visions.* Springer Berlin Heidelberg, pp. 1-16.

AARTS, E. and WICHERT, R., 2009. Ambient Intelligence. In: H. BULLINGER, ed, *Technology Guide.* Springer Berlin Heidelberg, pp. 244-249.

ABOWD, G.D., 1991. *Formal Aspects of Human-Computer Interaction. Thesis submitted for the degree of Doctor of Philosophy*, University of Oxford.

ABOWD, G.D., BEALE, R., DIAPER, D. and HAMMOND, N., 1991. Users, systems and interfaces: A unifying framework for interaction, *People and Computers VI: HCI'91: Usability Now: Proceedings of the British Computer Society Special Interest Group on Human-Computer Interaction* 1991, Cambridge University Press, pp. 73-87.

ANASTASOPOULOS, M., NIEBUHR, D., BARTELT, C., KOCH, J. and RAUSCH, A., 2005. Towards a reference middleware architecture for Ambient Intelligence systems, *ACM conference on object-oriented programming, systems, languages, and applications* 2005.

ANDRUSHEVICH, A., KISTLER, R., BIERI, M. and KLAPPROTH, A., 2009. ZigBee/IEEE 802.15.4 Technologies in Ambient Assisted Living Applications, *3rd European ZigBee Developers' Conference (EuZDC)* 2009.

ANGERMANN, A., BAUER, R., NOSSEK, G. and ZIMMERMANN, N., 2007. *Injuries in the European Union. Statistics Summary 2003-2005.* Vienna, Austria: Austrian Road Safety Board.

AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., COARASA, V., FALCO, J., GROUT, V., HASSAN, R., IBARZ, A., MARCO, A., PICKING, R. and ROY, A., 2011. Assembly and method for monitoring at least one household appliance, EP2302312 (A1).

AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., FALCO, J., GROUT, V., IBARZ, A., MARCO, A., PICKING, R. and ROY, A., 2011. Assembly and method for monitoring a set of household appliances, EP2302605 (A1).

AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., FALCO, J., IBARZ, A., MARCO, A., HASSAN, R., NITSCHE, K., KRAHMER, M. and SMIRNOV, A., 2011. Refrigerator and method for operating a refrigerator, EP2306129 (A1).

AROZARENA, A., ASENSIO, A., BLASCO, R., CASAS, R., MARCO, A., HASSAN, R., NITSCHE, K., KRAHMER, M., SMIRNOV, A., ARTIGAS, J.I. and COARASA, V., 2011. Washing machine and method for operating a washing machine, EP2302122 (A1).

AUGUSTO, J.C., NAKASHIMA, H. and AGHAJAN, H., 2010. Ambient intelligence and smart environments: A state of the art. *Handbook of Ambient Intelligence and Smart Environments.* Springer, pp. 3-31.

AZTIRIA, A., IZAGUIRRE, A. and AUGUSTO, J.C., 2010. Learning patterns in ambient intelligence environments: a survey. *Artificial Intelligence Review,* **34**(1), pp. 35-51.

BALLANTINE, J.A., GALLIERS, R.D. and STRAY, S.J., 1996. Information systems/technology evaluation practices: evidence from UK organizations. *Journal of Information Technology,* **11**(2), pp. 129-141.

BARTRÉS-FAZ, D., CLEMENTE, I. and JUNQUÉ, C., 1999. Alteración cognitiva en el envejecimiento normal: nosología y estado actual. *Revista de neurología,* **29**, pp. 64-67.

BAUER, G., STOCKINGER, K. and LUKOWICZ, P., 2009. Recognizing the use-mode of kitchen appliances from their current consumption, *Smart sensing and context* 2009, Springer, pp. 163-176.

BEECHER, V. and PAQUET, V., 2005. Survey instrument for the Universal Design of consumer products. *Applied Ergonomics,* **36**(3), pp. 363-372.

BEYER, H. and HOLTZBLATT, K., 1997. *Contextual design: defining customer-centered systems.* Morgan Kaufmann.

BHATTI, S., CARLSON, J., DAI, H., DENG, J., ROSE, J., SHETH, A., SHUCKER, B., GRUENWALD, C., TORGERSON, A. and HAN, R., 2005. MANTIS OS: An embedded multithreaded operating system for wireless micro sensor platforms. *Mobile Networks and Applications,* **10**(4), pp. 563-579.

BLASCO, R., CASAS, R., FALCÓ, J.L., GROUT, V. and PICKING, R., 2010. *D.7.2. Report with the results of the end users' test. Easy Line Plus Project public deliverable. Available: http://www.easylineplus.com/.*

BLASCO, R., CASAS, R., MARCO, Á, COARASA, V., GARRIDO, Y. and FALCÓ, J.L., 2008. Fall Detector Based on Neural Networks, *Proceedings of the International Conference on Bio-inspired Systems and Signal Processing BIOSIGNALS* 2008, pp. 540-545.

BLASCO, R., MARCO, Á, CASAS, R., IBARZ, A., COARASA, V. and ASENSIO, Á, 2009. Indoor localization based on Neural Networks for non-dedicated ZigBee networks in AAL, *Bio-Inspired Systems: Computational and Ambient Intelligence* 2009, Springer, pp. 1113-1120.

BLUETOOTH, 2012-last update, Bluetooth Technology Web Site. Available: http://www.bluetooth.com/Pages/Bluetooth-Home.aspx, 2012.

BONO NUEZ, A., MARTÍN DEL BRÍO, B., BLASCO MARÍN, R., CASAS NEBRA, R. and ROY YARZA, A., 2009. Quality of Life Evaluation of Elderly and Disabled People by Using Self-Organizing Maps, *Distributed Computing, Artificial Intelligence, Bioinformatics, Soft Computing, and Ambient Assisted Living* 2009, Springer, pp. 906-913.

BONO NUEZ, A. and ROY YARZA, A., 2008. *Evaluación de la calidad de vida de ancianos y discapacitados mediante técnicas de reconocimiento de patrones y mapas autoorganizados*, Universidad de Zaragoza.

BOTTS, M., PERCIVALL, G., REED, C. and DAVIDSON, J., 2008. OGC® Sensor Web Enablement: Overview and High Level Architecture. In: S. NITTEL, A. LABRINIDIS and A. STEFANIDIS, eds, *GeoSensor Networks.* Springer Berlin Heidelberg, pp. 175-190.

BSH, 2012-last update, BSH Electrodomésticos España, S.A. Available: http://www.bsh-group.es.

BSH, 2007-last update, Siemens Serve@Home home management system | Appliancist. Available: http://www.appliancist.com/accessories/siemens-home-management-system.html, 2012.

CARETECH, 2011, 2012-last update, Digital Carephone CareIP. Available: http://www.caretech.se/en-careip/en-digital-carephone-careip.html, 2012.

CASAS, R., BLASCO, R., GROUT, V., PICKING, R., ROBINET, A., HASSAN, R., MARCO, A. and ROY, A., 2009. *D.1.1.Definition of end users and technical requirements.Easy Line Plus Project public deliverable. Available: http://www.easylineplus.com/.*

CASAS, R., BLASCO, R., LAÍN, L., MARTÍN-DEL-BRÍO, B., BONO, A. and MARCO, A., 2009. *D.3.2. Design, architecture, development and test of e-servant. Easy Line Plus Project confidential deliverable.*

CASAS, R., BLASCO, R., VAQUERIZO, E., FALCÓ, J.L., GARRIDO, Y., PICKING, R., GROUTH, V., ROBINET, A. and ROY DELGADO, A., 2010. *D.7.1. End Users Evaluation Protocol. Easy Line Plus Project confidential deliverable.*

CASAS, R., BLASCO, R., ROBINET, A., DELGADO, A., YARZA, A., MCGINN, J., PICKING, R. and GROUT, V., 2008. User Modelling in Ambient Intelligence for Elderly and Disabled People. *Computers Helping People with Special Needs* 2008, pp. 114-122.

CASAS, R., MARCO, Á, FALCÓ, J., ARTIGAS, J. and ABASCAL, J., 2006. Ethically Aware Design of a Location System for People with Dementia, K. MIESENBERGER, J. KLAUS, W. ZAGLER and A. KARSHMER, eds. In: *Computers Helping People with Special Needs* 2006, Springer Berlin Heidelberg, pp. 777-784.

CHAN, M., CAMPO, E., ESTÈVE, D. and FOURNIOLS, J.Y., 2009. Smart homes—Current features and future perspectives. *Maturitas,* **64**(2), pp. 90-97.

CHEN, C., DAS, B. and COOK, D.J., 2010. Energy prediction based on resident's activity, *In Proceedings of the International workshop on Knowledge Discovery from Sensor Data* 2010.

CHEN, J., CHANG, K., CHI, P. and CHU, H., 2006. A smart kitchen to promote healthy cooking, *Proceedings of the 8th International Conference on Ubiquitous Computing (ACM UBICOMP 2006)* 2006.

CHEN, J., KWONG, K., CHANG, D., LUK, J. and BAJCSY, R., 2006. Wearable sensors for reliable fall detection, *Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. 27th Annual International Conference of the* 2006, IEEE, pp. 3551-3554.

CHEN, J.H., CHI, P.P.Y., CHU, H.H., CHEN, C.C.H. and HUANG, P., 2010. A smart kitchen for nutrition-aware cooking. *Pervasive Computing, IEEE,* **9**(4), pp. 58-65.

CHENG, C. and BONANNI, L., 2006-last update, counter intelligence - mit media lab. Available: http://www.media.mit.edu/ci/projects/intelligentspoon.html, 2012.

CHI, P., CHEN, J., CHU, H. and CHEN, B.Y., 2007. Enabling nutrition-aware cooking in a smart kitchen, *CHI'07 extended abstracts on Human factors in computing systems* 2007, ACM, pp. 2333-2338.

C-LAB, 2012-last update, Cooperative computing and communication laboratory. Available: http://www.c-lab.de/, 2012.

CLARKSON, P., COLEMAN, R., HOSKING, I. and WALLER, S., 2007. *Inclusive design toolkit.* Engineering Design Centre, University of Cambridge, UK.

COMBESSIE, J.C., 1986. A propos de méthodes : Effets d'optique, heuristique et objectivation. *Bulletin de Méthodologie Sociologique,* **10**(1), pp. 4-24.

COMYN, G., OLSSON, S., GUENZLER, R., ÖZCIVELEK, R., ZINNBAUER, D. and CABRERA, M., 2006. *User needs in ICT research for independent living, with a focus on health aspects.* Brussels: European Commission, Directorate-General Joint Research Centre. Institute for Prospective Technological Studies.

CONTIKI OS, 2012-last update, Contiki OS. Available: http://www.contiki-os.org/, 2012.

COOK, A.M. and HUSSEY, S., 2001. Assistive technologies: Principles and practice.

COOK, D.J., AUGUSTO, J.C. and JAKKULA, V.R., 2009. Ambient Intelligence: Technologies, applications, and opportunities. *Pervasive and Mobile Computing,* **5**(4), pp. 277-298.

COPPER, A., 2004. *The inmates are running the asylum.* AMS publishing.

DAY, H., JUTAI, J. and CAMPBELL, K., 2002. Development of a scale to measure the psychosocial impact of assistive devices: lessons learned and the road ahead. *Disability & Rehabilitation,* **24**(1-3), pp. 31-37.

DEMERS, L., MONETTE, M., LAPIERRE, Y., ARNOLD, D. and WOLFSON, C., 2002. Reliability, validity, and applicability of the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST 2.0) for adults with multiple sclerosis. *Disability and Rehabilitation, 24,* **1**(3), pp. 21-30.

DEMUTH, H. and BEALE, M., 2003. *Neural Network Toolbox. For use with MATLAB.* Nineth edn. The MathWorks, Inc.

DEY, A.K., ABOWD, G.D. and SALBER, D., 2001. A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. *Human-Computer Interaction,* **16**(2-4), pp. 97-166.

DIX, A., FINLAY, J., ABOED, G.D. and BEALE, R., 2004. *Human-Computer Interaction.* Prentice hall.

DUCATEL, K., BOGDANOWICZ, M., SCAPOLO, F., LEIJTEN, J. and BURGELMA, J., 2001. Scenarios for Ambient Intelligence in 2010, *ISTAG, IPTS, Seville* 2001.

DUMAS, B., LALANNE, D. and OVIATT, S., 2009. Multimodal interfaces: A survey of principles, models and frameworks, *Human Machine Interaction* 2009, Springer, pp. 3-26.

EASY LINE +, 2010, 2010-last update, Easy Line + project website. Available: http://www.easylineplus.com/, 2012.

EDEAN, 1999, 1999-last update, Approaches to Design for All. Available: http://www.education.edean.org/index.php?row=3&filters=f16&cardIndex=21.

EEML, 2008-last update, Extended Environments Markup Language: EEML. Available: http://www.eeml.org/, 2013.

EETIMES EUROPE, 2010-last update, Freescale and Indesit collaborate on smart appliance solutions for ZigBee connected white goods - Electronics Eetimes. Available: http://www.electronics-eetimes.com/en/freescale-and-indesit-collaborate-on-smart-appliance-solutions-for-zigbee-connected-white-goods.html?cmp_id=7&news_id=222903029, 2012.

ENOCEAN, 2012-last update, Radio Technology (RF) from EnOcean for Energy Harvesting Wireless Sensor Solutions | EnOc. Available: http://www.enocean.com/en/radio-technology/, 2012.

FAYED, N., CIEZA, A. and EDMOND BICKENBACH, J., 2011. Linking health and health-related information to the ICF: a systematic review of the literature from 2001 to 2008. *Disability & Rehabilitation,* **33**(21-22), pp. 1941-1951.

FENG, L., APERS, P. and JONKER, W., 2004. Towards context-aware data management for Ambient Intelligence, *Database and Expert Systems Applications. Springer* 2004, pp. 422-431.

FICOCELLI, M. and NEJAT, G., 2012. The Design of an Interactive Assistive Kitchen System. *Assistive Technology,* **24**(4), pp. 246-258.

FREERTOS, 2012-last update, FreeRTOS. Available: http://www.freertos.org/, 2012.

FREY, J., NESSELRATH, R. and STAHL, C., 2011. An Open Standardized Platform for Dual Reality Applications, *Proceedings of the International Conference on Intelligent User Interfaces (IUI)* 2011.

G2V, 2012-last update, ISDE ARAGON. Available: http://www.g2v.com/isdearagon/index.htm, 2012.

GÁRATE, A., HERRASTI, N. and LÓPEZ, A., 2005. GENIO: An Ambient Intelligence application in home automation and entertainment environment, *Proceedings of the 2005 joint conference on Smart objects and ambient intelligence: innovative context-aware services: usages and technologies. ACM* 2005, ACM, pp. 241-245.

GERA-IDENT, 2012-last update, Gis Gera Ident-Systeme GmbH. Available: http://gera-ident.de/, 2012.

GIANNAKOURIS, K., 2008. Ageing characterises the demographic perspectives of the European societies. *Eurostat, Statistics in focus,* **72**, pp. 2008.

GLYNDŴR UNIVERSITY, 2012-last update. Available: http://www.glyndwr.ac.uk/, 2012.

GOODMAN, G. and LUFT, P., 2002. Adoption of assistive technology for computer access among college students with disabilities. *Disability and Rehabilitation, 24,* **1**(3), pp. 80-92.

GROGER, L. and STRAKER, J., 2002. Counting and Recounting: Approaches to combining quantitative and qualitative data and methods. *Qualitative gerontology: A contemporary perspective.* New York: Springer, pp. 179-199.

GROSKY, W.I., KANSAL, A., NATH, S., JIE LIU and FENG ZHAO, 2007. SenseWeb: An Infrastructure for Shared Sensing. *MultiMedia, IEEE,* **14**(4), pp. 8-13.

GS1, 2012, 2012-last update, GS1 - The global language of business. Available: http://www.gs1.org/, 2012.

GU, G.Z., 2009. Context Aware Computing. *Journal of East China Normal University ( Natural Science),* **5**.

GYI, D., SIMS, R., PORTER, J., MARSHALL, R. and CASE, K., 2004. Representing older and disabled people in virtual user trials: data collection methods. *Applied Ergonomics,* **35**(5), pp. 443-451.

HASDOĞAN, G., 1996. The role of user models in product design for assessment of user needs. *Design Studies,* **17**(1), pp. 19-33.

HASHIMOTO, A., MORI, N., FUNATOMI, T., YAMAKATA, Y., KAKUSHO, K. and MINOH, M., 2008. Smart kitchen: A user centric cooking support system. *Proceedings of IPMU,* **8**, pp. 848-854.

HONG, J., SUH, E. and KIM, S.J., 2009. Context-aware systems: A literature review and classification. *Expert Systems with Applications,* **36**(4), pp. 8509-8522.

HORNIK, K., STINCHCOMBE, M. and WHITE, H., 1989. Multilayer feedforward networks are universal approximators. *Neural Networks,* **2**(5), pp. 359-366.

HOWE, K.R., 1992. Getting over the quantitative-qualitative debate, *American Journal of Education* 1992, pp. 236-256.

IBARZ, A., BAUER, G., CASAS, R., MARCO, A. and LUKOWICZ, P., 2008. Design and Evaluation of a Sound Based Water Flow Measurement System, *Smart Sensing and Context* 2008, Springer Berlin / Heidelberg, pp. 41-54.

IEEE 1451, 2011-last update, Smart Transducer Interface Standards. Available: http://www.nist.gov/el/isd/ieee/ieee1451.cfm, 2012.

IMSERSO, ed, 2009. *INFORME 2008. Las personas mayores en España. Datos estadísticos estatales y por Comunidades Autónomas.* ISBN: 978-84-8446-108-1 (Volumen I) edn. Instituto de Mayores y Servicios Sociales (IMSERSO).

INE, 2012-last update, Instituto Nacional de Estadistica. Available: www.ine.es.

INTERNATIONAL ERGONOMICS ASSOCIATION, 2011-last update, What is Ergonomics. Available: http://www.iea.cc/01_what/What is Ergonomics.html, 2013.

ISO 20282-1, 2006. Ease of operation of everyday products -- Part 1: Design requirements for context of use and user characteristics.

ISO 9241-11, 1998. Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 11: Guidance on usability.

ISO 9241-171, 2008. Ergonomics of human-system interaction -- Part 171: Guidance on software accessibility.

JARA, A.J., ZAMORA, M.A. and SKARMETA, A.F., 2011. An internet of things---based personal device for diabetes therapy management in Ambient Assisted Living (AAL). *Personal and Ubiquitous Computing,* **15**(4), pp. 431-440.

JICK, T.D., 1979. Mixing qualitative and quantitative methods: Triangulation in action. *Administrative Science Quarterly,* **24**(4), pp. 602-611.

JOHNSON, D., CLARKSON, J. and HUPPERT, F., 2010. Capability measurement for inclusive design. *Journal of Engineering Design,* **21**(2-3), pp. 275-288.

KEATES, S. and CLARKSON, P.J., 2003. *Countering design exclusion: An introduction to inclusive design.* Springer Verlag.

KILTZ, U., VAN DER HEIJDE, D., CIEZA, A., BOONEN, A., STUCKI, G., ÜSTÜN, B. and BRAUN, J., 2011. Developing and validating an index for measuring health in patients with ankylosing spondylitis. *Rheumatology,* **50**(5), pp. 894-898.

KOFLER, M.J., REINISCH, C. and KASTNER, W., 2011. An Intelligent Knowledge Representation of Smart Home Energy Parameters, *Proceedings of the World Renewable Energy Congress (WREC 2011)* 2011.

KOHONEN, T., 1990. The self-organizing map. *Proceedings of the IEEE,* **78**(9), pp. 1464-1480.

KRANZ, M., SCHMIDT, A., RUSU, R.B., MALDONADO, A., BEETZ, M., HORNLER, B. and RIGOLL, G., 2007. Sensing technologies and the player-middleware for context-awareness in kitchen environments, *Networked Sensing Systems, 2007. INSS'07. Fourth International Conference on* 2007, IEEE, pp. 179-186.

LEI, J., REN, X. and FOX, D., 2012. Fine-Grained Kitchen Activity Recognition using RGB-D, *ACM International Conference on Ubiquitous Computing* 2012.

LENKER, J.A. and PAQUET, V.L., 2003. A review of conceptual models for assistive technology outcomes research and practice. *Assistive Technology,* **15**(1), pp. 1-15.

LG, 2012-last update, LG Newsroom. Available: http://www.lgnewsroom.com/newsroom/contents/61738, 2012.

LI, X. and ZHANG, W., 2004. The design and implementation of home network system using OSGi compliant middleware. *Consumer Electronics, IEEE Transactions on,* **50**(2), pp. 528-534.

LIU, W., LI, X. and HUANG, D., 2011. A survey on context awareness, *Computer Science and Service System (CSSS), 2011 International Conference on. IEEE* 2011, pp. 144-147.

LOMBARDI, A., FERRI, M., RESCIO, G., GRASSI, M. and MALCOVATI, P., 2009. Wearable wireless accelerometer with embedded fall-detection logic for multi-sensor ambient assisted living applications, *Sensors, 2009 IEEE* 2009, pp. 1967-1970.

MARCO, A., CASAS, R., BAUER, G., BLASCO, R., ASENSIO, A., JEAN-BART, B. and IBAÑEZ, M., 2009. Common osgi interface for ambient assisted living scenarios. *Ambient Intelligence and Smart Environments.Volume 3: Behaviour Monitoring and Interpretation – BMI.* Netherlands: IOS Press, pp. 336-357.

MARCO, A., CIRUJANO, D., CASAS, R., BLASCO, R. and ASENSIO, A., 2012, 2012-last update, osgi4ami project website. Available: http://sourceforge.net/projects/osgi4ami/, 2012.

MARTÍN DEL BRÍO, B. and SANZ, A., 2006. Fundamentos de redes neuronales y lógica borrosa. Apuntes de asignatura. Departamento de Ingeniería Electrónica y Comunicaciones. Universidad de Zaragoza.

MARTIN, J.L., NORRIS, B.J., MURPHY, E. and CROWE, J.A., 2008. Medical device development: The challenge for ergonomics. *Applied Ergonomics,* **39**(3), pp. 271-283.

MEDLINEPLUS, 2013-last update, Cambios en huesos, músculos y articulaciones por el envejecimiento: MedlinePlus enciclopedia médica [Homepage of National Library of Medicine, USA], [Online]. Available: http://www.nlm.nih.gov/medlineplus/spanish/ency/article/004015.htm, 2013.

MERICO, D., MILEO, A. and BISIANI, R., 2009. Intelligent Wireless Sensor Networks for Assisted Living, *Emerging Paradigms in Informatics, Systems and Communication* 2009, pp. 35.

MICROSAR OS, 2012-last update, MICROSAR OS. Available: https://www.vector.com/vi_microsar_os_en.html, 2012.

MIELE, 2012-last update, Miele@home - Miele International. Available: http://www.miele.com/international/enint/products/miele_at_home.htm, 2012.

MIKKONEN, M., VÄYRYNEN, S., IKONEN, V. and HEIKKILA, M., 2002. User and concept studies as tools in developing mobile communication services for the elderly. *Personal and Ubiquitous Computing,* **6**(2), pp. 113-124.

MORGAN, D.L., 1997. *Focus groups as qualitative research.* Sage Publications, Inc.

MOTIVE TECHNOLOGY, 2012-last update, Motive Technology - Bespoke software, hotel websites, booking engine solutions and ecommerce in Cumbria and North West England - Motive Technology. Available: http://www.motivetechnology.com/Home, 2012.

NESSELRATH, R., HAUPERT, J., FREY, J. and BRANDHERM, B., 2011. Supporting Persons with Special Needs in Their Daily Life in a Smart Home, *Intelligent Environments (IE), 2011 7th International Conference on* 2011, IEEE, pp. 370-373.

NICOLESCU, B., CAMUS, M., MAGNIN, T. and VOSS, K., 1998. Levels of representation and levels of reality: towards an ontology of science, *The concept of nature in science and theology.Genève: Labor et Fides* 1998, pp. 94-103.

NIPSSR, 2002. *Population Projections for Japan:2001-2050. With Long-range Population Projections: 2051 - 2100.* National Institute of Population and Social Security Research.

NORMAN, D.A., 1988. *The design of everyday things.* 2002 edn. United States of America: Basic books.

O'GRADY, M.J., MULDOON, C., DRAGONE, M., TYNAN, R. and O'HARE, G.M.P., 2010. Towards evolutionary Ambient Assisted Living systems. *Journal of Ambient Intelligence and Humanized Computing,* **1**(1), pp. 15-29.

OSGI ALLIANCE, 2012-last update, OSGi Alliance website. Available: http://www.osgi.org/Main/HomePage, 2012.

OSGI ALLIANCE, 2010. *Challenges for Todays Consumer Electronics.* http://www.osgi.org/wiki/uploads/Markets/Challenges for Todays Consumer Electronics.pdf edn.

PAL AMUTHA, K., SETHUKKARASI, C. and PITCHIAH, R., 2012. Smart Kitchen Cabinet for Aware Home, *SMART 2012, The First International Conference on Smart Systems, Devices and Technologies* 2012, pp. 9-14.

PARK, S. and KAUTZ, H., 2008. Hierarchical recognition of activities of daily living using multi-scale, multi-perspective vision and RFID, *Intelligent Environments, 2008 IET 4th International Conference on* 2008, IET, pp. 1-4.

PAULO, P. and GAC, H., 2000. *Manual de geriatría y gerontología.* Universidad Católica de Chile.

PICKING, R., ROBINET, A., MCGINN, J., GROUT, V., CASAS, R. and BLASCO, R., 2012. The Easyline+ project: evaluation of a user interface developed to enhance independent living of elderly and disabled people. *Universal Access in the Information Society,* **11**(2), pp. 99-112.

PORTER, J.M., CASE, K., MARSHALL, R., GYI, D. and SIMS NEÉ OLIVER, R., 2004. 'Beyond Jack and Jill': designing for individuals using HADRIAN. *International Journal of Industrial Ergonomics,* **33**(3), pp. 249-264.

POULSON, D. and RICHARDSON, S., 1998. USERfit--a framework for user centred design in assistive technology. *Technology and Disability,* **9**(3), pp. 163-171.

PRESSER, M., BARNAGHI, P.M., EURICH, M. and VILLALONGA, C., 2009. The SENSEI project: integrating the physical world with the digital world of the network of the future. *Communications Magazine, IEEE,* **47**(4), pp. 1-4.

PUIG, G., GRACIA, M. and FALCÓ, J.L., 2005. *Sondeo sobre el uso de la lavadora por personas mayores en el entorno de Zaragoza.* Confidential report for BSH under private contract "Easy Line". Universidad de Zaragoza.

RAMOS, C., AUGUSTO, J.C. and SHAPIRO, D., 2008. Ambient Intelligence—the Next Step for Artificial Intelligence. *Intelligent Systems, IEEE,* **23**(2), pp. 15-18.

RFID JOURNAL, 2003-last update, Merloni Unveils RFID Appliances - RFID Journal. Available: http://www.rfidjournal.com/article/view/369/, 2012.

ROSSI, P.H., 1994. The war between the quals and the quants: Is a lasting peace possible? *New directions for program evaluation,* **1994**(61), pp. 23-36.

ROY DELGARDO, A., BLASCO, R., MARCO, A., CIRUJANO, D., CASAS, R., ROY YARZA, A., GROUT, V. and PICKING, R., 2010. Agent-based AmI System Case Study: The Easy Line Project. *Advances in Soft Computing: Trends in Practical Applications of Agents and Multiagent Systems.* pp. 157-164.

SALUDALIA, 2013-last update, Salud, enfermedades y medicina en Saludalia.com. Available: http://www.saludalia.com/, 2013.

SAMSUNG, 2012-last update, Samsung Refrigerator RF4289HARS. Available: http://www.samsung.com/us/appliances/refrigerators/RF4289HARS/XAA, 2012.

SANGELKAR, S., COWEN, N. and MCADAMS, D., 2012. User activity–product function association based design rules for universal products. *Design Studies,* **33**(1), pp. 85-110.

SCHALOCK, R.L. and VERDUGO ALONSO, M.A., 2003. *Calidad de vida: Manual para profesionales de la educación, salud y servicios sociales.* Alianza editorial.

SCHERER, J., LAURA, A. and CUSHMAN, M., 2001. Measuring subjective quality of life following spinal cord injury: a validation study of the assistive technology device predisposition assessment. *Disability & Rehabilitation,* **23**(9), pp. 387-393.

SCHERER, M., JUTAI, J., FUHRER, M., DEMERS, L. and DERUYTER, F., 2007. A framework for modelling the selection of assistive technology devices (ATDs). *Disability & Rehabilitation: Assistive Technology,* **2**(1), pp. 1-8.

SCHERER, M.J. and CRADDOCK, G., 2002. Matching person & technology (MPT) assessment process. *Technology and Disability,* **14**(3), pp. 125-131.

SCHWARTZE, V., FEUERSTACK, S. and ALBAYRAK, S., 2009. Behavior-sensitive user interfaces for smart environments, *Digital Human Modeling* 2009, Springer, pp. 305-314.

SELKER, T., 2006-last update, counter intelligence - mit media lab. Available: http://www.media.mit.edu/ci/projects/chameleonmug.html, 2012.

SELVABALA, V.S.N. and GANESH, A.B., 2012. Implementation of wireless sensor network based human fall detection system. *Procedia Engineering,* **30**(0), pp. 767-773.

SHELBY, Z. and BORMANN, C., 2009. *6LoWPAN: The wireless embedded Internet.* Wiley-Blackwell.

SHELL, J. and COUPLAND, S., 2011. Improved Decision Making Using Fuzzy Temporal Relationships within Intelligent Assisted Living Environments, *Intelligent Environments (IE), 2011 7th International Conference on* 2011, pp. 149-156.

SHONE, S.M., RYAN, S., RIGBY, P. and JUTAI, J.W., 2002. Toward a comprehensive evaluation of the impact of electronic aids to daily living: evaluation of consumer satisfaction. *Disability and Rehabilitation,* **24**(1-3), pp. 115-125.

SIIO, I., HAMADA, R. and MIMA, N., 2007. Kitchen of the Future and Applications, *Human-Computer Interaction.Interaction Platforms and Techniques* 2007, Springer, pp. 946-955.

STANKOVIC, J.A., 2008. Wireless sensor networks. *Computer,* **41**(10), pp. 92-95.

STEG, H., STRESE, H., LOROFF, C., HULL, J. and SCHMIDT, S., 2006. *Europe is facing a demographic challenge–Ambient Assisted Living offers solutions.*

TEDDLIE, C. and TASHAKKORI, A., 2003. Major issues and controveries inthe use of mixed methods in the social and behvioral sciences. *Major issues and controversies in the use of mixedmethods in the social and behavioral sciences.* Sage Publications, Inc, pp. 3-50.

TENNETI, R., JOHNSON, D., GOLDENBERG, L., PARKER, R.A. and HUPPERT, F.A., 2012. Towards a capabilities database to inform inclusive design: Experimental investigation of effective survey-based predictors of human-product interaction, *Applied Ergonomics* 2012, Elsevier.

TINY OS, 2012-last update, Tiny OS. Available: http://www.tinyos.net/, 2012.

TOMBAUGH, T.N. and MCINTYRE, N.J., 1992. The Mini-Mental State Examination: A comprehensive review. *Journal of the American Geriatrics Society,* **40**(9), pp. 922-935.

U.S. CENSUS BUREAU, 2012-last update, Resident Population Projections by Sex and Age: 2010 to 2050. Available: http://www.census.gov/, 2012.

UNIVERSIDAD DE ZARAGOZA, 2012-last update, Universidad de Zaragoza. Available: http://www.unizar.es/, 2012.

USB-UIRT, 2009-last update, USB-UIRT Home. Available: http://www.usbuirt.com/, 2013.

VACHER, M., PORTET, F., FLEURY, A. and NOURY, N., 2010. Challenges in the processing of audio channels for Ambient Assisted Living, *e-Health Networking Applications and Services (Healthcom), 2010 12th IEEE International Conference on* 2010, pp. 330-337.

VAINIO, A.-., VALTONEN, M. and VANHALA, J., 2008. Proactive Fuzzy Control and Adaptation Methods for Smart Homes. *Intelligent Systems, IEEE,* **23**(2), pp. 42-49.

VAN DEN BROEK, G., CAVALLO, F. and WEHRMANN, C., 2010. *AALIANCE Ambient Assisted Living roadmap.* Ios Press.

VAN ISACKER, K., GORANOVA-VALKOVA, M. and GRUDEVA, P., 2008. User Centred Design in an FP7 Elderly Project, *Procedures of UNITECH'08* 2008.

VAN KASTEREN, T., ENGLEBIENNE, G. and KRÖSE, B., 2010. Transferring knowledge of activity recognition across sensor networks, *Pervasive Computing* 2010, Springer, pp. 283-300.

VILLACORTA, J.J., JIMÉNEZ, M.I., VAL, L. and IZQUIERDO, A., 2011. A Configurable Sensor Network Applied to Ambient Assisted Living. *Sensors,* **11**(11), pp. 10724-10737.

WEISER, M., 1991. The computer for the 21st century. *Scientific American,* **265**(3), pp. 94-104.

WEMLINGER, Z. and HOLDER, L., 2011. The COSE ontology: bringing the semantic web to smart environments, *Toward Useful Services for Elderly and People with Disabilities* 2011, Springer, pp. 205-209.

WIFI ALLIANCE, 2012-last update, WiFi Alliance. Available: http://www.wi-fi.org/, 2012.

WIKIPEDIA, 2013, 2013-last update, Wikipedia. Available: http://www.wikipedia.org/, 2013.

WORLD HEALTH ORGANIZATION, 2003-last update, ICF Application and Training Tools. Available: http://www.who.int/classifications/icf/icfapptraining/en/index.html, 2013.

WORLD HEALTH ORGANIZATION, 2001-last update, International Classification of Functioning, Disability and Health (ICF), 2012.

WU, J., HUANG, L., WANG, D. and SHEN, F., 2008. R-OSGi-based architecture of distributed smart home system. *Consumer Electronics, IEEE Transactions on,* **54**(3), pp. 1166-1172.

XU, J., KOHLER, F. and DICKSON, H., 2011. Systematic review of concepts measured in individuals with lower limb amputation using the International Classification of Functioning, Disability and Health as a reference. *Prosthetics and orthotics international,* **35**(3), pp. 262-268.

YICK, J., MUKHERJEE, B. and GHOSAL, D., 2008. Wireless sensor network survey. *Computer networks,* **52**(12), pp. 2292-2330.

ZAINOL, Z. and NAKATA, K., 2010. Generic context ontology modelling: A review and framework, *Computer Technology and Development (ICCTD), 2010 2nd International Conference on* 2010, IEEE, pp. 126-130.

ZEIFMAN, M. and ROTH, K., 2012. Disaggregation of home energy display data using probabilistic approach, *Consumer Electronics (ICCE), 2012 IEEE International Conference on* 2012, IEEE, pp. 630-631.

ZIGBEE ALLIANCE, 2012-last update, ZigBee Alliance. Available: http://www.zigbee.org/, 2012.

ZIGBEE ALLIANCE, 2007-last update, TI Delivers Industry's First Location Detection System-on-Chip for ZigBee® Wireless Sensor Networking. Available: https://docs.zigbee.org/zigbee-docs/dcn/07/docs-07-5152-00-0mwg-ti-delivers-industrys-first-location-detection-system-on-chip-for-zigbee-wireless-sensor-networking.pdf.

# ANNEX I: FUNCTIONAL SPECIFICATION AND EXPECTED IMPACT

**Note that the following information is extracted from the public deliverable D.1.1. of EL+ project (Casas, Blasco et al. 2009).**

With all the information available and considering the technological boundaries in the frame of the project and the interest of the industrial partner in the project smart kitchen functionalities are described:

a) **Facilitate the use of the household appliances adapted to the disabilities or preferences of the user and include accessible interfaces and provide useful information and warnings about the use of the household appliances.** Specifically the following. Thanks to the influence of having the co-design session with social and health workers, it has decided not to change system's behaviour automatically, to avoid user's disorientation. Specifically the functions provided by appliance are the following:

| | | |
|---|---|---|
| **FRIGDE / FREEZER** | Display status | • On / Off / Problem / Disconnected<br>• Temperature<br>• Door open / closed<br>• Contents |
| | Configure. The user can set the device | • Target temperature |
| | Warnings | • Advise if the door is left open<br>• Advise if food is past its use-by date<br>• Advise if food is approaching its use-by date |
| **WASHING MACHINE** | Display status | • On / Off / Problem / Disconnected<br>• Door open / closed<br>• Time to finish<br>• Contents |
| | Configure. The user can set the device | • Switch On / Off<br>• Set program |
| | Warnings | • Advise of wrong fabric mix (e.g. white and coloureds)<br>• Advise of unsuitable fabrics (e.g. dry clean only)<br>• Advise if machine loaded but not yet on (forgotten to switch it on?)<br>• Advise if cycle interrupted<br>• Advise if unload incomplete (clothes left in?)<br>• Advise when machine is on final spin<br>• Advise when cycle finished |
| **HOB** | Display status | • On / Off / Problem / Disconnected |
| | Configure. The user can set the device | • Switch Off |
| | Warnings | • Advise if hob is left on with no pan |
| **OVEN** | Display status | • On / Off / Problem / Disconnected<br>• Temperature |

| | | |
|---|---|---|
| | | • Door open / closed<br>• Time to finish |
| | Configure. The user can set the device | • Switch On / Off<br>• Set the target temperature<br>• Set cooking time (start time / period in minutes) |
| | Warnings | • Advise when food is ready |

Table 49 Functionality summary

b) **Detect emergency situation and automatically take some actions**: warn the user, switch off some appliances (e.g. the hob and oven in case of fire or the washing machine if there are water leaks detected).

- Advise about a "Fire detected" emergency
- Advise about a "Smoke detected" emergency
- Advise about a "Water leaks detected" emergency

c) **Analyse all the data gathered to extract relevant information that could be useful for user's carer and/or relatives in order to evaluate the person's quality of life**. It is able to detect behaviour changes, loss of abilities (memory problems, oversights, etc.) of the user. For example, it seems clear that changes in HMI's navigation skill, opening the fridge too many times (without picking anything) or loss of skill of programming the washing machine might have relationship with loss of cognitive capability or disorientation.

The following table lists the expected level of benefits of the determined prototype functionalities for the elderly people in consideration of the main types of their disabilities. This table is created from the results of the analysis of the users' needs and the common work with experts in disability inside the project.

| | **Expected benefit**[11] | | |
|---|---|---|---|
| **Advanced functionalities of prototypes** | **Physical impaired** | **Sensory impaired** | **Mild-cognitive impaired** |
| Facilitate the use of the household appliances adapting to the disabilities or preferences of the user and using adapted interfaces. | | | |

[11]The level of benefit highly depends on the individual condition of the elderly people and may change in process of time. For instance the practical benefit of notifications or reminders is only important as long as physical impaired persons are able to react on the corresponding situation. As a sad consequence, a diminishing condition of the concerned persons can decrease the level of benefit dramatically.

| | | | |
|---|---|---|---|
| Indication of fridge/freezer status:<br><br>On/Off/Problem/Disconnected, door open or closed, current temperature | High | Medium | High |
| Display of fridge/freezer contents | High | Medium | Medium |
| Support for configuration of fridge/freezer settings:<br><br>Set target temperature | High | High | Medium |
| Indication of washing machine status:<br><br>On/Off/Problem/Disconnected, door open or closed, time to finish | High | Medium | High |
| Display of washing machine contents | High | Medium | Medium |
| Support for configuration of washing machine settings:<br><br>Set washing program, switch on/off | High | High | Medium |
| Indication of hob status:<br><br>On/Off/Problem/Disconnected | High | Medium | High |
| Support for configuration of hob settings:<br><br>Switch off | High | High | Medium |
| Indication of oven status:<br><br>On/Off/Problem/Disconnected, time to finish, temperature | High | Medium | High |
| Support for configuration of oven settings:<br><br>Set target temperature, switch on/off, set starting cooking time, set duration | High | High | Medium |
| **Provide useful information and warnings about the use of the household appliances** | | | |
| Advise if the fridge/freezer door is left open | High | High | High |

| | | | |
|---|---|---|---|
| Advise if food is past its use-by date | High | High | High |
| Advise if food is approaching its use-by date | Medium | Medium | High |
| Warning about fridge/freezer breakdown | High | High | High |
| Advise of wrong mix of clothes (e.g. mix of white and coloured clothes) | High | High | High |
| Advise of unsuitable fabrics (e.g. dry clean only) | High | High | High |
| Advise if machine loaded but not yet on | High | High | High |
| Advise if cycle interrupted | High | High | High |
| Advise if unload incomplete | High | High | High |
| Advise when machine is on final spin | High | High | High |
| Advise when cycle finished | High | High | High |
| Warning about washing machine breakdown | High | High | High |
| Advise if hob is left on with no pan | High | High | High |
| Warning about hob breakdown | High | High | High |
| Advise when food in the oven is ready | High | High | High |
| Warning about oven breakdown | High | High | High |
| Inform how a cloth should be washed, its colour, etc. | Medium | Medium | High |
| Inform how food should be cooked, its expiration date, etc. | Medium | Medium | High |
| **Detect emergency situation and automatically take some actions** | | | |

| | | | |
|---|---|---|---|
| Advise “Fire detected” emergency | High | High | High |
| Advise “Smoke detected” emergency | High | High | High |
| Advise “Water detected” emergency | High | High | High |

**Table 50Avanced functionalities & Expected benefit**

# ANNEX II DATA PROCESSING PAPERS

## FALL DETECTOR BASED ON NEURAL NETWORKS

# FALL DETECTOR BASED ON NEURAL NETWORKS

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Keywords: Fall detector, neural networks, ZigBee, wearable sensors, pattern recognition.

Abstract: Falls are one of the biggest concerns of elderly people. This paper addresses a fall detection system which uses an accelerometer to collect body accelerations, ZigBee to send relevant data when a fall might have happened and a neural network to recognize fall patterns. This method presents improved performance compared to traditional basic-threshold systems. Main advantage is that fall detection ratio is higher on neural network based systems. Another important issue is the high immunity to events not being falls, but with similar patterns (e.g. sitting in a sofa abruptly), usually confused with real falls. Minimization of these occurrences has big influence on the confidence the user has on the system.

## 1 INTRODUCTION

Aging of population is a well-known problem in developed countries. Nowadays, elderly people (+65 years old) represents in Spain more than 16% of the population (Eurostat, 2007). Falls are one of the major fears of the elderly and their relatives. Indeed, some authors estimate the amount of falls of people aged over 75 to be at least 30 percent per year (Sixsmith and Johnson, 2004). In the end, people's concern about falls and whether there will be someone there to help them in case of an emergency, prevent them to age at home (Rodriguez et al, 2005). As a result, people have to move to residences, usually causing negative effect in their health and happiness and resulting in high costs to the individual, their family or the Social Welfare System.

Fortunately, many initiatives are going on in order to increase the time people can stay at home. We will further see many fall detection systems enabling people to receive quickly assistance even when they are not able to request the assistance by themselves (e.g. immobilized or unconscious). Also, combination of these systems with telemedicine allows closer monitoring or collaboration of various experts in the diagnoses (Tunstall web, 2007).

Various methods have been described in order to detect falls in the elderly. Those based in a sensing infrastructure - infrared cameras (Alwan, et al., 2006), vision systems (Williams et al., 1998) or smart floors (Williams et al., 1998) - can be hardly used in many cases. We find wearable systems more appropriated in real scenarios because people refuse to have cameras everywhere in their homes and systems are much more expensive.

Inertial elements are mostly used for mobile monitoring, but still the perfect detector does not exist. Main reason is the difficulty in modelling a fall, it can happen in many different ways; it will not always be the typical big impact followed by inactivity and horizontality. Williams et al. use a shock sensor and a tilt switch to measure the inclination after the impact (Williams et al., 1998). Doughty et al. also use two sensors to perform the same two-stage-analysis (Doughty et al, 2000), which moreover is concreted in a commercial gadget from Tunstall (Nait-Charif and McKenna, 2004). Noury refines the procedure using an accelerometer to detect the shock, also a tilt switch, and adding a vibration sensor to estimate the physiological activity (Noury, 2002). Of course, the more variables measured, the more accurate the detection can be, but also the more complicated and expensive the hardware will be. Many actual works propose just using accelerometers to carry out the full detection (Noury, 2002; Degen et al, 2005; Chen et al., 2005). Main reasons are their low power consumption, reduced cost and versatility detecting different events -shocks, inclination and activity-. The devices presented in these works perform satisfactory fall detection: more of 80% of falls are correctly detected (Noury, 2002).

## 2 SYSTEM DESCRIPTION

Users must find fall detection systems trust-worthy and efficient in order to use them. Systems which detect all falls but generate many false alarms make users unconfident about it. Moreover, if we consider the difficulty of distinguishing between some kind of falls and ordinary movements in elderly people's life, threshold systems (those that generate an alert when acceleration rise above a fixed value) become not be reliable enough (Noury, 2002).

Figure 1.a. shows tri-axial acceleration when a person has a sideward fall. On the other hand, Figure 1.b. shows accelerations when a person sits down on a sofa abruptly. Both figures were obtained with a device which measures triaxial accelerations, hanged around the neck.

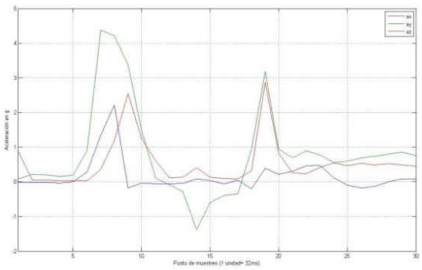

Figure 1a: Acceleration in three axes in a sideward fall.

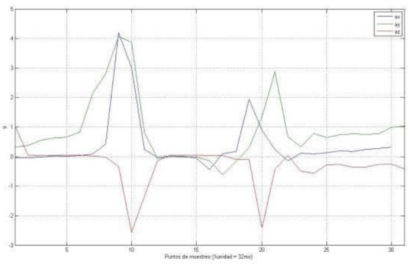

Figure 1b: Acceleration in three axes while sitting abruptly in a sofa.

As we can see, both figures have similar acceleration peaks being also the shapes pretty similar.

Our solution aims to distinguish falls from movements that have similar acceleration patterns not being falls using neural networks; that is to say, separate occurrences into true and false falls.

### 2.1 Blocks Diagram

The fall detector consists of a mobile device with an inertial sensor which is able to communicate through a ZigBee network. The system also needs a computer that analyzes data using a neural network. Figure 2 shows the portable device blocks: battery, sensor, microcontroller (μC), interface and Zigbee transceiver. Reduced size and low power consumption had been considered in the design process of every block.

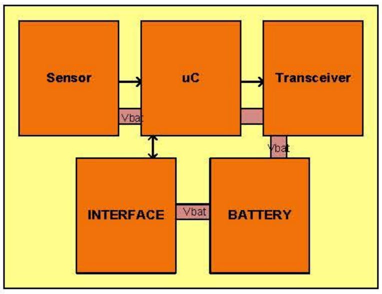


Figure 2: Blocks of the portable device.

The chosen sensor is MMA7260Q Freescale accelerometer because of its wide input voltage range (2,2 V - 3,6 V), current consumption (typically less than 500 μA and 3 μA in sleep mode) and reduced size (6x6x1,45mm). It also has three analog outputs that give the acceleration value in axis X, Y and Z. Its sensitivity is configured digitally into some ranges (1,5 g; 2 g; 4 g or 6 g). As some falls are above 4 g, our application uses the maximum range (6 g) and minimum sensitivity (200 mV/g).

The chosen microcontroller is Microchip's PIC16F688. It has eight A/D channels that can be configured to 10 bits. As well as working within a wide voltage supply range (2 V - 5,5 V), it also has very low current consumption (800 μA in active mode and 1 nA while sleeping).

Regarding communications, we discarded the development of a proprietary network for interoperability reasons. Other standard wireless protocols such as Bluetooth or WiFi consume too much energy as they are intended for higher data rates. We decided to use ZigBee because its adequate data rate (250 kbps), security (128 bits AES encryption), low latency (30 ms to join and 15 ms to access the network) and energy efficiency. Its interoperability with other potential applications (home control and automation), future projection of the protocol, and its consequent cost reduction were other strategic reasons behind our decision (Geer, 2005).

The chosen ZigBee chip is ETRX2 from Telegesis. This is a ZigBee module on the 2,4 GHz ISM band based upon the Ember's EM250 chip. We used the development environment proposed by Ember to develop a ZigBee-compliant network following mesh topology (ZigBee Alliance, 2007). The chip consumes 30 mA when receiving or transmitting data and 10 µA in sleep mode. As we will use the radio exceptionally, just when are reasonable indications about a fall (when a threshold is exceeded), average power consumption due to communication is reduced.

The user interface consists of a single button and a buzzer for user interaction. Figure 3 shows the mobile device prototype. Its size, including battery, is 58x36x16 mm and it weights 30 gr.


Figure 3: Mobile device prototype.

In order to make the device useful is extremely important to keep it on working long time using the same set of batteries. That is why we gave preference to power-conservative and size of batteries among other designing requirements like transmission rate or processing time. Precise battery life estimation is very difficult because it will depende on the number of false alarms generated; every time the threshold is exceeded it sends data via ZigBee. Anycase, with the battery used (3 V, 1000 mA·h), it can last for several months daily sending several false falls to analize.

## 2.2 Software

As we said before, we designed a neural net to detect falls also aiming to minimize the number of false-falls compared to simple threshold based detectors.

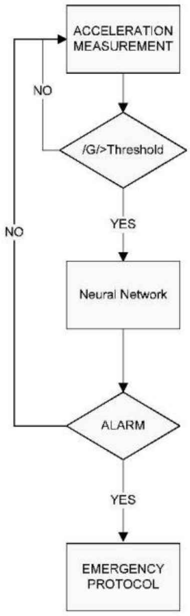


Figure 4: System's simplified flow diagram.

In our case, we use an acceleration threshold to get the "acceleration pattern" of the possible fall to be studied. Every 32 ms the device stores the current acceleration measurements. It keeps a buffer with the last 5 samples ($t_1 \approx 160$ ms). If the threshold is exceeded, a possible fall might have happened. Then we gather 25 samples more ($t_2 \approx 800$ ms) and all the data (960 ms) is sent via ZigBee to the PC. As we will see in section 3.2, those times and the threshold have been empirically set through acceleration pattern analysis of many falls and false-falls.

The "window time" ($t_w=t_1+t_2$) represents the time that the neural net analyzes the data in order to relation the detected event to a true fall.

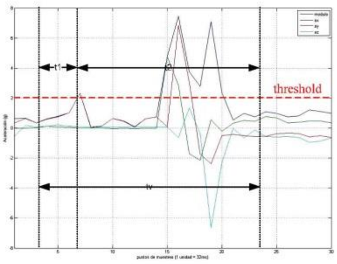


Figure 5: Window time.

In case the neural network detects a real fall, the PC asks the mobile device to buzz for one minute. During this time, the user can cancel the fall situation pressing the button; the user is okay and does not need assistance. In other case, an alert is sent to an assistance center asking for help.

## 3 NEURAL NETWORK DESIGN

We have chosen MLP (MultiLayer Perceptron) architecture because is the best neural network for pattern classification (Del Hoyo Alonso, 2003). MLPs are feedforward neural networks trained with the standard backpropagation algorithm. They are networks that learn how to transform input data into a desired response. As they are supervised, they require a set of known patterns with known responses to get trained. With one or two hidden layers, they can approximate virtually any input-output map. They have been shown to approximate the performance of optimal statistical classifiers in difficult problems (Neurosolution web, 2007).

Every acceleration point, within window time, is considered as input data to train neural network to distinguish between true and false falls (figures 1a and 1b). That is to say, if an event is represented by 30 samples for each axis (X, Y and Z), the number of inputs will be 90 (30x3). Consequently, it is the same as we give the net the whole graph to compare and classify.

We have decided to train the net with one hidden layer. To check if our choice is convenient or not, we have designed a test bench with different numbers of neurons, studying the absolute error in each case. To accelerate the training, we have chosen a bipolar sigmoid activation function for neurons of the hidden layer. The activation function of the output neuron is unipolar sigmoid so the output looks like a binary signal (1 = TRUE FALL; 0 = FALSE FALL).

The suitable number of neurons of the hidden layer is obtained doing simulations of different neural nets. Finally, we choose the one which produces the minimum absolute error. To reduce the number of simulations and to get patterns from the inputs able to generalize the results, we have defined a requirement: the number of inputs is greater than the number of neurons of the hidden layer.

### 3.1 Input Data Harvesting

Ten people of different ages, weight, height and sex imitated the movements of elderly people to create a data base of falls.

Table 1: Volunteers' characteristics.

| | |
|---|---|
| Age range | 25-40 years |
| Weight range | 44-105 kg |
| Height range | 1.58-1.90 m |

To get the data as close to reality as possible, the volunteers had the acceleration detector hanged around the neck. Volunteers were asked to simulate true and false falls situations.

TRUE falls:

Every volunteer falls down 10 times on a straw mat. The fall intensity changed (rough and soft) and the way of falling down too (side, front, backwards), hitting the ground with their back, hip, knees, etc.

FALSE falls:

Every volunteer flings himself down 5 times on the center and 5 times on the side of a sofa.

Every volunteer stumbles and hits a wall without falling down 5 times.

Every volunteer walks around for 2 minutes doing normal movements like sitting up and down in chairs, picking up things, etc.

During the test, the fall detector continuously samples the three acceleration axes each 32 ms sending them to a PC working as a data logger. In the end, we get a file with all the acceleration samples in axis X, Y and Z for every volunteer. The resulting data base consists of 99 samples of true falls (we had one error while collecting data) and 150 of false falls.

### 3.2 Input Data Analysis

First of all, data analysis has determined the window time length. After studying all the falls, we decided that an event could be represented with 30 samples (tv = 960 ms; t1 = 160 ms; t2 = 800 ms). This means that the microcontroller has to store always in memory the last five samples to send, in case the acceleration threshold is exceeded, the event to the PC to be analyzed.

With the window time selected, the number of inputs to the neuronal network is set to 90. In order to reduce the number of network entries -and consequently the network size- we have done a PCA (Principal Component Analysis). This method lies in referencing input data to a new origin and coordinate base.

In the new reference, the main components are chosen to be those with the maximum variance among samples (those with the highest covariance).

Therefore, if we take the samples representing more than 95% of covariance, the number of input will be reduced without losing significant information. This leads to suppose that the greater is the variance of an input, the more information it gives.

The acceleration threshold was decided experimentally. At first, guided by most of the bibliography (Chen et al., 2005), we chose a 3 g value. Then 97 out of 99 true falls and 121 out of 150 false falls surpassed the selected threshold.

Missing true falls is far worse than over-detecting false falls, thus we reduced the threshold to 2 g to prevent losing any fall. As expected, we got all the falls, but the number of false falls which surpassed the threshold, increased to 241 because even normal movements triggered the detection process.

After using PCA analysis with the 340 events (99 falls plus 241 false-falls), the number of inputs was reduced from 90 to 55, keeping the 95% of the covariance of the original data.

### 3.3 Network Performance

The network was trained used Levenberg-Marquardt algorithm (Neural-toolbox in Matlab).

We trained different MLP architectures 55xMx1 (being M the number of neurons in the hidden layer, $5 \leq M \leq 35$). We repeated this process ten times in order to ensure the network design and its performance. Each test randomly selected 80% of the events for training and 20% for validating. That is to say, from the whole 340 events (99 falls plus 241 false-falls), the validation group had 20 true falls and 48 events that could be confused with falls. In the end, a neural net with 22 hidden neurons was able to classify falls correctly.

When interpreting the neural net output give precedence to the fall detection. Thus, we decided that if the output is above or equal to 0.3, a fall is detected. On the other hand, if the output is below 0.3, the analyzed event was not a true fall.

In table 2 we can see the network performance for the ten tests.

Table 2: Validation group detection results.

| | Network fall detection / Fall events | Network fall detection / False-fall events |
|---|---|---|
| Test 1 | 20 / 20 | 0 / 48 |
| Test 2 | 20 / 20 | 0 / 48 |
| Test 3 | 20 / 20 | 1 / 48 |
| Test 4 | 20 / 20 | 0 / 48 |
| Test 5 | 18 / 20 | 1 / 48 |
| Test 6 | 20 / 20 | 1 / 48 |
| Test 7 | 16 / 20 | 1 / 48 |
| Test 8 | 18 / 20 | 0 / 48 |
| Test 9 | 17 / 20 | 1 / 48 |
| Test 10 | 15 / 20 | 0 / 48 |

We can see how the network is able to detect 92% of all the falls and filter up 99% of the events that can be confused with falls.

In figure 6, we show the network output we got for the validating group in third test.

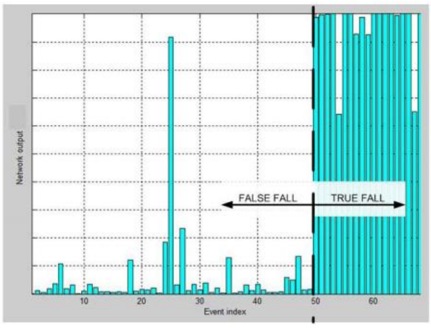


Figure 6: Network output for the third validation group.

## 4 CONCLUSIONS

The final results using MLP neural networks for fall detection have been quite satisfactory. The application classifies correctly 92% of the validation group falls, better performance than other detection methods: 80% in (Chen et al., 2005). Moreover, the number of false alarms is drastically reduced to 1%, which leads to enhance users trust on the fall detector. Nevertheless, a more extensive study with more users being also elderly has to be developed in order to gather more data and confirm the results.

Although the portable device can run for months with the same battery, the system needs a computer to analyze all the data. In order to reduce costs, it is possible to analyze the pattern remotely. As the amount of exchanged data is reduced, it could be sent via ADSL (if the person is at home), GPRS or even SMS to a service center. Anyhow our application gets better performance than others embedded in a microcontroller but a higher cost and complexity. To overcome this, we are currently minimizing the neural network size so it can run in a microcontroller or FPGA.

## ACKNOWLEDGEMENTS

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## REFERENCES

Alwan, M., et al., 2006. 'A Smart and Passive Floor-Vibration Based Fall Detector for Elderly'. Proc. The 2nd IEEE International Conference on Information & Communication Technologies: from Theory to Applications ICTTA'06, Damascus, Syria, April 2006.

Chen, J., et al., 2005. 'Wearable Sensors for Reliable Fall Detection'. Proc. 27th Annual International Conference of the Engineering in Medicine and Biology Society, IEEE-EMBS 2005, September 2005, pp. 3551–3554.

Degen, T., et al, 2005. 'SPEEDY: a fall detector in a wrist watch'. Proc 7th IEEE International Symposium on Wearable Computers, October 2005, pp. 184–187.

Del Hoyo Alonso, R. 2003. 'Supervised classification with Associative SOM.' IWANN 2003: 334-341

Doughty, K., et al, 2000. 'The design of a practical and reliable fall detector for community and institutional telecare', Journal of Telemedicine and Telecare, February 2000, 6, (1), pp. 150–154.

Eurostat web: http://epp.eurostat.ec.europa.eu/ last visited 2007

Geer, D., 2005. 'Users make a Beeline for ZigBee sensor technology'. IEEE Computer Magazine, 38, pp. 16–19.

Hansen, T.R., et al., 2005. 'Using smart sensors and a camera phone to detect and verify the fall of elderly persons'. Proc. European Medical & Biological Engineering Conference (EMBEC 2005), November 2005.

Nait-Charif, H., and McKenna, S. J., 2004. 'Activity Summarisation and Fall Detection in a Supportive Home Environment'. Proc. of the 17th international Conference on Pattern Recognition, (Icpr'04), Washington DC, August 2004, 4, pp. 323–326.

Neurosolution web.
http://www.nd.com/definitions/mlp.htm last visited 2007.

Noury, N., 2002. 'A Smart Sensor for the remote follow up of activity and fall detection of the elderly'. Proc. 2nd Annual International Special Topic Conference on Microtechnologies in Medicine & Biology, IEEE-MMB2002, Madison-USA, May 2002, pp. 314–317.

Rodriguez J.M., et al, 2005. 'Portable System for Patient Monitoring With Wireless Technologies'. The European Journal for the Information Professional, October 2005, 5, (5), pp. 46–52.

Sixsmith, A., and Johnson, N., 2004. 'A smart sensor to detect the falls of the elderly', IEEE Pervasive Computing, April-June 2004, 3, (2), pp. 42–47.

Tunstall web. http://www.tunstall.co.uk last visited 2007.

Williams, G., et al., 1998. 'A smart fall and activity monitor for telecare applications'. Proc. of the 20th IEEE Annual International Conference of the Engineering in Medicine and Biology Society, October 1998, 3, pp.1151–1154.

ZigBee Alliance: 'ZigBee Standard', 2007

# INDOOR LOCALIZATION BASED ON NEURAL NETWORKS FOR NON-DEDICATED ZIGBEE NETWORKS IN AAL

# Indoor Localization based on Neural Networks for Non-Dedicated ZigBee Networks in AAL

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**Abstract.** Indoor localization is one of the most appealing technologies in Ambient Assisted Living (AAL) applications, providing support for diverse services such as personal security, guidance or innovative interfaces. Dedicated systems can be deployed to provide that information, but it is possible to gain advantage of available elements to compute a location without requiring additional hardware. In this paper, a ZigBee network designed for a home control application is improved with a localization functionality based on neural networks, achieving room-level accuracy, and non introducing additional infrastructure constraints to the original application.

**Keywords:** Indoor localization, Neural networks, ZigBee, Ambient Assisted Living.

## 1 Introduction

There is a wide variety of systems that can provide the location of mobile indoors. Aside from those based on vision [1]—which do not require from a specific device to be located—or inertial ones [2]—on which the device measures its acceleration to integrate its position—, localization systems operate by making mobile device interact with some fixed devices. Usually, the mobile device receives some signal emitted by the fixed devices or vice versa, that can be ultrasonic [3][4][5], light [6][7][8] or RF [9][10][11].

These signals can be used in many different ways, like measuring the angle of arrival (AOA) and obtaining a location by triangulation, or estimating the distance between the mobile devices and the fixed devices by measuring time of arrival (TOA), time difference of arrival (TDOA) or received signal strength (RSSI), and compute location by multilateration or just provide a reference location by proximity to the fixed devices.

Higher accuracy is achieved with those systems that can measure these signals precisely, and can use analytic models to compute location (intersections of beams in AOA, circles in TOA or hyperbolic in TDOA), which normally require from specific deployments. An example of these systems is the one from Ubisense [12], which uses ultra wide band (UWB) signals and combines AOA and TDOA measurements to achieve an accuracy of a few centimeters. However, the cost of this system is in accordance with its accuracy, and can be prohibitive for many applications.

An interesting approach is to use Wi-Fi to compute location, like WHEREMOPS [9] WiPS [10] and Ekahau [13] systems do. That way, it is possible to reuse our WLAN existing infrastructure, but only Wi-Fi enabled devices can be located. These systems usually do not use analytic models to estimate location, but often compute a RSSI fingerprint for every possible location in the application scenario. The accuracy of these systems is about 3 meters—going to 1 meter in the best cases—, which can be enough for many applications.

Although Wi-Fi networks are available in many environments, in AAL applications it is common that wireless sensor networks (WSN) based on lighter technologies than Wi-Fi—such as ZigBee—are used. ZigBee [14] is a wireless standard designed to ease deployment of WSN, providing auto routing, self-healing mechanisms, very low power consumption, and it is of big interest to use it to provide location of mobile devices. ZigBee manufacturers like Texas Instruments include location-ability in their ZigBee transceivers [15], but as with other localization systems, it is required the mobile device to receive data from a number of fixed—reference—devices. Computing the location of a mobile device using analytic models requires 3 measurements to achieve a solution and more are needed to ensure redundancy and robustness to errors [16]. The same happens with fingerprint-based location techniques, which provide better results when more measurements are available. This means that it is often necessary to oversize the network in order to enable localization.

In this paper, it is proposed to use neural networks (NN) in order to compute location of a mobile device within a ZigBee network, but using the minimum number of nodes, i.e. only those strictly needed to the targeted application and the network requirements, without deploying extra nodes. First, scenario application and neural network design is presented. Then, localization provided by the neural networks is evaluated and lastly, conclusions and future work are presented.

## 2 Setup description

Is it possible to perform localization by using a non-dedicated ZigBee network? Within the MonAMI project [17] we have defined a smart AAL scenario where every sensor, actuator and HMI device uses ZigBee as communication network, with similar approaches in other related projects like EasyLine+ [18] or AmbienNet [19], and the objective is to provide these installations with localization services without increasing the cost, i.e., using the existing ZigBee infrastructure.

Obviously, we do not expect to achieve the accuracy of the localization systems presented in previous sections but just to provide room-level accuracy, which is enough for many home environments applications.

### 2.1 Scenario setup

To probe that hypothesis, we have deployed a ZigBee network on 4$^{th}$ floor of Bldg. Ada Byron at University of Zaragoza. In this environment—similar to a hospital or a residence—a number of ZigBee outlet actuators (devices able to connect and disconnect mains powered devices) has been distributed. These devices represent a set of sensors and actuators commonly present in smart environments. Its distribution was not designed for localization and follows a pseudo-random distribution, intended only to provide communication coverage in the entire scenario. From now on, we will call these reference devices as beacons, whose location of is represented in figure 1 by caps pointing to lobe direction of biggest radiation.

A mobile ZigBee device consisting on a HMI with two buttons, accelerometer—fall detector—and temperature sensor will be used as the localizable device, which we will denote as tag, and its position can be seen also in figure 1.

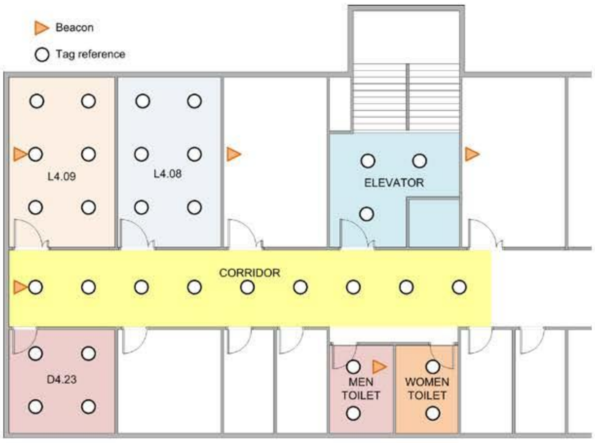


**Fig. 1.** Scenario map. Fixed devices are denoted by arrow caps, and tag reference locations are represented by circles.

### 2.2 Test definition

With the scenario presented, we consider the following experiment to validate our hypothesis.

The objective is to achieve room-level accuracy, so seven interest areas in the scenario are defined as location targets. Then a user, carrying the tag connected to the ZigBee network, will take up several positions inside each of these localization areas.

For every of these positions, four measured will be collected, each one with a different user orientation (north, west, south, east). Each measurement consists on the received signal strength (RSSI) with which the tag receives its neighbors.

This sequence was repeated in 32 locations, generating a pattern database with 500 sets of RSSI measurements. Information about the location of the beacons was not stored, as only RSSI was used to estimate the location of the tag.

## 3 Neural Network design

With the aim of discovering what NN drew best results, two methods were performed; a MultiLayer Perceptron (MLP) based on different architectures and a Self Organizing Map (SOM).

### 3.1 Data adaptation

Our database were normalized among (-1, 1) to facilitate the training of both networks. Previously, like the RSSI range is from -100 to 0, when a beacon is not listened by the tag, we assign the -105 value.

Next step was filtering the database. Three groups were made from database depending on the rule used to filter:

- *Group 1*: points where the tag detects at least one beacon.
- *Group 2*: points where the tag detects at least two beacons.
- *Group 3*: points where the tag detects at least three beacons.

There was no need to continue filtering because only 5 beacons were deployed. Finally, for every single group, three subgroups were created randomly: train (80% of points), test (10%) and validation (10%).

### 3.2. MLP

MultiLayer Perceptron architecture is one of the best NN to classify patterns [20]. MLP is a feedforward NN, trained with the standard backpropagation algorithm. MLP learns to link input data to a desired response. As it is supervised, it requires a set of known patterns and their corresponding responses during training process. With one or two hidden layers, it can approximate virtually any input-output map.

First of all it was necessary to decide the most suitable architecture to face the problem. So, a $5\times M\times 7$ architecture was chosen; where the 5 inputs are the RSSI of each beacon, M represents the number of hidden neurons and 7 the number of outputs which correspond to the locating areas.

To analyze network outputs, two thresholds were defined: Activation Threshold (AT) and Selection Threshold (ST). An output must exceed AT to be considered active and must be, at least ST, far away from the next output to be declared as the winner. In this case, AT and ST were fixed at 0.1 and 0.4 respectively.

Some MLP were simulated changing the value of M. For each group described in the previous section, the train subgroup was used to train the network and the test subgroup was used to detect the best network according to the minimum error obtained. Finally, five more simulations were done using the chosen architecture and defining its error as the mean of the validation error of all the simulations (validation subgroup was neither used for training the network nor for selecting it).

### 3.3. SOM

SOM are a good tool for the visualization of high-dimensional data. They can convert n-dimensional data into a simple geometric, for example 2-dimensional. They can be used also to produce some kind of abstractions [21] and they are really useful grouping data with similar characteristics. Matlab and the SOM ToolBox [22] has been used in order to train and generate the SOM.

In order to find out the best organizing map, one simulation, which consisted of 30 repetitions, was done training some maps and using the train subgroup. The selected map was the one which threw the minimum test error. Finally, this simulation was repeated five times and the error of the map was defined as the mean of the validation error of all the simulations (as with the MLP, validation subgroup was neither used for training the map nor for selecting it).

To quantify the error of each map, two methods were used:

a) *One label*. Neurons of the map are labeled by vote, that is to say, a neuron is labeled with the name of the zone where it has been activated more times.
b) *Two labels*. Neurons of the map are labeled by frequency (e.g. if a neuron has been activated 10 times by zone A, 5 by zone B and 1 by zone C, the neuron will be labeled with two labels: zones A and B). It does not happen everywhere in the map, but in specific boundaries. As we will consider later in conclusions, this method can be applied because of the surrounding peculiarities of the problem.

In both methods an error will be assumed every time a neuron is activated by a zone which is not linked to.

## 4 Evaluation

### 4.1. MLP

Tests conducted with MLP have not provided clear results. There is not a relationship between the number of beacons that the tag listens to and the location error. Nevertheless, all the methods that are using RSSI for location agree that the more beacons the better accuracy. MLP can be considered as a universal functions estimator [23] but, in this case, we have not enough information to obtain an algorithm. Maybe it is the reason why this architecture cannot provide a good solution.

The best architecture found in this case has been 5×18×7 with an average validation error of 20.2%.

### 4.2. SOM. One label method.

The first tests conducted with SOM showed a clear relationship between the number of beacons that the tag listens and location error (table 1). The average validation error decreases when the tag listens to more beacons. However, this error is still high, around 18.7 % in the best case (group 3).

**Table 1.** Classification error with SOM using only one label.

| Group number | Test error | Validation error |
|---|---|---|
| 1 | 17.20% | 24.00% |
| 2 | 12.65% | 19.59% |
| 3 | 11.11% | 18.66% |

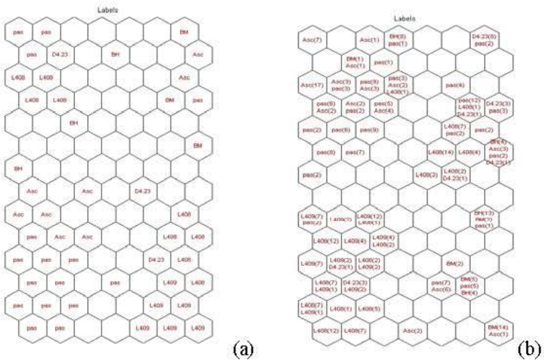

**Fig. 2.** SOM map for one label (a) and two labels (b) methods.

## 4.2. SOM. Two labels method

This fact leads to analyze the physical nature of the problem. The localization systems based on RSSI with ZigBee locates their resolution among 3m and 5m depending on the number of beacons (or fixed nodes). In this case, where a network with a minimum number of beacons has been forced, it would be logical to think that the accuracy in meters should be 5 meters or more.

Also, in the transition of localization areas without physical separation (door setting or the separation area without wall between the elevator hall and the corridor) the RSSI will be very similar. Therefore, if this system provided a location in meters it would not be difficult to provide coordinates and a radius of confidence. When this situation takes place, each time one user is placed less than 5 meters away from the contiguous area, the system will detect the user to be in one of the areas located in the radius of confidence within the two areas.

How can this idea be explained to SOM? If the activation of neurons is studied in detailed, it will be observed that there are areas in the map which are activated mainly by stimulus of two areas, i.e. "zone A" (7) and "zone B" (2). If the wining label is considered, in this case" zone A", when points are set in the "zone B", which are very close to this area, and the map activates the neuron, the situation is considered as an error. Nevertheless when using any other method, if it is within the radius of confidence, it is considered correct.

Therefore, if two labels are considered in those neurons responding to two specific boundaries, it won't be know whether the user is located in the "zone A" or in "zone B", but the area in which the user is located will be known, and probably even the boundary among them. Obviously, it can occur that the neuron is activated by stimulus in the two areas separated by 5 meters, being this unusual situation. In this case one only label will be considered.

Taking into account this situation the error in the localization is cut down drastically to 7.1% for the sample- 3. In contrast, in some situations the network feedback is "zone A"-"zone B" instead of one only area.

## 5 Conclusions

After analyzing the test results, we can conclude that it is possible to perform location at room-level accuracy using only the RSSI of a non-dedicated location ZigBee network as input. This system has a lower precision than other systems which are using a dedicated location ZigBee network with more fixed nodes. Nevertheless, it can provide an extra location service in smart environment which are using ZigBee at no cost.

If we can guarantee that the tag can listen to three or more beacons in every position, this system can locate with an average location error rate of 7.1 %. This result is important since it can be used to decide improving the coverage in an existing installation if localization services are wanted.

Besides that, a novel two labels classification method has been introduced, proving its relationship with the physical problem.

Future work points to reduce uncertainty in limited areas by using tracking algorithms that helps to discriminate between non-joined areas.

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## References

1. S. Julier, S., Bishop, G.: Tracking: how hard can it be?. In: IEEE Computer Graphics and Applications, Vol. 22 (6), 22--23 (2002).
2. Jonker, P., Persa, S., Caarls, J., de Jong, F., Lagendijk, I.: Philosophies and technologies for ambient aware devices in wearable computing grids, Computer Communications 26, 1145--1158 (2003).

3. Priyantha, N. B., Chakraborty, A., Balakrishnan, H.: The Cricket location-support system. In: 6th Annual international Conference on Mobile Computing and Networking, MobiCom '00, pp. 32--43. ACM, New York, NY (2000).
4. Ward, A., Jones, A., Hopper, A.: A New Location Technique for the Active Office, IEEE Personal Communications, Vol. 4 (5), 42--47 (1997).
5. Marco, A., Casas, R., Falco, J., Gracia, H., Artigas, J. I., Roy, A.:. Location-based services for elderly and disabled people. Comput. Commun. 31, 6, 1055--1066 (2008).
6. Want, R., Hopper, A., Falcão, V., Gibbons, J.: The active badge location system. ACM Trans. Inf. Syst. 10, 1, 91--102 (1992).
7. Römer, K.: The Lighthouse Location System for Smart Dust. In: 1st international Conference on Mobile Systems, Applications and Services, MobiSys '03. Pp. 15-30. ACM, New York, NY (2003).
8. Welch, G., Bishop, G., Vicci, L., Brumback, S., Keller, K., Colucci, D.: High-Performance Wide-Area Optical Tracking: The HiBall Tracking System. Presence: Teleoper. Virtual Environ. 10, 1, 1--21 (2001).
9. Wallbaum, M.: WHEREMOPS: An Indoor Geolocation System, In: IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications, Vol. 4, pp. 1967--1971, IEEE Press, New York (2002).
10. Kitasuka, T., Hisazumi, K., Nakanishi, T.: WiPS: Location and motion sensing Technique of IEEE 802.11 devices. In: Third International Conference on Devices Information and Applications, Vol. 2, pp. 346--349, IEEE Press, New York (2005).
11. Anastasi, G., Bandelloni, R., Conti, M., Delmastro, F., Gregori, E., Mainetto, G.: Experimenting an Indoor Bluetooth-Based Positioning Service. In: 23rd International Conference on Distributed Computing Systems, pp 480--483 (2003).
12. Cadman, J.: Deploying Commercial Location-Aware Systems. In: Fifth International Conference on Ubiquitous Computing, pp. 4--6 (2003).
13. Ekahau Real Time Location System, http://www.ekahau.com/, 2009
14. ZigBee Alliance, http://www.ZigBee.org
15. Texas Instruments, Low power RF System-on-Chip for ZigBee Applications, http://www.ti.com/corp/docs/landing/cc2431
16. Casas, R., Cuartielles, D., Marco, A., Gracia, H. J., Falco, J. L.: Hidden Issues in Deploying an Indoor Location System. In: IEEE Pervasive Computing 6, 2, pp. 62--69 (2007).
17. Monami Project site: http://www.monami.info/, 2009
18. EasyLine+ Project site: http://www.easylineplus.com/, 2009
19. AmbienNet Project site: http://www.atc.us.es/ambiennet/, 2009
20. Del Hoyo, R, Buldain, D. Marco, A.: Supervised classification with Associative SOM. In: 7th International Work-Conference on Artificial and Natural Neural Networks IWANN 2003, pp. 334--341 (2003).
21. Teuvo Kohonen. The Self-Organizing Map (SOM). http://www.cis.hut.fi/projects/somtoolbox/theory/somalgorithm.shtml
22. SOM ToolBox. Helsinki University of Technology. http://www.cis.hut.fi/projects/somtoolbox/ SOM ToolBox
23. Funahashi, K. I.: On the approximate realization of continuous mappings by neural Networks. In: Neural Networks, 2 (3), pp. 183--192 (1989).

## ANNEX III. FUNCTIONALITIES EVALUATED IN EACH TEST SITUATION

This annex summarizes the functionalities tested in each test situation.

**Situation 1: "Coming home from shopping".** The participant comes home from shopping and s/he is required to store all the items from the shopping bag into the fridge, freezer or cupboards. One of the items is out of date.

**Situation 2: "Making dinner".** The participant is asked to show a frozen pizza to the standalone reader so the interface identifies the item and asks the user if s/he wants to cook it. If yes it goes to the set_oven_configuration with the needed parameters (parameters can be hardcoded in the scenario if not implemented). The participant is in the living room (maybe watching TV) when the food in the oven is finally done cooking.

**Situation 3: "Doing my laundry".** The participant is asked to do a laundry (maybe just the spinning program if no water) using different clothing items.

**Situation 4: "My house is on fire".** The participant is resting and watching TV while the hob is on. The smoke detector is triggered simulating an emergency.

Functionalities versus situations:

| | **Situations** | | | |
|---|---|---|---|---|
| **Advanced functionalities of prototypes** | **S1** | **S2** | **S3** | **S4** |
| Indication of fridge/freezer status:<br>On/Off/Problem/Disconnected, door open or closed, current temperature | X | | | |
| Display of fridge/freezer contents | X | | | |
| Support for configuration of fridge/freezer settings:<br>Set target temperature | | | | |
| Indication of washing machine status:<br>On/Off/Problem/Disconnected, door open or closed, time to finish | | | X | |
| Display of washing machine contents | | | X | |
| Support for configuration of washing machine settings:<br>Set washing program, switch on/off | | | X | |

| | | | | |
|---|---|---|---|---|
| Indication of hob status:<br><br>On/Off/Problem/Disconnected | | | | X |
| Support for configuration of hob settings:<br><br>Switch off | | | | X |
| Indication of oven status:<br><br>On/Off/Problem/Disconnected, time to finish, temperature | | X | | X |
| Support for configuration of oven settings:<br><br>Set target temperature, switch on/off, set starting cooking time, set duration | | X | | X |
| Advise if the fridge/freezer door is left open | X | | | |
| Advise if food is past its use-by date | X | | | |
| Advise if food is approaching its use-by date | X | | | |
| Warning about fridge/freezer breakdown | X | | | |
| Advise of wrong mix of clothes (e.g. mix of white and coloured clothes) | | | X | |
| Advise of unsuitable fabrics (e.g. dry clean only) | | | X | |
| Advise if machine loaded but not yet on | | | X | |
| Advise if cycle interrupted | | | X | |
| Advise if unload incomplete | | | X | |
| Advise when machine is on final spin | | | X | |
| Advise when cycle finished | | | X | |
| Warning about washing machine breakdown | | | X | |
| Advise if hob is left on with no pan | | | | |

| | | | | |
|---|---|---|---|---|
| Warning about hob breakdown | | | | |
| Advise when food in the oven is ready | | X | | |
| Warning about oven breakdown | | X | | |
| Inform how a cloth should be washed, its colour, etc. | | | | |
| Inform how food should be cooked, its expiration date, etc. | | X | | |
| Advise “Fire detected” emergency | | | | X |
| Advise “Smoke detected” emergency | | | | X |
| Advise “Water detected” emergency | | | | |
| Inform whenever there are changes in conduct patterns that can identify any loss of abilities in the user. | | | | |
| Adapt system´s functionality to the user(supervised by the caretaker) | | | | |

# ANNEX IV. EVALUATION TOOLS

BACKGROUND INTERVIEW QUESTIONNAIRE (BIQ)

Interviewer ID:

Participant ID:

# User background interview

DATE OF TESTING: SESSION:

| How is this form being completed? | |
|---|---|
| Directly by the user | ☐ |
| -OR- | |
| Filled in by proxy (carer, spouse, etc) on behalf of the user | ☐ |
| **If the form is filled in by proxy:** | |
| Are answers exactly what the user tells the proxy to write? | ☐ |
| -OR- | |
| Are answers what the proxy assumes of the user?<br>(e.g. user is unable to answer for her(him)selve) | ☐ |

## I. Participant Information

We cannot identify you from the information that we are requesting in this section, but it will help us to analyse the results of this questionnaire if you could give us some general information about yourself.

**Are you?**

☐ Male ☐ Female

**How old are you?**

| Less than 50 | 50-59 | 60-69 | 70-80 | Over 80 |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

**Where do you live?**

| Private Home | | Residence | |
|---|---|---|---|
| ☐ | Without assistance | ☐ | Non assisted |
| ☐ | Periodic home assistance | ☐ | Assisted |
| ☐ | Periodic visits to an assistance centre | ☐ | Mixed |

**What is your most recent education?**

| No studies | Primary | Secondary | GCE A-levels or SCE | Higher education | Masters degree | PhD |
|---|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**What is/was your main occupation?**

| | |
|---|---|
| ☐ Management | ☐ Health |
| ☐ Natural and Applied Sciences | ☐ Art, Culture, Recreation and Sport |
| ☐ Sales and Services | ☐ Primary industry |
| ☐ Business, Finance and Administration | ☐ Processing, Manufacturing and Utilities |
| ☐ Social science, Education and Government | ☐ Trades, Transport and Equipment operators |
| ☐ Other___________________________ | |

## II. Household activities experience

**How often do you use household appliances?**

| | | | |
|---|---|---|---|
| ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |

**With which frequency do you use these appliances?**

| | | | | |
|---|---|---|---|---|
| Washing machine | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |
| Fridge | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |
| Oven | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |
| Cooker hob | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |
| Microwave | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |
| Dishwasher | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |
| Other: ____________ | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |
| Other: ____________ | ☐ Never | ☐ Barely | ☐ Sometimes | ☐ Often |

**Usual activities (e.g. housework, family or leisure activities)**

| | |
|---|---|
| ☐ | I have no problems with performing my usual activities |
| ☐ | I have some problems with performing my usual activities |
| ☐ | I am unable to perform my usual activities |

Among all household tasks, with which ones do you need extra help to carry on the task? (E.g. do the laundry, do the shopping, ironing, cooking, do the washing up, sweeping etc.)

____________________________________________________________

____________________________________________________________

____________________________________________________________

_________________________________________________________

__________________________________________________________

## III. Disability

A Disabled person is defined in the Disability Discrimination Act (2005) as someone with a physical or mental impairment that has a substantial and long-term impact on their ability to carry out day-to-day activities. This excludes situations where sight can be corrected by glasses or contact lenses. Having read this do you consider yourself to be covered by the definition?

☐ Yes ☐ No

If you answered "Yes" to the question above, would you like to please indicate the nature of your disability (tick as many as are applicable):

| Limited visual ability | | Limited aural ability | | Limited physical ability | | Limited mild-cognitive ability | |
|---|---|---|---|---|---|---|---|
| High | ☐ | High | ☐ | High | ☐ | High | ☐ |
| Medium | ☐ | Medium | ☐ | Medium | ☐ | Medium | ☐ |
| Low | ☐ | Low | ☐ | Low | ☐ | Low | ☐ |

## IV. Computer Experience

If you have never used computers, you have finished the test. If not, answer the following questions.

**How much experience have you had with these technologies?**

| | None | Basic | Average | High | Expert |
|---|---|---|---|---|---|
| Computers | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mobile phones, PDA... | ☐ | ☐ | ☐ | ☐ | ☐ |

**How many hours a day do you use a computer?**

| 1-3 hours | 3-8 hours | More than 8 hours |
|---|---|---|
| ☐ | ☐ | ☐ |

**What do you typically use your computer for?**

| | |
|---|---|
| ☐ Games and pleasure | ☐ Design & graphics (architecture, modelling etc.) |
| ☐ Multimedia (music, videos, pictures etc.) | ☐ Communications (email, chat, etc.) |
| ☐ Accounting/Finance | ☐ Shopping online |
| ☐ Data storage (i.e., data bases) | ☐ Searching for information on the Internet |
| ☐ Word processing or publishing | ☐ Other ___________________________ |

**Thank you for your participation!**

# SITUATION QUESTIONNAIRES (SQ)

# Situation questionnaires

Note: the grey area must be filled by the observers and/or test moderator, and the rest has to be filled with users' answers.

| **Situation 1: "Coming home with shopping"** | | | |
|---|---|---|---|
| How long did the situation take? | | | |
| How many trials did the user need? | | | |
| Is the user able to perform the interaction(s) successfully? | Yes: ☐ | No: ☐ | Partly: ☐ |
| **Do you find these functionalities useful? (Ask the user)** | **Yes** | **No** | **Partly** |
| Indication of freezer/fridge status | | | |
| Indication of freezer/fridge contents | | | |
| Advise if the freezer/fridge door is left open | | | |
| Advise if the use-by date of food is exceeded | | | |
| Advise if food is approaching the use-by date | | | |

| **Situation 2: "Making dinner"** | | | |
|---|---|---|---|
| How long did the situation take? | | | |
| How many trials did the user need? | | | |
| Is the user able to perform the interaction(s) successfully? | Yes: ☐ | No: ☐ | Partly: ☐ |
| **Do you find these functionalities useful? (Ask the user)** | **Yes** | **No** | **Partly** |
| Indication of oven status | | | |
| Audible/visual notifications/reminder of ready-to-eat food | | | |
| Support for remote configurable settings | | | |
| Content-addressed cooking suggestions | | | |

| **Situation 3: "Doing my laundry"** | | | |
|---|---|---|---|
| How long did the situation take? | | | |
| How many trials did the user need? | | | |
| Is the user able to perform the interaction(s) successfully? | Yes: ☐ | No: ☐ | Partly: ☐ |
| **Do you find these functionalities useful? (Ask the user)** | **Yes** | **No** | **Partly** |
| Indication of washing machine status | | | |
| Indication of washing machine contents | | | |
| Audible/visual notification of wrong mix of clothes | | | |
| Audible/visual notification of unsuitable clothes | | | |
| Audible/visual notification of cycle on final spin | | | |
| Support for remote configurable settings | | | |

| | | | |
|---|---|---|---|
| Content-addressed programme suggestions | | | |
| Audible/visual notification of the washing cycle complete | | | |

| **Situation 4: "My house is on fire"** | | | |
|---|---|---|---|
| How long did the situation take? | | | |
| How many trials did the user need? | | | |
| Is the user able to perform the interaction(s) successfully? | Yes: ☐ | No: ☐ | Partly: ☐ |
| **Do you find these functionalities useful? (Ask the user)** | **Yes** | **No** | **Partly** |
| Advise "Fire detected" emergency | | | |
| Advise "Smoke detected" emergency | | | |
| Indication of hob status | | | |
| Support for remote configurable settings: turn off the hob | | | |

| **Notes:** |
|---|
| |

## OBSERVATION FORM (OF)

# User Observation Questionnaire

**Interviewer ID:**

**Participant ID:**

## Impressions:

| **The participant:** | Strongly disagree 1 | 2 | 3 | 4 | Strongly agree 5 |
|---|---|---|---|---|---|
| P1. Sees and identify the icons/text | | | | | |
| P2. Seems to understand the meaning of written notifications including symbols and icons | | | | | |
| P3. Hear the notifications | | | | | |
| P4. Seems to understands the meaning of audible notifications | | | | | |
| P5. Uses correctly the speaking commands | | | | | |
| P6. Seems to understand how to use the product with speaking commands | | | | | |
| P7. Uses correctly the TV remote control | | | | | |
| P8. Seems to understand how to use the product with the TV remote control | | | | | |
| P9. Uses correctly the touch screen | | | | | |
| P10. Seems to understand how to use the product with the touch screen | | | | | |
| P11. Seems confident using the system | | | | | |
| P12. Seems to understand the system | | | | | |
| P13. Interacts with the kitchen appliances easily | | | | | |
| P14. Has learnt easily to use the product | | | | | |
| P15. Can the user start and execute a task by himself/herself without external help? | | | | | |
| P16. If a different sound is introduced (notification), is the user capable of recognizing it and of finding out from where it comes? | | | | | |
| P17. Remembers a pending task (commands/facts) | | | | | |

## Observation/Comments:

USER QUESTIONNAIRE (UQ)


**Interviewer ID:** **Date:** **Session:**

**Participant ID:**

## USABILITY

### 1. Do you think the product was easy to use?

| Very difficult | Difficult | Normal | Easy | Very easy |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments (Did it require physical effort, mental effort?):**

### 2. Do you think it was easy to learn how to use the product?

| Very difficult | Difficult | Normal | Easy | Very easy |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments:**

### 3. Do you think the product adapts to your particular needs and abilities?

| Totally does not adapt | Does not adapt | Adapts | Adapts well | Totally adapts |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments (how to enhance the product):**


### 4. Do you think there might be any risks related to the use of the product?

In your case: Physical risks, intimacy risks, others (specify …):

| Totally unsafe | Very unsafe | Neither | Very safe | Totally safe |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

In the environment: Visual impact, physical barriers, ecologic risks, others (specify …):

| Totally unsafe | Very unsafe | Neither | Very safe | Totally safe |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

### 5. How do you think the product reacts to the different input devices?

In the case of: Touch screen

| Very bad | Bad | Normal | Good | Very good |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

In the case of: TV remote control

| Very bad | Bad | Normal | Good | Very good |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

In the case of: Speaking command

| Very bad | Bad | Normal | Good | Very good |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |


## ACCESSIBILITY

**6. Were the element/icons of the screen easy to see and identify?**

| Very difficult | Difficult | Normal | Easy | Very easy | Not used |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

(If you have selected "not used" discard next questions and go to #9)

**7. If you have had any difficulty, please, mark the features that have been a problem.**

| Colours | Contrast | Forms | Extracting form from the global set | Brightness | Size |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**8. Were elements/icons easy to understand?**

| Yes | No | Partially |
|---|---|---|
| ☐ | ☐ | ☐ |

**9. If you have had any difficulty, please, mark the elements that have been a problem.**

| Text | Icons | Other |
|---|---|---|
| ☐ | ☐ | |

**10. What interfaces have been easier to use?**

| TV | Touch screen | Mobile device | Others |
|---|---|---|---|
| ☐ | ☐ | ☐ | |

**11. What do you think about the sounds of the product? (messages, warnings, etc)**

| Very bad | Bad | Normal | Good | Very good | Not used |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

(If you have selected "not used" discard next questions and go to #11)

**12. If you think that the sound of the product is bad or very bad, what sound features will you improve?**

| Level | Clarity | Ambient noise | Location of the sound source | Other |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | |

13. Do you think that the spoken notifications/beeps were comprehensible?

| Totally incomprehensible | Very incomprehensible | Comprehensible | Very comprehensible | Totally comprehensible |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

14. If you think that the spoken notification/beeps are totally incomprehensible/very incomprehensible please, mark the reason.

| Notification are too large | Beeps are incomprehensible | Others |
|---|---|---|
| ☐ | ☐ | |

15. Do you think that the speaking commands are easy to use?

| Very difficult | Difficult | Normal | Easy | Very easy | Not used |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

(If you have selected "not used" discard next questions and go to #13)

16. If you think that the speaking commands are difficult/very difficult to use please, mark the reason.

| Too complicated | Too much to remember | Difficult to learn | Too much information | Not enough information | Others |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | |

17. Do you understand how to use the product with speaking commands?

| Yes | No | Partially |
|---|---|---|
| ☐ | ☐ | ☐ |

18. Do you think that is easy to use the product with the TV remote control?

| Very difficult | Difficult | Normal | Easy | Very easy | Not used |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

(If you have selected "not used" discard next questions and go to #15)


19. If you think that the product is difficult/very difficult to use please, mark the reason.

| Too complicated | Too much to remember | Difficult to learn | Too much information | Others |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | |

20. Do you understand how to use the product with the TV remote control?

| Yes | No | Partially |
|---|---|---|
| ☐ | ☐ | ☐ |

21. Do you think that is easy to use the product with the touch screen?

| Very difficult | Difficult | Normal | Easy | Very easy | Not used |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

(If you have selected "not used" discard next questions and go to #17)

22. If you think that the product is difficult/very difficult to use please, mark the reason.

| It is complicated | Too much to remember | Difficult to learn | It shows too much information | It does not provide enough information | Others |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | |

23. Do you understand how to use the product with the touch screen?

| Yes | No | Partially |
|---|---|---|
| ☐ | ☐ | ☐ |

24. Do you think that, in general, the product is easy to use?

| Very difficult | Difficult | Normal | Easy | Very easy |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |


25. If you think that the product is difficult/very difficult to use please, mark the reason.

| Too complicated | Too much to remember | Difficult to learn | Too much information | Not enough information | Others |
|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | |

26. In general, do you understand how to use the product?

| Yes | No | Partially |
|---|---|---|
| ☐ | ☐ | ☐ |


## FUNCTIONALITY

**27. In general, do you think the product is suitable to accomplish the purposes explained at the beginning of the test?**

| Totally unsuitable | Very unsuitable | Suitable | Very suitable | Totally suitable |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**28. Do you think the product will help you to carry out daily activities?**

| Totally unhelpful | Very unhelpful | Helpful | Very helpful | Totally helpful |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**29. Do you think the product can increase your quality of life?**

| Not at all | A bit | Some | Very much | Totally |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**30. Do you think you will be able to live more independently using this product?**

| Not at all | A bit | Some | Very much | Totally |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:


## PERFORMANCE

### 31. After having performed the test, do you think the product works reliably?

| Totally unreliable | Very unreliable | Reliable | Very reliable | Totally reliable |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| Comments: | | | | |

### 32. Did you find the help messages useful? (only relevant if help was used)

| Totally unhelpful | Very unhelpful | Helpful | Very helpful | Totally helpful |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| Comments: | | | | |


## SATISFACTION

### 33. Were you comfortable using the product?

| Totally uncomfortable | Very uncomfortable | Comfortable | Very comfortable | Totally comfortable |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

### 34. Did you feel embarrassed using the product?

| Totally embarrassed | Very embarrassed | Embarrassed | A bit embarrassed | Not embarrassed |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

### 35. Overall, are you satisfied with the product?

| Totally unsatisfied | Very unsatisfied | Satisfied | Very satisfied | Totally satisfied |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**FUTURE USE/OUTCOME**

**36. Do you think you might end up dependent of the product if you use it in the future?**

| Great dependence | Much dependence | Some dependence | Little dependence | No dependence |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments:**

**37. Do you consider that this product may isolate you from your actual social relationships?**

| Total isolation | Much isolation | Some isolation | Little isolation | No isolation |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments :**

**38. If the price of the product was similar to a conventional appliance, would you buy it?**

| Definitely not | Probably not | Perhaps | Probably | Definitely |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

**Comments:**

## CAREGIVER QUESTIONNAIRE (CQ)

# ANNEX IX. BACKGROUND CARER QUESTIONNAIRE (BCQ)

The BCQ objective is to find and measure the relevant information about the carer and (if it's the case, of the person cared for).

## I. Participant information

We cannot identify you with the information acquired in this section but it will help to analyse the results of the questionnaire if it provides any feedback regarding general information about you.

**Sex**

| Male | Female |
|---|---|
| ☐ | ☐ |

**¿Where do you usually perform your caretaker tasks?**

| Private home | | Assistance centre | |
|---|---|---|---|
| ☐ | Familiar | ☐ | Residence |
| ☐ | Home help | ☐ | Daylight centre |
| ☐ | Other ..... | ☐ | Other..... |

**¿What is your professional profile?**

## II. Disability

Does the person you are helping have a disability?

☐ Yes ☐ No

Percentage of recognised disability _______%

Do you mind to tell us about the disability or limitations of the person you are helping and if they are recognized? (Select as many as applicable)


| limited visual disability | limited audible disability | limited physical disability | limited cognitive disability |
|---|---|---|---|
| High ☐ | High ☐ | High ☐ | High ☐ |
| Average ☐ | Average ☐ | Average ☐ | Average ☐ |
| Low ☐ | Low ☐ | Low ☐ | Low ☐ |

### III. User´s knowledge level about new technologies and/or computing (e.g. personal computer)

If you have never used a computer, you can skip this part. If you did, please answer the following questions.

**¿How much experience do you have with new technologies?**

| | Nothing | Basic | Average | High | Expert |
|---|---|---|---|---|---|
| Internet | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mobile phones | ☐ | ☐ | ☐ | ☐ | ☐ |
| e-mail | ☐ | ☐ | ☐ | ☐ | ☐ |
| Office tools | ☐ | ☐ | ☐ | ☐ | ☐ |

**Thanks for your participation**


# ANNEX X. CARER QUESTIONNAIRE (CQ)

The objective of the CQ is to find the opinion of the carer about the system, its features and its capacity to extend the time a person can remain independent.

**Do you think the product would be easy to use?**

| Very difficult | Difficult | Normal | Easy | Very easy |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| Comments (Did it require physical effort, mental effort?): | | | | |

**Do you think it would be easy to learn how to use the product?**

| Very difficult | Difficult | Normal | Easy | Very easy |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| Comments: | | | | |

**Do you think the product would adapt to the particular needs and abilities of the person you care?**

| Totally does not adapt | Does not adapt | Adapts | Adapts Well | Totally adapts |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| Comments (how to enhance the product): | | | | |

**In general, do you think the product would suitable to accomplish the purposes explained?**

| Totally unsuitable | Very unsuitable | Suitable | Very Suitable | Totally suitable |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |
| Comments: | | | | |


**Do you think the product will help the person you care to carry out daily activities?**

| Totally unhelpful | Very unhelpful | Helpful | Very Helpful | Totally helpful |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**Do you think the product can increase the quality of life of the person you care?**

| Not at all | A bit | Some | Very much | Totally |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**Do you think the person you care will be able to live more independently using this product?**

| Not at all | A bit | Some | Very much | Totally |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**Put yourself in the place of someone who is taking care of a family member.**
**If the appliance equipment had s similar cost than another one,**
**¿Do you think it could be interesting to purchase? ¿for how much?**

| Up to 2.000€ | from 2.000 to 4.000€ | from 4.000 to 6.000€ | More than 6.000€ | I will not buy it |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ |

Comments:

**Score from 1 to 5 the usefulness you think that the functionalities of the system have regarding the related activities.**

| ACTIVITIES | Health maintenance | | Carry out domestic tasks | | | Make decisions* |
|---|---|---|---|---|---|---|
| **SYSTEM FUNCTIONALITIES** | Avoid risks at home | Ask for help in case of emergency | Prepare a meal | Do Shopping | Do laundry/ironing | Domestic Tasks |
| Show appliance status through the adapted interfaces | | | | | | |
| Show fridge contents and trigger a warning if any food items are expired or about to expire | | | | | | |
| Show washing machine contents to know the type of clothes | | | | | | |
| Trigger a warning if there is a wrong mix of clothes or unsuitable fabric. | | | | | | |
| Program appliance status through the adapted interfaces | | | | | | |
| Program suggestions when using the oven or the washing machine | | | | | | |
| Trigger warnings and reminders when the appliances require attendance (Door left open, Laundry finished, etc) | | | | | | |
| Trigger emergency warnings (fire, smoke, flood) and act in case there is no response (for example, turn off appliances automatically if there is smoke) | | | | | | |
| Detect routine changes in the kitchen to inform whenever there are changes in conduct patterns that can identify any loss of abilities in the user. | | | | | | |
| Detect routine changes in the | | | | | | |


| | | | | | | |
|---|---|---|---|---|---|---|
| kitchen to adapt system´s functionality to the user(supervised by the caretaker) | | | | | | |

*for carers attending people with cognitive disability or mental illness

### ¿Could you give us your opinion about the data collection survey?

**Comment things you miss, things you would remove, interpretation, simplicity …**

**THANKS FOR YOUR COLLABORATION**