

# Ambient Assisted Living Deployment Aims to Empower People Living With Dementia. (AnAbEL)

MSc by research in Ambient Assisted Living  
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## **ABSTRACT**

Ambient Assisted Living aims to support the wellbeing of people with special needs by offering assistive solutions. Those systems focused on dementia claim to increase the autonomy of people living with dementia by monitoring their activities. Thus, topics such as Activity Recognition related to dementia and specific solutions such as reminders and tracking users by Global Positioning System offer great advances that seek users' safety and to preserve their healthier lifestyle. However, these solutions address secondary parties by providing useful activities logs or alerts but excluding the main interested user: the person living with dementia. Although primary users are taken into consideration at some design stages by using user-centred design frameworks, final products tend not to fully address the user's needs. This paper presents an Ambient Intelligent system aimed to reduce this limitation by developing a final solution more strongly focused on enhancing a healthy lifestyle by empowering the user's autonomy. Through continued activities monitoring in real-time, the system can provide reminders to the users by coaching them to keep healthy routines. Continuous monitoring also provides a complete user's behaviour tracking and the context-awareness logic used involves the caregivers through alerts when necessary to ensure the user's safety. This article describes the process followed to develop the system aimed to cover the previous concerns and the practical feedback from health professionals over the system deployment working in a real environment.

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## Table of Common Abbreviations

<b>AAL</b>	Ambient Assisted Living
<b>ADL</b>	Activities Of Daily Living
<b>AmI</b>	Ambient Intelligent
<b>APP</b>	Application
<b>AR</b>	Activity Recognition
<b>BLE</b>	Bluetooth Low Energy
<b>GPS</b>	Global Positioning System
<b>GUI</b>	Graphical User Interface
<b>IIS</b>	Microsoft Internet Information Services
<b>IoT</b>	Internet Of Thing
<b>MCI</b>	Middle Cognitive Impairment
<b>MR</b>	MReasoner
<b>MW</b>	Middleware
<b>PIR</b>	Passive Infrared Sensor
<b>PwD</b>	People Living With Dementia
<b>UCD</b>	User Centred Development
<b>UWB</b>	Ultra Wide Band

# 1. Introduction

## 1.1. Dementia

The Diagnostic and Statistical Manual of Mental Disorders 2013 (DSM-5) attributes the origin of cognitive impairment to different disorders and diseases such as Alzheimer's disease, Cerebrovascular disease (Vascular Neurocognitive Disorder), Frontotemporal Lobar Degeneration (Frontotemporal Neurocognitive Disorder), Dementia with Lewy Bodies (Neurocognitive Disorder with Lewy Bodies), Parkinson's disease, Huntington's disease, Traumatic Brain Injury, HIV Infection, Prion Disease another medical condition and multiple etiologies. Besides, it distinguishes between two main grades of general definitions: Dementia and mild cognitive impairment (MCI). According to DSM-5, dementia refers to a severe cognitive decline where acquired cognitive impairment has become severe enough to compromise social and/or occupational functioning, whilst MCI is an intermediate state between normal cognition and dementia.

Dementia is not a disease itself but rather a set of symptoms caused by different diseases previously listed. However, it is considered a degenerative disorder that, currently, does not have an efficient treatment to cure. Despite that, existing treatments aim to reduce the impairment or other conditions related to secondary symptoms (depression, anxiety, physical functionality, etc.), to give people living with dementia (PwD) a better lifestyle.

The risk factors associated with incidence of dementia are very diverse and each one has a different impact on each disorder. (Hugo & Ganguli, 2014) presents risk factors about dementia population as demographical, genetic, medical factors, psychiatric risk (as anxiety or depression), head injury, protective factor (related to the brain ability to manage the effects), pharmacological factor, educational, lifestyle (diet, sport) and environment. However, regardless of factors, the incidence of dementia is strongly related to age, with a greater incidence from 65 years when the risk is 5 times bigger (approximately 15 to 20 percent of people aged 65 or older have MCI) according to the Alzheimer's Association report (2015). Today's developed countries, where the quality of life guarantees people to reach larger longevity, older population is growing and thereby the dementia incidence associated as well (Hugo & Ganguli, 2014).

Despite the fact that there is no efficient test to catalogue a person into dementia or MCI, there are common symptoms associated with dementia. Professional worldwide Health Services and Alzheimer's Organisations reached a consensus/agreement to highlight the following:: memory loss, difficulty concentrating, finding it hard to carry out familiar daily tasks, such as getting confused over the right change when shopping, struggling to follow a conversation or find the right word, being confused about time and place and mood changes. Although these symptoms can vary in severity and occurrence among the different diseases and persons, they are the main cause of problems for PwD, relatives and the Health care sector.

Currently, Alzheimer's is the most extended degenerative disease among the other dementia disorders and it is characterised by progressive brain damage (loss of synapses and neurons). It is the main cause of death in the UK over other diseases as heart diseases or lung cancer, as (Alzheimer's Research, 2018) indicates. Alzheimer's disease presents all of the previous symptoms among other particular ones. Although it is commonly diagnosed in the 80s and 90s, many cases can be diagnosed since their fifth decade. The life expectancy is about 10 years after the first symptoms of dementia but it can vary depending on other factors such as onset age, the severity of cognitive impairment, other diseases, etc.

The forecasts about dementia do not seem positive. They predict a high increase in the UK by next years. Currently, the number of PwD is about 1 million in the UK (35 million around the world) but the incidence in population will reach more than double of persons affected by dementia by 2050, which will suppose a rise of 146% as describe Alzheimer's Research (2018) and Alzheimer's Association report (2015). Some organisations have already started to consider dementia as an epidemic that needs to be taken more seriously by governments.

These statistics also describe a global situation. Many organisations are aware of the situation beyond the issues that affect person impairment and discomfort and pose the impact on the society as a whole: in the UK, PwD occupies one in four beds in Hospital. Although each country invests different amounts of public money in dementia, (Wimo, et al., 2013) estimated an amount in 2010 of US\$ 604 billion worldwide in 2010. In addition to public expenses, many PWD families do not have access to health and community support



services, by many reasons, and they have to cover the cost, becoming a heavy burden for some of them.

These costs include hiring a personal nurse or caregiver or adapting the house to the user's requirements. The former is probably the most important to ensure the required security and care, which implies continuous professional monitoring of the person with dementia which, otherwise, would be done by relatives or volunteers.

Another important concern, but more focused on the PwD, is the self-harm behaviours that have a negative impact on their health. These behaviours can occur directly or indirectly, for example, performing basic Activities of Daily Living (ADL) incorrectly or not performing them at all by omission. Some common ADLs such as eating, sleeping, drinking or bathing can be complicated to achieve by PwD. Others more directly harmful such as mobility problems can generate falls or cognitive deterioration, which may lead to, for example, elopement (unexpectedly leaving the house) or wandering (Lai & Arthur, 2003). These can endanger PwD wellbeing by getting lost in a city and other dangerous situations outside home at inconvenient times. In addition, the occurrence, performance, and duration of ADLs and behaviours can be important indicators of the PwD cognitive decline. Although it is not yet clear how they interrelate, knowing these parameters can help to provide effective and adjusted social care to the person's situation (Kaufmann & Engel, 2016).

Although it is recommended that PwD remains at home at initial dementia stages, and they prefer it as well, they need help and support in their daily routine activities as well as monitoring from caregivers to guarantee their safety. This situation raises discussions in terms of ethics since initial stages and middle dementia impairment persons are aware they need help but they do not want to lose their autonomy or be confined (Smebye, et al., 2015). Thereby the value of autonomy versus the need to prevent harm and distress clashes with the relationship between caregivers and PwD. Many documented cases describe how caregivers' wellbeing is affected by stress from their jobs such as (Almvik, et al., 2006), (Astrom, et al., 2004) or (Morgan, et al., 2008). The previous authors also describe how the caregiver's environment affects their wellbeing such as the constant stress and psychological wear they suffer but also it influences on PwD care. Despite an extensive nursing literature and works focused on managing and dealing with PwD, currently, the daily life of this guild

is complicated, turning the PwD environment into a complex issue for the people involved, which is necessary to address. Therefore, there is an extended claim about more support from public and governmental institutions.

Finally, although this document refers to people living with dementia, it is interesting to highlight that the same term in this context can refer to any person with some degree of cognitive decline, since some researches referenced here have worked on cognitive decline term alluding to the same problems faced by this work.

## **1.2. State of the art**

Today's society is witnessing another technological revolution. While the first one was the Internet and then Mobiles, the rapid growth of smart devices technology in every aspect of life is creating a new paradigm. The amount of these smart devices generated the necessity of interconnecting them and, thereby, arising the new paradigm of Internet of Things (IoT). The current widespread and affordability of newer technology developments such as better and more efficient processing, wireless connections everywhere, GPS, Bluetooth, etc. are making possible Mark Weiser's concept of Ubiquitous Computing proposed in 1988, which is becoming increasingly realised. All actions taken in our current life implies a complex background process which helps us, supports us, informs us and, summarising, doing our life easier. For these new environmental analyses and possibilities, many subjects arose such as context-awareness, Ambient Intelligent (AmI), Theory of Planned Behaviour (TPB) or Ubiquitous Computing.

Ambient Assisted Living (AAL) uses the previous techniques to support and enable people with special needs to live independently for as long as possible. This paradigm is experiencing fast growth in connection with assistive technology and smart home environments, including new devices, specially addressing PwD concerns. AAL work braces several interconnected topics such as Activity Recognition (AR), IoT, User-Centric Design (UCD) and Co-design in addition to those mentioned above.

There are many AAL dementia approaches based on care robots such as (Tapus, et al., 2009), friendly communication such as (Tyack, et al., 2017), medication management such as (Reeder, et al. 2013) approach, home monitoring (Karakostas, et al. 2015) or location

tracking (Lin, et al. 2012). Other projects also included theoretical approaches aimed to preserve and guarantee the privacy and security of the users (Robillard, et al. 2018). Each solution uses different techniques and technologies that make this field too vast to research. Thus other works focus on the acceptance of precise technologies such as (Liu, et al., 2017) which focuses on GPS acceptance in dementia environments, or surveys wherein the authors analyse a technology such as (Yousaf, et al. 2019) does with mobile Health (mHealth) solutions. Currently, AAL is driving global programs to stimulus and funding projects such as the AAL Programme in Europe.

This research aims at-home monitoring but also takes some ideas from other areas as it is explained along the document. Home monitoring uses IoT technologies and AR techniques to provide information about the users' activities in the house. Thus, research within AR presents many approaches to detect and categorise indoor activities such as ADLs. Those focused on PwD such as the system proposed by (Lazarou, et al., 2016), allow to monitor user's activities and save the information for later professional analysis and comprehensive data visualisation solution. The activities statistics help professionals to discover abnormal behaviours and develop personal interventions for the user. In particular, (Lazarou, et al., 2016) also allows users to configure reminders such as "taking medication" and offers an interface wherein PwD can check their activities information as well as load a list of tasks related to an activity.

Other works focused on nursing homes such as (Fernández-Llatas, et al., 2013) and (Fernández-Llatas, et al., 2011) propose a users' pattern recognition system to automate the conduct disorder detection and react individually to dementia symptoms detected. Although these works depend strongly on nurses' interventions they provide a valuable contribution addressed to AR focused on PwD.

These previous works take into consideration the use of "intrusive" devices. I understand as intrusive devices those devices that conflict with some user's privacy concerns for example using cameras or microphones. In this line there are some AR works that use cameras (Pirsiavash & Ramanan, 2012) or microphones (Ward, et al., 2006) to infer the activities. However, regardless wherein the AAL system is deployed or the type of

sensors used, their goals are the continuous monitoring and/or categorising ADLs for later observations to design personalised interventions based on abnormal patterns.

Using purely non-intrusive sensors some works such as (Li, et al., 2019) lead a study on recognising daily activities, although it uses young people in the research, it shows the ADL recognition is possible by using non-intrusive sensors. The same idea is used by (Stucki, et al., 2014) but focusing on dementia. It reveals the difference in PwD's patterns compared with the same aged "healthy" person by using non-intrusive sensors. Other works use wearable sensors to recognise activities. (Lara & Labrador, 2013) analyses the use of this technology wider.

The techniques to improve AR detection and classification accuracy is still a challenge. For example (Cook, et al., 2013) surveys analyse different techniques and methods used for AR and describe their pros and cons. Works such as (Nef, et al., 2015) also presents a performance evaluation using different common AR methodologies.

Others approach incorporate newer devices to improve the AR, for example, the user localisation inside home to distinguish among activities of other residents such as (Zhou, et al., 2011) by using Ultra Wide Band (UWB) technology or to enhance the activity recognition using Bluetooth Low Energy (BLE) to provide user location (Filippoupolitis, et al., 2017).

There are AAL solutions that address specific problems. They claim to prolong users' healthy lifestyle and autonomy by alerting caregivers in case an abnormal situation occurs. Some examples are solutions to detect falls such as (Gupta & Dallas, 2014) which uses a wearable accelerometer or (Ozdemir & Barshan, 2014) that uses machine learning to enhance the detection of falls. In addition, there are solutions that track down users, PwD, outdoors using Global Positioning System (GPS) such as (Paiva & Abreu, 2012), that also provide commercial gadgets currently on the market.

Other approaches more user centred are reminders solutions, which aim to help PwD to maintain a healthy daily routine. The idea about interacting with PwD was proposed some time ago by (E. Pollack, et al., 2003) wherein was described the idea as well as problems and possible solutions within an ALL system based on recognising behaviours and taking action automatically within dementia environments. However, this pioneer

system did not have the current technology and the system was complicated to deploy in a real scenario. Solutions that are more recent use the users' mobile (or other portable device such a tablet) to send alerts. (McNaull, et al., 2014) and (Lazarou, et al., 2016) show an example of solutions that use reminders and aid the PwD directly. (Yu, et al., 2015) describes how reminders using mobile devices have a positive impact helping users with their tasks when they are prompted. Nocturnal project (Augusto, et al., 2014) also describes how the environment is used to entice the user into safer situations, for example using music and lights to bring the user back to bed when wandering during the night. Related to wandering there are some works such as (Kim, et al. 2009) or (Vuong, et al. 2011) that present different algorithms to detect wandering. In this line (Lin, et al, 2018) also include elopement behaviour as a kind of wandering to be detected by using active infrared sensors.

Many of these solutions can be found today's in the market including artefacts focused on specific cases within dementia such as reminders, adapted phones, watches or GPS (Sauer, 2019).

In general, there is a wide spectrum of research within AAL focus on dementia. Although many expose a theoretical approach, they describe and analyse different issues related to technology within dementia environments. Thus, in general, the AAL system goals assisting older people with cognitive impairment should focus on covering some of next points:

- Ensuring people safety in their daily life.
- Supporting the necessary daily activities and tasks enhancing the person's autonomy.
- Alerting secondary people (caregiver) when unusual, risky or harmful situations happen.
- Offering comprehensive information about a person's cognitive status.

In addition to the technical aspects of development, AAL must consider users' ethical concerns in general and PwD in particular since these systems work with sensitive data. These concerns address to respect, preserve and ensure the user privacy, personal data protection, transparency of the system, user autonomy, offer equality and dignity and, obviously, non-harm and beneficence of the user. The framework UCD came up to involve the final user during the whole process of a system development: from initial stages by

gathering requirements until the final product design. From this idea emerged frameworks focused on preserving and protecting the users' ethical concerns. For example, the ethical frameworks proposed by (Jones, et al., 2015) describes the processes to ensure the ethical aspects of the system. In addition, other approaches such as co-designing aim to involve users in the design of final products according to their needs. Depending on the system to develop some of the ethical framework requirements are easier to deal with or even do not appear directly as an issue in the system, but, regardless, they should be analysed and lead to an AAL development.

## 2. Thesis

### 2.1. Current AAL limitations

Although some current AAL solutions use a UCD approach to design and develop and claim to enhance the PwD autonomy longer, in fact, many of them are not aimed at the primary user, in this case PwD as the direct final user. On the contrary, they focus on secondary users such as caregivers, nurses, doctors or relatives. This “limitation” is common in solutions that use AR to monitor the user. They offer valuable information about PwD daily activities but it addresses secondary users and sometimes, as (Lazarou, et al., 2016) work, primary users can monitor themselves. However, it still exists the risk the user does not check it by forgetting or omission. Thus, current AR approaches do not guarantee a real PwD autonomy which still depends strongly on caregiver monitoring.

Solutions aimed at specific situations such as fall detection or GPS outdoor location presents this issue too. They are helpful covering a problem by alerting caregivers about a user’s problem that the system cannot resolve by itself. In this case the mentioned limitation is not too strong since a computer system cannot lift the person. However, the primary user has no decision in the process.

Reminders, as the most user centred approach explained here, have shown great results on elderly. However the users, and more precisely PwD, can ignore reminders therefore, the application does not guarantee the user accomplishing an activity or task.

Solutions which can offer more certainty about the user activities such as cameras or microphones to infer user’s activities, face ethical concerns regarding privacy. Also users reject them as very invasive. But they still have limitations that address the person who monitors, that is, to secondary users.

The acceptance of technology used to support the elderly is currently increasing within that population (Wang, et al., 2019), however current AAL systems seem to omit, in some way, the primary users as the main target. Also PwD and professionals claim to involve more PwD in the design of technology such as (Kort, et al. 2019) describes. Therefore it is desirable AAL system developers involve primary users more.

## 2.2. Motivation

Considering the previous limitations, it emerges the idea about the possibility to deploy a friendly system to support and coach PwD to stay independent longer by empowering their autonomy interacting with them. Friendly implies using non-intrusive and unobtrusive devices, which does not affect the environment of the person nor implies to acquire new knowledge for the user as (Orpwood, et al., 2005) highlights about system address to PwD. Also, friendly implies to offer clear and understandable graphical user interface in those elements addressed to interact with users.

To achieve that, I should pose some questions that are the central axis of the present research, however, it is foreseen that some questions around each one arise:

- Is it possible to detect some physical PwD activities and behaviours in real-time inside the house using non-intrusive sensors?
- Is it possible to parameterise these patterns adapting them to different users' characteristics?
- Is it reliable a system able to interact with PwD by supporting and coaching them?
- Are these sort of systems able to enhance PwD autonomy whilst preserving their safety?

Work as (Manca, et al., 2017) or (Stucki, et al., 2014) answers the first question but I explained before their approaches have some issues such as using intrusive or obtrusive devices. In addition, ADL's that have been studied previously within AR, although they can give support enough, some behaviours are not considered. For example, (Hoof, et al., 2011) highlights that wandering is an unresolved matter in AAL, therefore, it is going to imply a challenge in this research due no previous works focus on that in a practical way..

The second question has been less analysed previously. However, its response depends on the analysis and system used for AR, although, from nursing works can be extracted some clues about how PwD behaviours and routines differ among them.

The last two questions pose the challenge to deploy and validate the system in a real environment working with PwD. However, initial functional development tests can



demonstrate that the system detects activities and takes the expected actions. Thus, the first stage is to propose and define the system.

## 2.3. Proposal

Building up from previous works in AR focusing on ADLs and combining with the solutions ideas for reminders, the present work suggests an approach to empower PwD. Also, the fact that IoT devices are currently widespread thereby accessible and affordable for almost all populations make it easier to develop ubiquitous systems within users' environments. Thus, taking advantage of AAL approaches and technology within everyone's reach, I proposed to deploy an Ambient Intelligent system addressed to enhance PwD autonomy and wellbeing at home. The system should be able to detect anomalous dementia-related ADLs and behaviours performed at home. Hence, it warns first the primary user about a particular situation when necessary, for example skipping a meal should be reminded. In addition, since the system remains working in the AR process, it can determine whether the user is revising that behaviour and performing the activity, for example eating something. In case the primary user does not resolve the situation, the system can implicate secondary users through an alert holding them updated about the situation and possible risk, therefore, allowing them to take a suitable intervention if required.

Summarising, I propose as system that consists in a continuous user monitoring by using AR within non-intrusive environment able to:

- Notify and remind primary users about tasks, empowering their autonomy.
- Alert caregivers when needed, reducing the workload but ensuring user safety.

This work presents a system aimed to achieve an Ambient Assisted Empowered Living: AnAbEL. It represents an AmI system addressed to people with dementia or cognitive decline focused on their wellbeing. The goals are enhancing PwD autonomy and coaching them to preserve a healthier lifestyle.

Next sections describe the general ideas that guide this project as well as the deployment to achieve the final system based on:

- Detecting real-time ADLs and behaviours related to dementia using non-intrusive sensors that provide useful information about daily life routines.
- Implementing a user's friendly interface to configure the system. It allows setting and adjusting the system to each user and environment in order to evaluate the activities.
- Providing primary user and secondary user interactions by using technology allowing notifications and reminders.
- Providing a scalable smart system environment able to integrate newer technologies, devices and concepts that allows the system to grow along time.

### 3. Methodology

This work extracted initial knowledge from the literature survey in dementia health and AAL. This literature has been found from many sources such as the web of Alzheimer's Associations such Alzheimer's Association, Alzheimer's Research U.K. and NHS , MDX My Library search, Google Scholars and Base-search. Recent work in AAL, Smart Homes and Ambient Intelligent (AmI) have in high consideration the use of user-centric approach to design and develop these systems and was helpful in defining the methods. In particular, this work was inspired by the User-centred Intelligent Environments Development Process (U-CIEDP) (Augusto, et al., 2018). However, since the Master program is limited to a year it is complicated to develop the whole scheme that is more realistic in longer projects. There are also some limitations related to validations due to Research Ethics. That fact does not allow including PwD to participate in any stages of the development. Thereby, I applied U-CIEDP methodology in a simplified version as figure 1 shows. This new scheme guided this research successfully despite the boundaries.

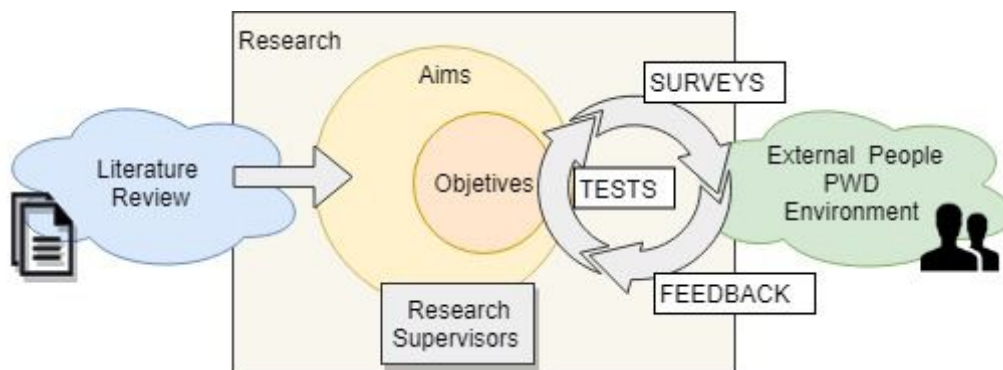


Figure 1. Methodology diagram followed in this research.

Following this methodology, I defined the initial ideas and requirements to set aims and objectives to develop an AmI system which can detect ADL and behaviours related to dementia in the home. The first attempts were guided by a literature review process that informed the meetings with my supervisors to satisfy a system following AAL and dementia requirements.

The initial design was refined using a first survey which provided information to support an initial design but also some considerations to improve or discard. During the whole development process, the system was tested and refined by using external feedback

and knowledge from the supervisory team. The external feedback came from professionals within dementia and volunteers such as carers, nurses and GPs throughout the surveys. I also involved students in Environmental Health interested in housing adaptations for PwD as this document describes further down. In addition, during this research Dementia Care professionals from different London Councils and experts from Dementia Care events around the UK, wherein this project was presented, provided direct feedback in many occasions.

### 3.1. Study design

I surveyed to define an initial system approach based on previous research contributions within nursing, AR, AAL, etc. The survey addressed people with experience within dementia such as caregivers, relatives, nurses, doctors, etc. Public Health professionals led and supported the questionnaire design. The survey can be accessed in Figshare<sup>1 2</sup> (notice the survey was developed in two languages, English and Spanish, getting 10 responses from the former and 4 from the last one). Appendix C contains the questionnaire in English of the survey.

Using an on-line survey it was possible to reach more people, reduce the cost and facilitate data processing. On the contrary, to secure meaningful answers, I sent the survey to different contacts at dementia research centres in London and Spain. The invitation to take part in it was accompanied by a summary about the project. Finally, 14 surveys were collected from people who have more than one year of experience working with PwD.

The survey is divided into different categories. An initial one poses questions related to the contestant experience such as position (volunteer, professional caregiver, nurse, etc) years of experience or environment wherein they mainly develop the job (nursing homes, hospital, personal home). These questions intend to assess the contestant experience and support the rest of questions: a little experience of a volunteer could be less meaningful than a professional with many years working within dementia. Fortunately, the final profile of

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<sup>1</sup> [https://mdx.figshare.com/articles/Survey\\_Using\\_AAL\\_to\\_support\\_people\\_with\\_dementia/8063849](https://mdx.figshare.com/articles/Survey_Using_AAL_to_support_people_with_dementia/8063849)

<sup>2</sup> [https://docs.google.com/forms/d/e/1FAIpQLSd9wc3-05hpPCTCpxvzhJygX3Kdprs7H0hMgwQnr3T1RPwi5Q/viewform?usp=sf\\_link](https://docs.google.com/forms/d/e/1FAIpQLSd9wc3-05hpPCTCpxvzhJygX3Kdprs7H0hMgwQnr3T1RPwi5Q/viewform?usp=sf_link)

the participants were very similar, being almost all professional with more than 5 year of experience.

Other sections focus on the ADL and behaviours that according to their experience can help me to understand, for example, which ADLs and behaviours are more common and important to monitor and which ones are easier to accomplish without external help. These questions will guide the initial elections of ADL to develop in the system maintaining a balance between the importance of the ADL to monitor and the autonomy of the person. The survey also asks about how they, as experimented caregivers, can notice the person has certain behaviour and what kind of interventions they take. That helps me to lead the design of activity recognition algorithms and the design of the system actions. For example choosing ADLs and behaviour since they highlighted eating, sleep, understanding how to detect wandering or how caregivers intervene when detecting some of these behaviours that helps me to approach the system actions.

The latest section aims to understand the relation between PwD and technology. For example, by asking which sort of devices are more common in their daily life and what they use them for. In this case, the contestants do not provide valuable information since, according to the survey outcomes; they do not usually use technology with PwD. In these cases, however, related literature provides wider information to base some approaches in this work.

### **3.2. System requirements**

From the literature review, feedback and initial survey, I set initial requirements for the system. I summarise the main system requirements which influence the system design, although they are described more precise throughout this document:

- Providing an IoT infrastructure around the house aiming to detect the user's physical actions in the house.
- Providing a tool to analyse user's activities information from sensors and generate a response on-time.
- Providing an interface to configure the system and adapt it to the user.
- Providing a way to send warnings and alerts to users and carers.

- Providing a way to present the information gathered from the user's activities
- Using technology to distinguish users .
- Enabling the system with enough security to guarantee the privacy of user information.

These requirements are explained in more detail throughout the next sections.

### 3.3. Evaluation design

It was not possible to validate the system with PwD in a real home environment within the campus due to health and safety regulations related to Middlesex research ethics. However, we benefited from Middlesex University allowing students to visit the lab and view real demos. This facilitated their involvement and our preparation of demos. Then we contacted students with interest and knowledge about ageing, dementia and housing but also current technology concerns.

Then as part of system refinement and evaluation, I presented a first Pilot developed to students in Environmental Health involved in housing and dementia. They visited the lab and I explained and demonstrated the system to them. Finally, they filled an anonymous brief survey (see Appendix D) to gather their impressions. It was oriented to get wider feedback from people. The section *Test and Evaluation* explains the outcomes of this survey.

I also presented the Pilot to professionals of UK Health Care and Environmental Health sectors who provided additional feedback. They emphasised the usefulness of this system to cover current dementia issues by enhancing PwD autonomy and supporting caregivers. Although I did not register their feedback, in summary, their concerns focused on privacy and security, reinforcing the general worries expressed by other stakeholders. Thereby, although security and privacy are not the main targets of this research, the development of this system includes security and privacy measurements that the next sections describe.

The Computer Science Research Ethics Committee of Middlesex University previously approved the surveys, questionnaires and methods used during this research.

## 4. System architecture

This section describes the basic parts needed to build the AnAbEL system as well as their design based on requirements from AAL, AmI systems and nursing work.

### 4.1. Detecting ADLs and behaviours (AR)

AmI systems have to be integrated and embedded within the daily user's environment providing ubiquity. They also have to exploit the useful contextual and situational information from this environment (Context Awareness) (Acampora, et al., 2013). In this research approach, the ubiquity is reached using non-intrusive sensors that do not alter the environment and respects privacy concern requirements. In addition, sensors are a crucial part of Context Awareness which is inferred by a temporal reasoning (Guesgen & Marsland, 2010) proposed for this system. That provides an efficient logic implementation to retrieve environmental information and produce real-time outcomes about the user's activities.

In order to select an initial reasonable number of ADLs to monitor, the selection process was based on choosing the most important activities. "Eating", "Drinking", "Sleeping" and "Bathing" could be considered more important to monitor than, for example "dressing", since they are crucial to achieve a healthy lifestyle but, also, because some deviations in these habits are relevant measures about cognitive state related to disorders in PwD as is pointed by Alzheimer's Association report (2015).

Likewise, according to the surveys described at *Study Design* section, "eating", "drinking" (hydration) and "sleeping" are considered the most important activities to monitor within a PwD daily routine so they seem the best choice for an initial consideration. In addition, they have been pointed as the easiest to do by PwD without external help that avoids the system intervening in users' complex activities that can affect their wellbeing.

Among common behaviours related to dementia this project focuses on those which implies physical activity. Then other common behaviours such as incongruent speech or repeat questions are not considered. (Lai & Arthur, 2003) and (Steinhauer, et al., 2010) point to wandering behaviour as an important one to be handled since it is one of the most troublesome of behavioural problems related to dementia. In addition, our surveys depict

that more than 90% of respondents have witnessed wandering episodes in their personal experience.

Another common behaviour is leaving the house unexpectedly or “running away” from the building, also called “elopement”, which seems important to be controlled since it implies a potential risk by leaving the house at unusual times. This behaviour is also pointed out by (Lai & Arthur, 2003) (Steinhauer, et al., 2010) as well as survey results which show that the majority of participants (more than 90%) have observed elopement episodes.

The last criterion to select ADLs is that they should adapt to the current environment (see *System infrastructure* section). The initial sensors available for this research are non-intrusive and can cover many activities detection such as motion sensors, reed sensors for doors and windows, pressure sensors used on beds or sofa/chairs, energy sensors in appliances or table lamps and switch sensors to control room lights.

Finally, ADLs selected to incorporate initially to this system are “eating”, “sleeping”, and behaviours such as “wandering” and “elopement”.

Human behaviour being complex to figure out using the current technology as limitations of AAL systems have been underscored by previous works such as (E. Pollack, et al., 2003). Thus, this work will refer to ADLs and behavioural detection as pieces of evidence about them even if they are written as “the user is eating”. However, (Steinhauer, et al., 2010) describes how a reasoning timing approach is able to offer a closer framework to detect human activities. It also spotlighted the problem derived from this kind of systems: the strongly defined behaviours that avoid users' adaptations. This fact drives the idea of developing a user's interface to configure behaviours and obtain a better system adaptation to the user environment.

## 4.2. Interface

The previous idea exposed about the user's interface needed also defines an AmI system characteristic: to provide user's personalisation and adaptations (Acampora, et al., 2013) . Thus, I decided to provide AnAbEL with options to enhance system adaptation to users. This resource proposes a user interface to configure parameters related to users' activities, some building characteristics and the system logic.



Each user has different times to perform daily routines as well as the time spending to execute the activity differs, thus, the initial interface approach focuses on covering these variations. The first aim was to allow the user to configure daily timetables for each activity wherein the activity happens usually, assuming the opposite situation as unusual and worth of attention. Regards to ADL and behaviours, it is important to understand why they are healthy/unhealthy, usual/unusual or safe/risky, in essence, when the system should provide support. It is accepted that ADLs must be adjusted to user routine and a deviation in time to carry out them or the time spent performing an activity can be symptoms about something going wrong as Alzheimer's Association report (2015) or (Alberdi, et al., 2016) explain. Consequently, once timetables are provided for each activity, the system needs to assess them in order to warn the user. For example, the user usually goes to sleep around 10 PM, but if one day the activity is happening at 11:30 PM, this behaviour can be considered "unusual" as well as it can mean the user is feeling disorientation or anxiety, also described by the previous works. However, that conclusion is left for a qualified caregiver who will be able to analyse and appraise the situation. Furthermore, an activity can happen at an unusual time; Leaving the house during the day can be normal for some users since they go for walk, but when this action happens at unsafe time, such as mid-night, can be related to user disorientation, then the system decides to take action when comparing the activity with the users schedules. Thereby, timetables configuration is an essential user's personalisation to provide.

The "threshold" parameters define when AnAbEL should intervene by warning the user and alerting the caregivers after detecting an "unusual" activity. For example, depending on the habits, the user can start the activity later or spend more time than other people spend then the activity is perfectly carried out without system warnings or alerts. Thus, it is proposed two sorts of thresholds for each behaviour: one indicates to the system when it has to warn the primary user about the unusual activity and another one is used to alert secondary users to take action in case the primary user has not resolved the situation alone.

With regards to user adaptations, as each person has a different form to communicate depending on culture, environment, personality, cognitive impairment, etc. it would be

interesting to provide a component to offer effective prompting to the user as (Braley, et al., 2018) and (Boyd, et al., 2017) describe. Among some initial ideas such as using sounds (music or familiar voices) or lights to interact and guide the primary user, finally I chose the mobile device explained in the next sections. For this reason, AnAbEL interface should give the option to select the mean to interact to primary user as well as configured possible feedbacks from primary user, trying to fit the communication context and to reduce misunderstandings and PwD anxiety (Lamparero, 2015) and (Boyd, et al., 2017).

In order to provide wider parametrisation and to show that more sort of facets of the system can be configured, not just the timetables and thresholds, I suggest a parameter for wandering detection. It relates to the user's physical condition and house design and it is based on the time taken by a user to go from a room to another, which depends on the physical user condition and the house design (room distances).

Parameters described try to cover different areas by customising user lifestyle or preferences (schedules and question/answer), the system logic (time to issue an alert) and adapt the system to the environment (the spent time going among rooms).

### **4.3. System actions**

Another Aml characteristic is anticipatory (Acampora, et al., 2013) which defines the system interventions without users' deliberate mediation. Thus, AnAbEL's anticipatory is to take actions addressed to users to achieve some task autonomously. Once the user activity is detected, assessed and catalogued as "healthy/unhealthy usual/unusual", What can AnAbEL do to improve the user's autonomy?. It seems reasonable thinking that by reducing caregivers' surveillance and intervention it enhances the user autonomy. To achieve that, AnAbEL should cover a basic caregivers' task: preventing PwD harm.

In the initial dementia and cognitive impairment stages, preventing harm by reminding the user to do some tasks or to stop an unusual behaviour is crucial. Nursing work shows how using the correct words with PwD, can be effective to remind or amend a behaviour as (Zhou, et al., 2011) and (Lazarou, et al., 2016) show. In addition, the previous reminder systems commented show good results about rectifying user behaviours through mobile messages. Real natural language level interaction between user and system is

difficult due to the current technology limitation. Advances within the Internet of Things, Artificial Intelligence and Language Processing are promising and it opens a huge number of possibilities. Some researchers describe different interventions with PwD using artefacts as lights or sounds such as (Lamparero, 2015) and (Hanford & Figueiro, 2018), although, always under supervision of the caregiver who can control the reaction of the person. Current smart environments allow easily performing these actions by controlling lights and smart devices like smart TVs, radios or other appliances. Even if a primary user warning system is effective and it can increase PwD autonomy, they cannot lose the security from a continuous caregiver monitoring, hence AnAbEL keeps the caregivers figure into consideration by enabling the system to alert the caregiver in case it is needed. Figure 2 shows the whole process flow of the AnAbEL system.

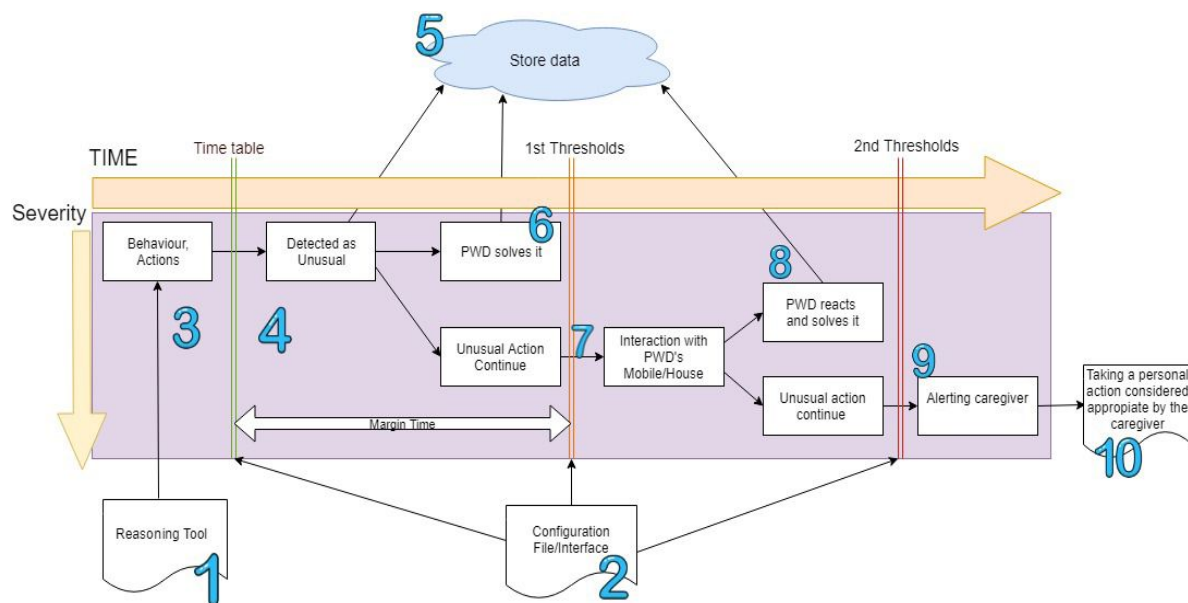


Figure 2: Overview of system flow. the system(1) works on AR (3). Using (2) user configuration as timetables, the system figures out some unusual happenings (4). User resolves the situation before a time (6) or user continues (7) then the system notifies the user. User reacts to the alert and changes the behaviour (8), but if he/she goes on the caregiver is alerted (9) to take a human action (10). (5) Represents the server where all activities and behaviours are stored.

Eventually, as number 5 in figure 2 represents, all information gathered such as ADLs, behaviours, alerts and user's feedback could be stored. This way, AnAbEL provides wealth of information, as other AR systems, addressed to professional assessment, tracking evolution, adapting or modifying routines or interventions of PwD.

## 5. System infrastructure

I have described some key features and concepts of the system in a generic way. The next ones explain its technical aspects at a higher level of detail as well as the environment wherein it has been deployed.

### 5.1. Intelligent environment

AnAbEL deployment has been performed within the Smart Spaces lab at Middlesex University. The Research Group on Development of Intelligent Environments<sup>3</sup> sets up part of the Smart Spaces lab as a smart house for research and experiments on sensing supported systems. Figure 3 shows an accurate map of the lab with hardware elements installed inside, such as a server, distribution of used sensors and the smart hub (Vera Plus model<sup>4</sup>). Although the intelligent environment infrastructure existing at the lab is described in the SEArch architecture (Augusto, et al., 2019), the next section explains the parts related to this work.

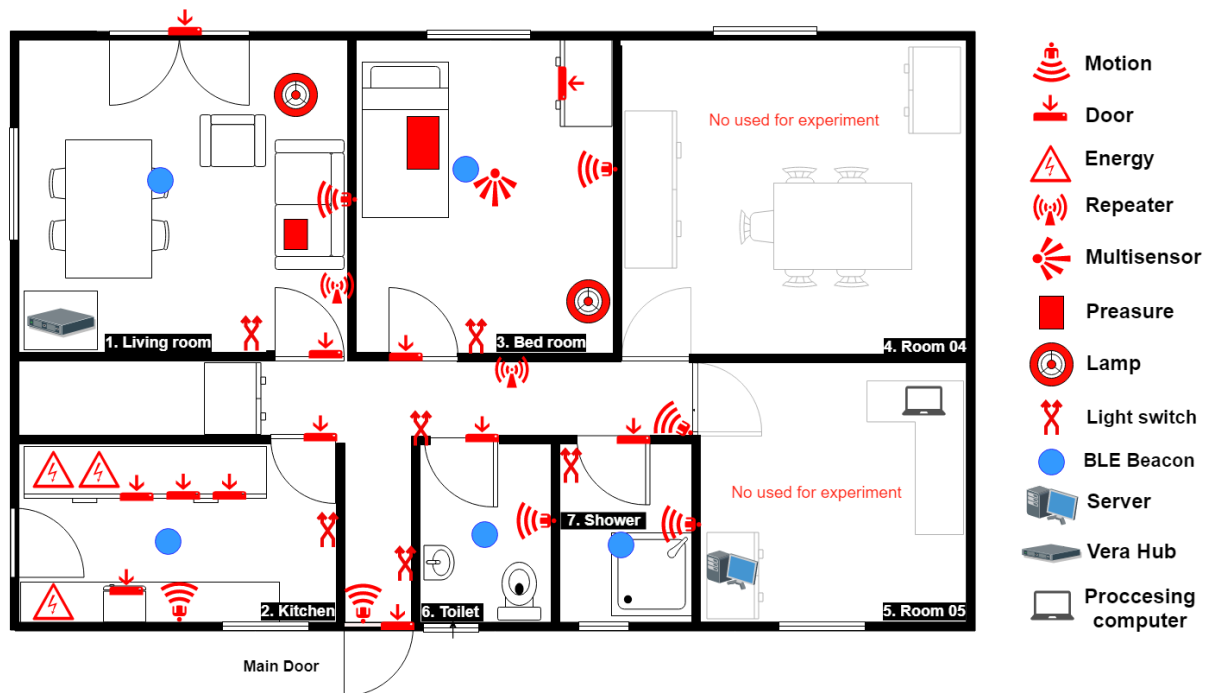


Figure 3. Map of the lab with the devices deployment. In this research, the server hosts the processing computing.

<sup>3</sup> <http://ie.cs.mdx.ac.uk>

<sup>4</sup> <https://getvera.com/products/veraplus>

The lab is equipped with a Vera hub device to manage the main sensing environment. Vera hub provides a Z-wave network to connect devices and request properties (state, battery level, etc.) as well as to change some of their properties. Devices can be “sensor” or “actuators” depending on the function. Thus, we name “sensor” those devices which can *transform a physical dimension into a digital signal*, for example: the presence of light into a digit 1, and “actuator” those ones which can *transform a digital signal into a physical dimension*, for example a digit 1 command into a light being turned on.

We define the signal value in both cases as “sensor state” which represents a meaningful value about an environmental event. For example, a motion sensor has the “trigger” property that defines our “state” of the sensor and when it detects movement in a room this property takes value 1, and 0 in the opposite case, that is, no movement detected. Also, by changing an actuator “state” means modify the value of this property, for example, turning a light OFF or ON implies modifying the “trigger” actuator property with 0 or 1 respectively. Notice that an actuator can be also requested so some devices can work as sensors and actuator in the same scenario, for example, the lights can be modified by a user giving information about user action (sensor), or by the system when it sent a command to turn light OFF/ON as a response to a previous event (actuator).

The devices installed in the lab and managed by Vera are (Figure 4 shows sensors photo):

- Passive InfraRed (PIR) sensor: it detects movement using infrared variations. The state of this sensor can be 1=movement detected or 0=no movement. PIR sensors reset automatically to 0 after a time since they were triggered. This value can be modified using Vera interface. For this project, all PIR were set with the minimal time allowed to reset in the used model (5 seconds). This configuration seemed reasonable to manage them since by using a temporal reasoning application it is easier to determine whether the user is not in a room anymore using this tool than waiting for PIR default reset.
- Smart energy plug device: Whatever appliance can be plugged to this device and connected to the electrical installation. When the sensor “trigger” property is “1” (ON) it lets the electricity pass and the appliance works. However, the appliance can

be OFF and the device ON then giving a false positive of the real state. Thereby, the system requests other property: it checks “watts usage” property to know if the appliance is working (on) or not (off). That case shows an example of the “state” concept in this work. These devices can work as a sensor and actuator.

- Reed sensor: This sensor consists in two separate magnetic pieces. When both pieces are in proximity, the internal circuit is close and the value of the property used as state is 0. If both pieces are separated the sensor state value is 1. These sensors are used in room doors and windows but also in cupboards, lockers or fridge, to determine whether they are open or close.
- Bulb device: this device works as sensor and actuator. As a sensor gives info about the bulb is ON or OFF and as actuator it can block or leave the electricity pass to the bulb.
- Pressure sensor: Original pressure pads were modified adding a reed sensor to be able to connect with Vera throughout the Z-wave network. This sensor detects the pressure when somebody stands on it. They are used on bed, chairs or sofas.
- Switch sensor: They work similar to bulb devices but they are installed on the walls like normal light switchers yet they can inform about the state of the light and to change the value (On/ Off).

Also, figure 4 shows a Bluetooth Low Energy (BLE) beacon tagged with number 7. They are not Vera Z-Wave sensors but BLE beacons work providing environment information through a different communication protocol than used by Vera. Section *Localisation system: BLE beacons* explains this technology.

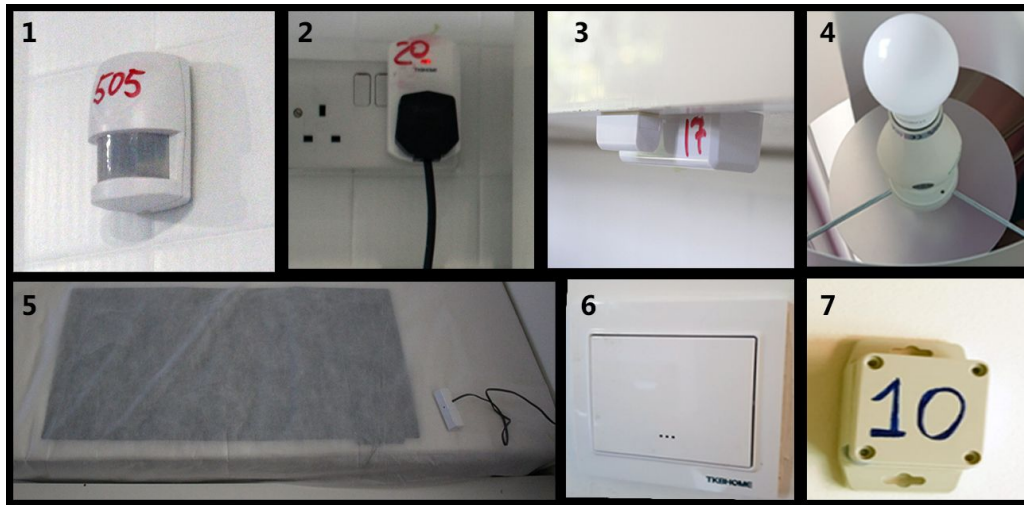


Figure 4. Some installed sensors in the lab.

## 5.2. Server

The lab hosts a server which is used to place and manage the different databases, web API and reasoning applications used for AR functions. The operating system running at the server is Windows 10 and it uses Internet Information Services (IIS) as a web server.

MySQL is the database management system installed in the server because, among other reasons, it is open-source and offers the scalability and flexibility that a research development needs. The database is used by the different systems working in the lab to retrieve and store data.

The web server manages a RESTful API developed in PHP which provides a layer between external applications and databases allowing to manage their requests. It also hosts web pages for different applications such as the user interface for this project.

Despite the research has been carried out in a close environment, connections between the server and other system elements use HTTPS through a self-signed certificate (use for deployment stages), as well as database encrypt the user's passwords and others basic measures related to security in elements such as firewall, Operating System and IIS. The implementation of some security measures are aimed at developing an environment as real as possible.

### 5.3. MReasoner

The application used in this project to perform the activity recognition task is MReasoner (MR) described in (Ibarra, et al., 2014). This reasoning tool is developed in Java and provides the mechanisms to retrieve and infer information from the sensing environment in real-time.

#### MReasoner language

The MR is a rule-based temporal reasoner. Its language allows rules to be triggered based on conditions met at specific times or lasting for some length of time. In our system these conditions are related to the states and their changes captured by the sensors. The MR rule structure is *Ssr((antecedents) -> consequent)*: when the conditions in “antecedents” are TRUE the rule is triggered after which “consequence” will become TRUE. “Ssr” type rules apply this effect immediately at a logic level. MR allows another type of rules with delays effects however, they are not used in this project.

The MR atomic element (variables) which form “antecedents” and the “consequent” are called states. Since there are different layers in the system, it should not be confused. For example, MR “state” and Vera “state”, although they are related, while in Vera, a “state”, is the value of a property, in MR it is the name of a variable. I say they are related because MR is able to associate a state with one sensor then the value of the state in a code execution depends on the value of the sensor. MR distinguishes between two types of “states”:

- **Independent states** are those which do not change their value as consequent in a rule. (e.g. motion sensor is represented by an independent state which sets its value in function of the motion sensor value, but this value is independent of any MR conclusion).
- **Dependent states** represent those states which are the consequent in some rule, but also they can be “antecedents” in other rules. For example, “if it is detected movement in the kitchen then the user is in the kitchen (userInTheKitchen)” and “if the user is in the kitchen then put the kettle on”. This example is not very practical yet illustrates that “userInTheKitchen” is a dependent state.

Next example illustrates the translation of a basic action into rules:



“if movement is detected in the living room then turning on living room light” and “if no movement is detected then turning off living room light”.

*ssr((MotionLivingroom)-> LightLivingroom);*

*ssr((#MotionLivingroom)-> #LightLivingroom);*

MReasoner also manages time conditions for a state in different ways based on the present assessment time. That means, an antecedent state can be evaluated along a period. The operators to manage time are:

- Absolute time coding by the operator “[...]”. E.g.: light is on for the last 30 seconds which is translated as *[...][30s.]LightOn*
- Relative time coding by “<->”. E.g.: Light was on at least one during the last 30 seconds: *<->[30s.]LightOn*.
- Time interval: the previous operators can be used with periods. E.g.: “between 7 PM and 8 PM the light is on is similar to:

*ssr(([-][19:00:00-20:00:00] LightOn)->...)*

They are the basic operators to work with MR but it provides many other commands, some of them will explain in future examples if they are used.

### **MReasoner working**

MR polls external systems each second requesting current state values which have been declared in the rules. In the case of the Vera system, MR examines it each second getting an updated picture about the whole home situation. The state's values are updated in the process and according to the rules, which model an activity, get a conclusion. This conclusion could change internal states or actuators which will modify Vera sensor values.

Since IoT solutions are growing and offering new technologies covering new issues or improving previous ones, this AmI system should offer an easy way to add more systems enhancing its scalability. For example, this project posed the need to distinguish the primary user from other house occupants, but Vera does not support any technology to get some similar. The challenge to add a new sort of devices distinct from Vera addressed to that aim, such as BLE localisation, is revolved by using an ad-hoc middleware (MW), which has been

developed for this project. The MW allows MR to manage other technologies and systems in an easy way, actually, the communication MR-Vera is managed through this MW.

## 5.4. Middleware

There are AAL works focused on the middleware solutions. However, a middleware is not an aim of this research but this one is conceived to cover some limitations at the current lab infrastructure such as allowing communications between applications and integrations of new technologies. The approach for the middleware development in this project is based on using URL requests to different applications to get or set information regardless of platform or language used. Thereby, this MW is closed to XMPP<sup>5</sup> protocol ideas but adapted to this project.

Most commercial systems offer protocols to access the information stored in a database or file such as Vera is accessible using HTTP commands. Other non-commercial systems demand some development to save and get data which implies use a database. In this case, the database can be accessed easily by developing a simple public API. About that assumption, the proposed MW can retrieve data through an API from many different systems as Vera which provides the API. However, BLE technology used here just provides the board device to emit a Bluetooth signal, thus it is necessary making adaptations such as include a database with the current user position (see *Localisation system: BLE beacons* section). Now that is offering access to these databases through an API, MW can retrieve the information easily. Other sorts of systems can be added to the MW and they could be polled for information adding more functionality to the system. Figure 5 shows a scheme of this environment part.

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<sup>5</sup> <https://xmpp.org/>

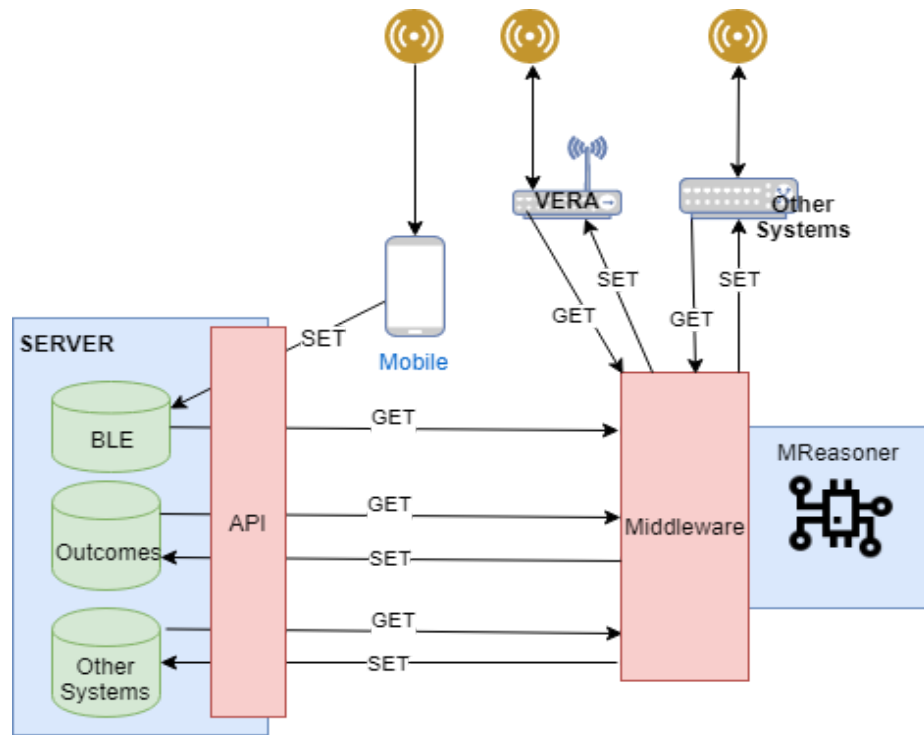


Figure 5. Middleware communication scheme. It shows the flow among the system's technologies by using CRUD requests to the different APIs.

The MW does not currently have an interface to facilitate the addition of a new system. It offers several abstract java classes which allow adding a new system class to manage it by implementing basic methods to “get” and “set” among some more, as well as attributes as IP, URL format, services, etc. The addition of a new system class loads the basis configuration necessary to request information. Once, is defined the new class to communicate with the new system, each sensor which belongs to the new one has to be defined in the databases. There is a method inherited which allows to load all sensors provided by the new system automatically which makes the addition easier. The information provided is related to the properties of each system.

Although MW looks limited because no interface supports it, other systems have been tested working together. Actually, this MW is used to incorporate to AnAbEL the user indoor localisation based on BLE beacons.

## 5.5. Localisation system: BLE beacons

In the UK around 60% of PwD live at home and it estimates that 86% are not living alone according to statistics from Alzheimer's Research (2018). Even the 14% of PwD living alone, it is quite likely they share time with caregivers, relatives or friends in the house. Thereby, this work seeks to face the multi-user architecture looking for a more realistic environment. Trying to cover the whole spectrum makes necessary to develop a system to distinguish among residents at home.

Several works show different methods and technologies to get an accurate indoor user's position which also allows to differentiate among users who are performing a task by examining the proximity to other devices or hints. Despite, UWB such as (Zhou, et al., 2011) seems the most accurate technology to get that, it implies an additional device, such as a wearable sensor, to connect user's mobile and UWB devices. Other technologies such as (Torres-Sospedra, et al., 2019) uses pre-installed WIFI networks around the user's environment avoiding the need to install new devices. Since, there is no consensus between which one, WIFI or Bluetooth devices, gets better results, in this project has been implemented BLE beacons technology based on (Sora & Augusto, 2018) work.

The BLE beacons deployment around the house, as well as a related Android application developed for this technology to detect the user, was tested with several configurations of beacons placement. The main BLE problem to be faced is the variation in beacon signal strength, caused by objects such as walls, lockers and, more importantly, the user's body. That issue causes changes in the nearest BLE detected by the android device, even if the android device remains still. It generates continuous "jumps" among the nearest beacons detected.

The most stable configuration found has been installing two beacons per room separated both about 1-1.5 meters. This way "jumps" happen statistically more often between both placed in the same room. It is still the case that a beacon from another room is detected as more powerful even if the user is not in that room. In this case, the lapse of time registered by this beacon is insignificant compared to the sum of lapses from both BLE in the same room. Thus, it is possible to create an effective filter and clean these outliers. In addition, the Android application to check the beacons includes the use of the device

accelerometer to check the beacons signals just when the user is moving, reducing this way non-significant data originated by the jumps. Figure 6 summarises how the localisation system is implemented in the lab.



Figure 6. General picture of localisation system using BLE beacons and user's mobile.

## 6. System development

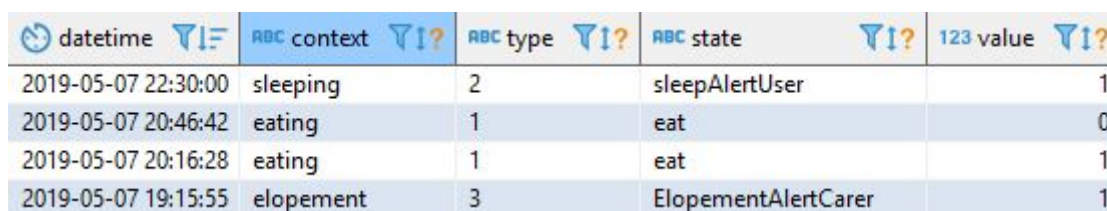
Although MW and BLE beacon systems were developed as part of AnAbEL project, this section focuses on those system parts that were mentioned at section *System Architecture*. Since these components strongly interconnect, the order of next sections is not related to how they were developed but they are explained to provide a better understanding.

### 6.1. Managing contextual information

As a user performing normal activities inside the house, different sensors are activated according to the activity. Information from Z-Wave sensors is managed by Vera hub and from the BLE by the user's mobile which stores the current user location in the database. MR uses the MW to retrieve data from different systems and use that data to update states which drive rules. The consequence of the rules related to activities is saved in the "Outcomes" scheme. Thus, MR connects to Vera, BLE and Outcomes.

Outcomes scheme formed by an API and database wherein is defined the information and structure related to activities: eating, sleeping, wandering and elopement. Here are defined "states" used by MR rules and they are managed as Vera sensors through the MW. Since "Outcomes" is added to the MW, when MR manages state from "Outcomes", changes are updated automatically, as other Vera actuators (see figure 5).

For example, in "Outcomes" is defined the "eat" activity which represents whether the user is eating or not. "eat" is a state name used by MR in the rules which is set "eat"=1 when detecting the user is eating and saved in the database (Figure 7).



datetime	context	type	state	value
2019-05-07 22:30:00	sleeping	2	sleepAlertUser	1
2019-05-07 20:46:42	eating	1	eat	0
2019-05-07 20:16:28	eating	1	eat	1
2019-05-07 19:15:55	elopement	3	ElopementAlertCarer	1

Figure 7. Screenshot from table "outcomes" that stores the information from AR.

These states are defined previously in the table "states" in "Outcomes" with further attributes. MW to load those used by MR in the rules uses this table. Figure 8 shows an

example. A “state” belongs to a context “eating”, “sleeping”, “wandering” or “elopement”. It keeps the “states” group by activities or contexts, helping the subsequent process of analysis to get statistics and charts. Also, a state can be set as “state” (as internal state), “warnUser”, “alertCaregiver” or “userState” type. Thus, “eat” state can be considered as internal state because it just is updated and saved (it can be used for graphs and statistics as I show further on), whilst “warnUser” and “alertCaregiver” are those types which indicate the system should generate alerts. For example, assume the user is not going to sleep during the time set on interface timetables:

*ssr((sleepSchedule ^ #sleep)->sleepAlertUser.*

The system will use the change in the consequent “sleepAlertUser”, defined as “warnUser” type, to know if it has to warn the user. Also, consider the user is leaving the house at an unusual time that will be “elopementAlert”, which is defined as “alertCaregiver” type, this way, the system alerts the caregiver when “elopement” state is set to 1. Last, “userState” represents those feedbacks from users, by the moment this type is associated with user responses from mobile devices.

ABC state	123 type	ABC context	ABC text
ElopementAlertCarer	3	elopement	[NULL]
ElopementAlertUser	2	elopement	[NULL]
eat	1	eating	[NULL]
elopement	1	elopement	User goes out after hours
goIn	1	elopement	User is going in
goOut	1	elopement	User is going out
irregularSleep	1	sleeping	[NULL]
mealAlertCarer	3	eating	[NULL]

Figure 8. Example of states used and defined in “Outcomes” database.

Notice at this point the states can be called in different ways and updated depending on different criteria. However, updating a state name in Outcomes implies updating the text in the rule, otherwise, MR does not relate this state name with Outcomes.

The “Outcomes” logs store the change of states by saving the “state” name, the context and type of this one, the new value and time when it changes as well as an extra “info” field used for user responses.

## 6.2. User’s interface

The interface has been developed thinking in easy management and understanding. It has been developed using HTML5 and JavaScript, JQuery library, which dynamically generates the interface by requesting the interface's database. Since the interface can be configured by the primary user, I applied design recommendations focused on clearer and easier understanding for elderly such as font style and size, layout and elements colours or contrast among others (FaisalMohamedYusof, et al., 2014). For example, initially, it has been chosen black letters on white background and the opposite to distinguish sections to have a high contrast. Also, since it is likely a secondary user will configure the system using the interface, it does not have to be difficult to understand and assuming the secondary user does not have strong knowledge managing these applications. Figure 9 shows the basic parameters such as schedules, threshold and response.

Since the system stores the information about ADLs, it is important to show these activities information in an understandable way. Thus, the interface provides a tab which displays an ADLs graph which is developed using Highchart.js library. Figure 10 shows one of the possibilities about how the information can be shown. This graph displays data grouped by ADL/behaviour along the time and loads by default the user’s time tables from interface to use as reference the current user's schedules. These intervals are shown with grey bars in figure 10. The information related to daily activity recognition is loaded by selecting a day and overlapping a little on the previous one. This information is represented with a green background colour when activities have been done inside of “usual” times, while red colour are used to display those with some deviation from the normal routine. Also, it displays the warnings to users with specific points on the graph. They have different colours if they are user’s warnings or caregiver’s alerts. The figure 10 shows in yellow the warnings and in blue the alerts. This helps to evaluate if they are happening at a proper time and deduce whether the warning system is coaching the user.



More types of statistics graphs/charts can be added according to requirements: once the sensitive information is stored, it is easy to create new ones according to the requirements. For example, (Lazarou, et al., 2016) shows interesting ones.

You can watch an explanation video demo of interface in Figshare<sup>6</sup>.

#### AnAbEL - User's Interface

The screenshot shows the 'EATING' configuration tab in the AnAbEL interface. It includes a top navigation bar with tabs for MONITORING, EATING (selected), SLEEPING, ELOPEMENT, and WANDERING, along with Save and Cancel buttons. The main area is divided into three sections: Schedules, Alerts, and Message. The Schedules section has three time slots: 07:00 to 09:00, 13:00 to 14:30, and 19:00 to 21:00, each with a delete icon. An 'Add period' button is below. The Alerts section has input fields for 'Alert to caregiver after' (3600 seconds) and 'Alert to user after' (1800 seconds). The Message section has a 'Message to user' field with the text 'Have you eaten already?' and a list of 'Responses available to the user' including 'Yes', 'No, I am going to eat now', 'Peter cooked for me', and 'I am not hungry', each with a delete icon. An 'Add response' button is at the bottom.

Figure 9. Interface of “eating” activity configuration showing the parameters that are common for all activities.

#### AnAbEL - User's Interface

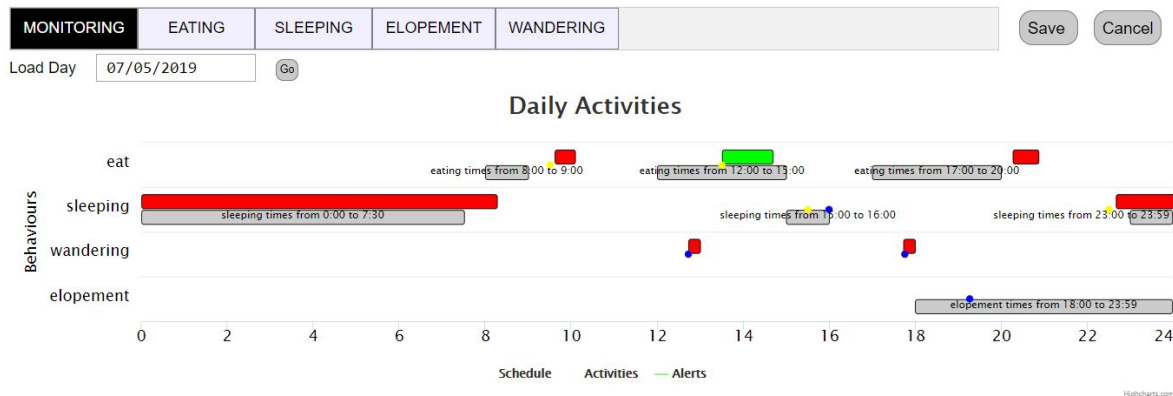


Figure 10. Interface tab showing the activities done by the user in a precise day.

### 6.3. Mobile application: interacting with users

In 4.2 Interface is mentioned that mobile technology is a good choice to interact with the user, although other alternatives regarding the environment could be considered such as

<sup>6</sup> [https://mdx.figshare.com/articles/AnAbEL\\_user\\_s\\_interface/10003142](https://mdx.figshare.com/articles/AnAbEL_user_s_interface/10003142)

using music or lights. Nevertheless, as (Orpwood, et al., 2005), PwD will struggle to learn new technologies used at home and these technologies and devices should be familiar. In addition, since elderly population in developed countries are familiar with mobile phones (Wang, et al., 2019), it seems reasonable that AnAbEL relies on the user's mobile technology to warn and to alert.

Likewise, to the interface, the mobile application (APP) design is simple and mainly focuses on easy understanding by providing the basic information, since the layout is the biggest challenge to face in an application addressed to PwD. Therefore, the main concern has been to show the information as clearer and more complete as it can.

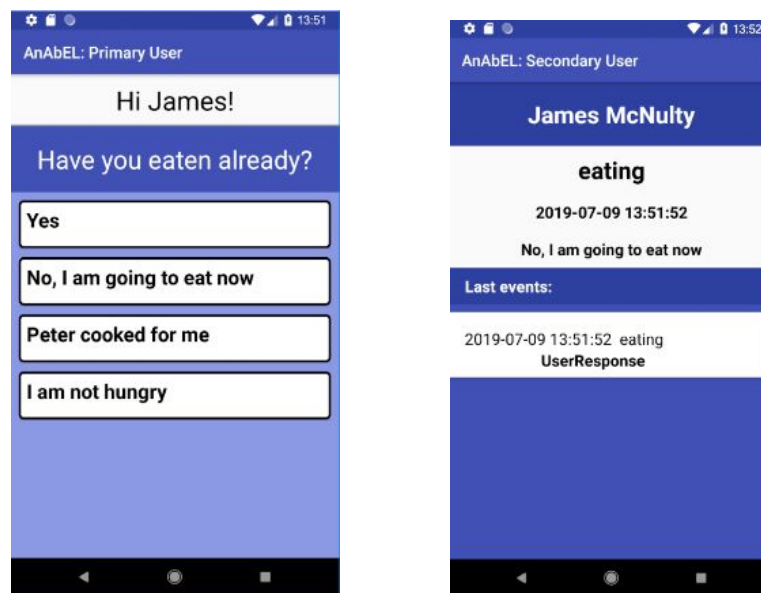


Figure 11. On the left the APP GUI for primary users that shows alerts when the system registers a state “warnUser” with value 1. On the right the secondary user Interface shows an alert when the primary user responds to a question or when the system sets a state “alertCareviger” to 1. Also, keep a scroll list which shows the latest alerts received

The APP has been developed in Android and it queries “Outcomes” each second to guarantee real-time feedback. Another approach, maybe more efficient, could be posed such as the server sends a message to user mobile when needed, but this architecture implies to get an agreement with a telephone company to send messages, consequently, in a lab environment, that scheme seems the most reasonable option.

The APP offers the possibility to users logging and showing different Graphic User interfaces (GUI) depending on the user role (primary user or secondary user). Whether it is launched as a primary user, the phone receives an alert related to the activity by showing the text message set in the user's interface for this activity (Figure 11) and, also, the list of responses predefined in the user's interface to choose one. When the user selects a response, that is sent to the server and creates a row type "userState" in "Outcomes" (Figure 7). When the APP is launched as a secondary user, the phone receives an alert with the primary user response (Figure 11). This way a secondary user can evaluate the situation based on his own experience and knowledge about primary user daily life and character. Regardless whether the primary user has given feedback, if the "unusual" situation continues the system creates an alert to the secondary user when the threshold time "alert caregiver" has elapsed (Figure 11) and the information about the "activity" is loaded by the secondary user phone as an alert. Also, the secondary user screen displays a list with the last events that occurred, offering a wider picture about the situation.

#### **6.4. Activity recognition and assessment**

Although it has explained how MReasoner rules work, the artificial intelligence of the process could seem complex. The next section explains how ADLs and behaviours have been transcribed to rules following some ideas from previous work such as (Tran, et al., 2010). Among many combinations of rules to model situations, here they are described as simpler as it can, but it could be getting more complex by adding more possible cases or scenarios in each activity.

##### **Eating activity**

An approach to obtain an "indicator of the user is eating" could be:

The user is in the kitchen using some appliance such as a microwave, kettle or opening the fridge or a closet with food. This translation of "eat" activity into MReasoner rules, including user position using BLE (called here "userKitchen" which means the user's localisation is detected in the kitchen) is:

1. *ssr((Cupboard4 ^ kitchenmotion ^ userkitchen)->eat);*
2. *ssr((Cupboard6 ^ kitchenmotion ^ userkitchen)->eat);*
3. *ssr((fridgedoor ^ kitchenmotion ^ userkitchen)->eat);*
4. *ssr((Microwave ^ kitchenmotion ^ userkitchen)->eat);*
5. *ssr((Kettle ^ kitchenmotion ^ userkitchen)->eat);*

Other important point is the need to reset the “eat” state which means the user is not eating (#eat) or finished eating. This logic is based on an estimated time, which is included in the rules and indicates the user is not in the kitchen doing something related to eating any more. For this case is assumed that one minute after all sensors involved in “eat” do not show activity and user position is “not in the kitchen” then it could be an indicator that the user has finished eating:

1. *ssr([-[60s.]#Cupboard4 ^ [-[60s.]#KitchenMotion ^ #userKitchen)->#eat);*
2. *ssr([-[60s.]#Cupboard6 ^ [-[60s.]#KitchenMotion ^ #userKitchen)->#eat);*
3. *ssr([-[60s.]#FridgeDoor ^ [-[60s.]#KitchenMotion ^ #userKitchen)->#eat);*
4. *ssr([-[60s.]#Microwave ^ [-[60s.]#KitchenMotion ^ #userKitchen)->#eat);*
5. *ssr([-[60s.]#Kettle ^ [-[60s.]#KitchenMotion ^ #userKitchen)->#eat);*

Now, the system can find out whether the user is eating and when finishes, which are stored in “Outcomes” and shown in the interface monitoring (see figure 10). Afterwards it is necessary to evaluate the activity “eat” and catalogue it as usual/unusual within the eating context. Next rules show the periods designated for user's “eat” daily routine which are loaded from the interface and converted them into rules by MR (see figure 9):

1. *ssr((clockBetween(00:00:00-06:59:59)) -> #eatSchedule);*
2. *ssr((clockBetween(07:00:00-9:00:00)) -> eatSchedule);*
3. *ssr((clockBetween(13:00:00-14:30:00)) -> eatSchedule);*
4. *ssr((clockBetween(14:30:01-18:59:59)) -> #eatSchedule);*
5. *ssr((clockBetween(19:00:00-21:00:00)) -> eatSchedule);*
6. *ssr((clockBetween(21:00:01-00:00:00)) -> #eatSchedule);*

Here, it is introduced the command *clockBetween()* which sets a consequent value according to the current computer time. Also, MR works with intervals at the same day, for that reason are added rules 1 and 6 in the code above. According to user “eatSchedule” and “eat” activity, it is possible to play with rules by modelling different situations depending on what is searched, that means “assess the situation”. For example, let assume an unhealthy case: if the user is eating after hours then alert the caregiver, being “eatingAfterHours” a “Outcomes” state with context “eating” and type “alertCaregiver”:

```
ssr((#eatSchedule^eat)->eatingAfterHours);
```

In order to illustrate a scenario that embrace user and caregiver, it can define: if the user is not eating after half hour (configured at the interface) within the defined times to do it, the system reminds user to eat and alerts the caregiver 1 hour later from the beginning schedule if the user has not eaten yet:

1. `ssr(([-][1800s.]eatSchedule ^ [-][1800s.]#eat) ->unhealthyEatingWarnUser);`
2. `ssr(([-][3600s.]eatSchedule ^ [-][3600s.]#eat) ->unhealthyEatingCarer);`

Above, the times (1800 and 3600 seconds) are loaded from the interface, being “unhealthyEatingWarnUser” a “warnUser” type and “unhealthyEatingAlerCarer” an “alertCarer” type. These two rules evaluate the situation according to user configuration and notify users of the situation.

Here it has been explained how MR rules works in a real case: when there is no indicators about user is eating within a schedule, the system changes a state type “warnUser” to make known to the user's device (mobile App) the user has a warning, and the same with the caregiver's device.

### **Sleeping activity**

The process follows the same logic used to detect “eat” activity. First defining what is the indicator that the user is sleeping in the current environment. It is easy to assume whether the pressure pad on the bed is activated (false) then the user could be sleeping and

vice versa. However, to show a more complex situation, it assumes that the user can be on the bed reading and using the light (“BedroomLighOn” line 2 in the code below) or sitting on the bed doing some activity (e.g. folding clothes) which involves “BedroomMotion” (line 3 of the code). Thus, to recognise this activity is used a pressure pad placed on bed, sensor movement and the switcher both placed in the bedroom. Here, the user localisation is omitted, however “userBedroom” state can be added in lines 1 to 4 below analogously to the state “userKitchen” within “eat” activity .

Finally, the system infers “the user could be sleeping” if there is no movement, the light is off and user is on the bed:

(BedroomBedPressure is 1/True if no detect pressure, #BedroomBedPressure is 0/False if detects pressure)

1. *ssr((#BedroomBedPressure^#BedroomLight^ #BedroomMotion)->sleep);*
2. *ssr((#BedroomBedPressure^BedroomLight^ #BedroomMotion)->#sleep);*
3. *ssr((#BedroomBedPressure^#BedroomLight^ BedroomMotion)-> #sleep);*
4. *ssr((BedroomBedPressure)->#sleep);*
5. *ssr(([-][1800s.] #sleep ^ [-][1800s.]sleepSchedule) -> sleepAlertUser);*
6. *ssr(([-][3600s.] #sleep ^ [-][3600s.]sleepSchedule) -> sleepAlertCarer);*
7. *ssr((clockBetween(00:00:00-09:00:00)) -> sleepSchedule);*
8. *ssr((clockBetween(09:00:01-14:59:59)) -> #sleepSchedule);*
9. *ssr((clockBetween(15:00:00-16:00:00)) -> sleepSchedule);*
10. *ssr((clockBetween(16:00:01-21:59:59)) -> #sleepSchedule);*
11. *ssr((clockBetween(22:00:00-23:59:00)) -> sleepSchedule);*

More situations can be expressed such as alerting the user when he/she sleeps after hours or when is not getting up at a reasonable time:

*ssr((sleep^#sleepSchedule)->sleepAlertUser);*

Also it was tested an irregular sleep pattern as the user gets out of bed several times during the night. Although, this information could be monitored by checking the “sleep” state during night time in the graph, as example, whether it is wanted to alert the user or caregiver, it could be done similar to:

1. *ssr*(([-][30s.]BedroomBedPressure ^ sleepSchedule)-> getOutBed);
2. *ssr*(([-][5s.]#BedroomBedPressure) ->#getOutBed);
3. *ssr*((<->[60s.]getOutBed ^ <->[60s.]#getOutBed ^ sleepSchedule)->pattern1);
4. *ssr*(([-][60s.]pattern1 ^ <->[60s.]getOutBed ^ sleepSchedule)->pattern2);
5. *ssr*(([-][60s.]pattern2 ^ <->[60s.]getOutBed ^ sleepSchedule)->pattern3);
6. *ssr*((pattern3)-> irregularSleep);

The rules above work analogously to a counter. If the pattern “getOutBed” repeats during the night (coded by sleepSchedule) three times, the system deduces the “irreguralSleep” situation. If the state is an “alertCaregiver” type, the caregiver will be alerted about the anomalous situation during the night. This pattern is interesting to analyse due to sleep interruption is considered an important behaviour within sleep habits in PwD as many research point, such as (Hanford & Figueiro, 2018).

### **Wandering behaviour**

Dementia professionals associate wandering episodes with PwD anxiety from disorientation. Although this behaviour implies different sorts of situations (Lai & Arthur, 2003) such as night restless, pacing or makes repetitive movements, this approach focuses on covering a precise case: when a user walks around the house. This behaviour can be detected using one PIR sensor in each room in combination with BLE localization system. That deployment provides information about user changing locations continuously. The system can know the time spent in each room and in moving among them using the MReasoner capability of inferring the time. Thus, it is possible to deduce whether a user is spending enough time in a room to do some activity or if the user has no aim. When the action "going in and going out from a room without any aim" remains for a time, we can assume the user is wandering. Appendix B shows the code used in MReasoner to detect wandering which also is explained below.

The rules used to describe this behaviour include PIR and BLE sensors (see Appendix B). The approach is: each time there is a change of room the state “pattern” is activated (lines 9-18 Appendix B). These rules use 30 seconds load from the interface (Figure 9) as the time spent by the user moving between rooms. “pattern” state continues active (true or 1 value)

while the user is moving into two or more rooms and it is reset after this action is not detected any more (lines 19-23 Appendix B). However, if “pattern” stays activated enough time, that means the user is changing room many times in a short period of time, then it could imply wandering evidence (line 25 Appendix B). Consequently the user is warned and caregiver alerted according to the time interface (lines 26-27 Appendix B) (figure 9). Notice, there are no scheduled rules for wandering because these times are not configured at the user's interface hence the behaviour is “unusual” all time. Next example describes the previous situation and shows another way to express user localisation using together PIR sensors and BLE (lines 1-8 Appendix B).

### **Elopement behaviour**

Professionals within dementia describe elopement as a type of wandering since it is related to user's anxiety and disorientation. However, here is differentiated from wandering because elopement implies a peculiar action: leaving the house which is a more dangerous situation. It also requires the use of different devices than those to detect wandering between rooms inside the house.

Since this behaviour implies going out from the house, the first step is to define what constitutes “goOut” and it is interesting to define when the user comes back to the house “goIn”. “goIn” is important in order to reset the “goOut” state (if the user has gone in then is not out) and to monitor how long the user is out (lines 5 and 4 below). Notice that the difference between “goOut” and “goIn”, since both states use the same sensors to trigger, is the sequence when one happens regards the other. Thus, “goOut” is defined as first detects movement inside the house and later the door is opened. The opposite means “goIn”, that is, first detects the door opened and later the movement inside. In the *Testing* section this case is explained wider.

A BLE beacon placed in the corridor next to the entrance door gives the state “userCorridor”. Figure 12 shows the database rows affected by this action.



1. `ssr((clockBetween(10:00:00-19:00:00)) -> elopementSchedule);`
2. `ssr((#clockBetween(00:00:00-09:59:59)) -> #elopementSchedule);`
3. `ssr((#clockBetween(19:00:01-23:59:59)) -> #elopementSchedule);`
4. `ssr((<->[3s.]FrontdoorMotion ^ [-][1s.]#EntranceDoor ^ EntranceDoor ^ userCorridor) -> goOut);`
5. `ssr((<->[10s.]EntranceDoor ^ [-][1s.]#FrontdoorMotion ^ FrontdoorMotion ^ <->[3s.]userCorridor) -> goIn);`
6. `ssr([-][1s.]#goOut ^ goOut ^ #elopementSchedule) -> elopementAlertUser);`
7. `ssr([-][30s.]#goOut ^ goOut ^ #elopementSchedule) -> elopementAlertCarer);`
8. `ssr((goOut ^ [-][1s.]#goOut)->#goIn);`
9. `ssr((goIn ^ [-][1s.]#goIn)->#goOut);`
10. `ssr([-][1s.]elopementAlertUser) -> #elopementAlertUser);`
11. `ssr([-][1s.]elopementAlertCarer) -> #elopementAlertCarer);`

Elopement sequence in database. First the system detects the user is going out so the system warns the user immediately. The user responds to the warning by selecting “I go to the Doctor”. The caregiver receives this information and decides whether the situation needs an intervention.













 datetime 	 context 	 type 	 state 	 value 	 info 
2019-07-01 18:00:35	elopement	4	UserResponse1	1	I go to Doctor
2019-07-01 18:00:26	elopement	2	ElopementAlertUser	1	[NULL]
2019-07-01 18:00:25	elopement	1	goOut	1	[NULL]

Figure 12. Example of "elopement" behaviour gathered in the database. The system detects “goOut” and generates an user’s alert (elopementAlertUser). Then the user receives the message in the APP and responds “I go to the Doctor”. This response is send to the caregiver who would determine the appropriate action if necessary.

## 7. Testing and Validation

I tested each application developed independently by using functional tests. Thus, once all AnAbEL components were deployed together I used integration tests. It allows users to adjust and fix the components until to reach the best possible accuracy and bug-free system within the environment described. These tests, however, were basic software testing more focused on the reliability than, for example, performance. However, I took the efficiency into consideration to analyse some key points, since the number of applications working together and the complexity of some task, force me to develop a system able to work in a home environment.

Despite software development being covered by previous tests, as (Augusto, et al., 2019) points, there are some gaps about context testing within Intelligent Environments. The context is outside of classical development testing yet it is a crucial element in these sorts of systems. In this research, different contexts such as each ADLs and behaviours or some action related to them were tested following the methodology proposed by (Augusto, et al., 2019). For example, texting a human behaviour in this system involves different elements that can affect or alter the context such as sensors, MReasoner, connections, databases, etc.

Appendix A provides a table using this methodology as a case of study which is explained below. It depicts the system elements (enablers) involved in the context tested along with their initial states and the outcomes in each test. Thus, Next example summarises one of some testing processes for elopement:

*Testing elopement context feature 1 (EloCF1): If the user leaves the house at a time ( $T_d$ ) during a period  $[T_a-T_b]$  configured in the user's interface, then notifying the user at  $\tau$  (seconds to alert the user once this behaviour is detected) after the "goOut" action is detected.*

The main door reed sensor and corridor motion sensor close to the main door trigger the "goOut" state. As I explain in the *Elopement behaviour* section, I should define an order: "first movement is detected inside the house and later the door is opened". Initially, I estimated that 2 seconds was enough between actions. However as table 1 shows in the first test (column Test1), it gives an undesirable outcome compared to the expected one. Checking the enablers that also are not having the expected outcomes, I conclude that the

problem is the action “goOut” that is not detected since the value of the sensor is not triggering as I expected. That fact helps to discover that the movement is detected earlier I thought. Whether motion sensors reset to 0 (by default 5 seconds later) when the user opens the doors and the motion sensor has changed the state at least second ago, there is no action detected. From here, I concluded that the definition of rule “goOut” is not precise, so I modified the “goOut” rule by defining it as “if during at least the last 3 seconds the motion sensor has been activated” as the code in the *Elopement behaviour* section shows. Also, the time operators used in the rule were changed to adapt the rule to the new suggestion, although here this is not explained, the above explanation summarises well the process. I tested the new configuration (Test2) showing the expected outcome in several attempts as the table shows, so that configuration remains.

In addition, some AR assessment examples can be watched at Figshare<sup>7</sup> repository. Here the activity recognition is tested. Also, a video testing AnAbEL was recorded<sup>8</sup> to prepare a presentation in British Computer Society Machine Intelligence Competition 2019<sup>9</sup>. AnAbEL was presented as an example of SEArch Architecture by (Augusto, et al., 2019). The system finally won the competition.

Although in this document, activity rules have been presented separately, they are merged in a template that is loaded by MReasoner using the parameters from interface by setting automatically the schedules and alerts times. That facilitates adding or modifying activities and makes that AnAbEL works like an integrated tool instead, as it could seem in the explanation above, some tools working separately.

Tests, as shown in the videos, present the success of software and AR components; however, the validation from PwD user’s experience is still desirable. Nevertheless, finally AnAbEL covers the initial system requirements proposed:

- Continuous monitoring to detect on time ADLs and behaviours related to dementia using non-intrusive and unobtrusive sensors.

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<sup>7</sup>

[https://mdx.figshare.com/articles/Detecting\\_real-time\\_behaviour\\_inside\\_the\\_house\\_using\\_non-intrusive\\_devices\\_within\\_people\\_with\\_dementia\\_context\\_/7406360](https://mdx.figshare.com/articles/Detecting_real-time_behaviour_inside_the_house_using_non-intrusive_devices_within_people_with_dementia_context_/7406360)

<sup>8</sup> [https://mdx.figshare.com/articles/Testing\\_AnAbEL\\_system\\_wandering\\_detection\\_by\\_using\\_BLE\\_localisation/10008926](https://mdx.figshare.com/articles/Testing_AnAbEL_system_wandering_detection_by_using_BLE_localisation/10008926)

<sup>9</sup> <http://www.bcs-sgai.org/micomp/intro.php>

- Providing a user's friendly interface to show useful ADLs information and to configure the system by adjusting to each user and environment.
- Providing notifications to PwD and alerts to caregivers when needed.
- Providing, by using the middleware and MReasoner, a scalable system that is able to integrate newer technologies, devices and activities definitions.

## 7.1. User evaluation

Thus, the system was presented to different groups of users, 22 people in total divided in four groups. Their average age is about 30s and they are taking BSc or MSc within Environmental Health. It was aimed to collect impressions from a collective of people with interest and knowledge about ageing and housing but at the same time, as students, they can pose current technology concerns. They were invited to come to the laboratory and receive an extensive explanation through the system and some demonstrations. Afterwards, they filled an anonymous brief survey related to their perceptions about the project, giving positive feedback and valuable personal impressions about it.

Thus, as figure 13 shows, around 76% of contestants responded they were sure that these sorts of systems can improve the life of people with some cognitive impairment, whilst the rest had some concern. No one expressed a rejection about it but the highlighted AAL technology could be decisive in the future. However, they expressed concerns about the technology acceptance by PwD, as other studies exposed here describe. Although, more than a half of them considered that this system can enhance strongly user's autonomy by guiding them (66%) and improve the healthy lifestyle of PwD. These issues support the idea of further cooperation with other professionals focused on improving this system by creating real environments to test and working closely.

Do you think this sort of technology (AAL / smart houses) can improve the people with cognitive decline (PCD) life?

21 responses

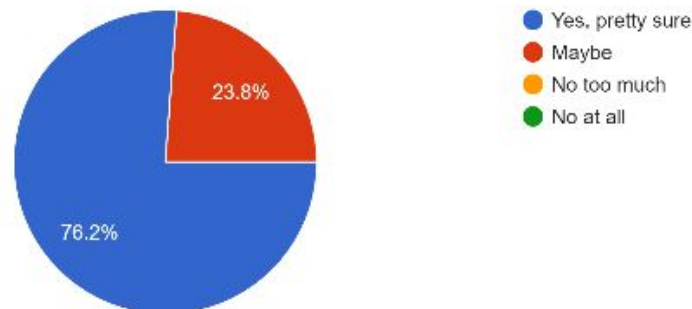


Figure 13. Student answers graph generated by Google forms.

Regarding empowering the user's autonomy and support to caregivers as the main goals of AnAbEL, the students expressed that these points are important and positively covered by this technology as figure 14 shows. Also, they strongly agreed the system could be very helpful in both enhancing autonomy and improving the user's safety. As figure 15 depicts, one important concern expressed at survey by many participants was a possible misunderstanding about the users' information offered by the system that can provoke a bad intervention or diagnostic of PwD. Previous AAL work already pointed to this issue, wherein a little malfunction in the system or in an isolated sensor could generate wrong outcomes. This concern should guide future work within system reliability.

### In your opinion, What are the more important points using these technologies in PCD life?

21 responses

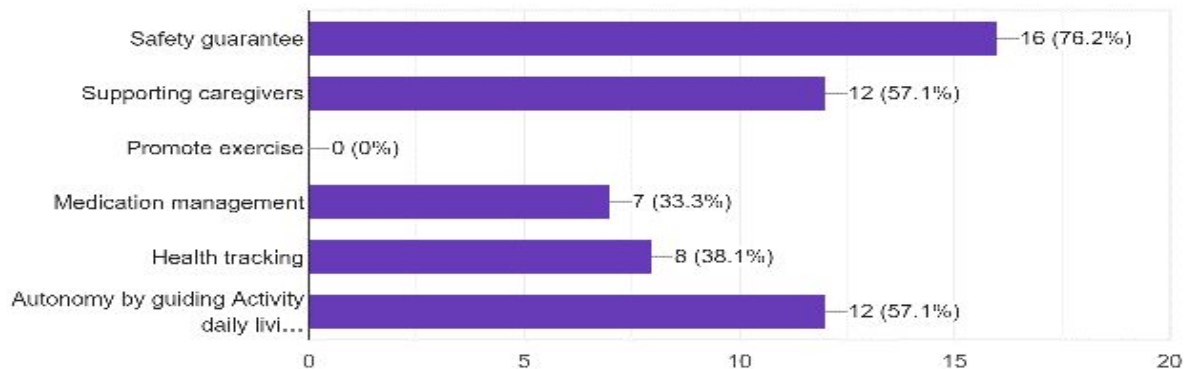


Figure 14. Points to be covered by AAL systems according to students. (Graphic provides by Google Forms)

### What are your main concerns about the use of this technology in PCD life?

21 responses

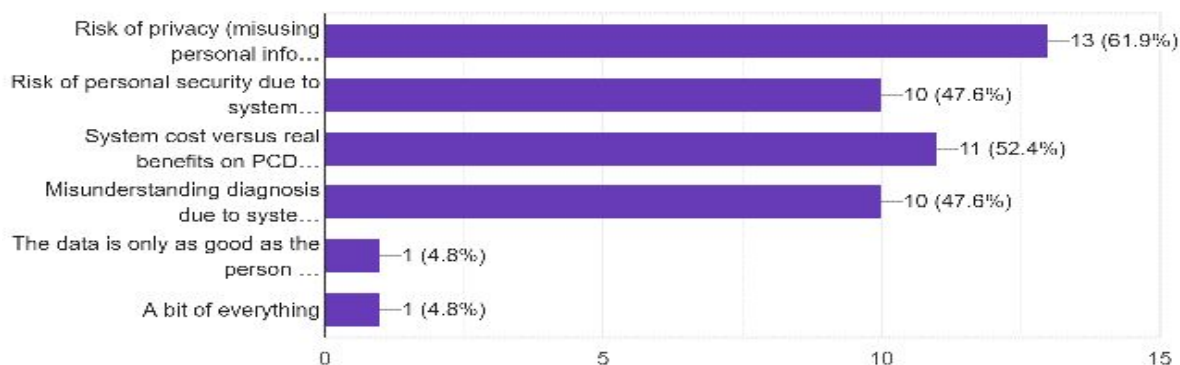


Figure 15. Students' main concerns about technology. (Graphic provides by Google Forms)

In general, the contestants expressed concerns about the final ratio between system cost and real benefits on PwD life. This issue could be covered since the IoT growth is bringing costs down. Current cost of our solution is one payment of approximately £1000

(equipment) and provides a good value for money option considering the importance of the service provided. Obviously, a full validation in a real environment is crucial to confirm this fact.

Finally, I also presented the project to external people involved in housing and dementia from Public Health of Croydon and Barnet Councils and NHS. They visited the lab and showed a big interest in the project after the proper system explanation. They pointed out that the current lacks in housing and dementia are similar to the limitations described in this work and confirmed this sort of systems could cover them.

## 7.2. Discussion

AAL approaches focused on dementia provide excellent solutions to improve life and guarantee the safety of PwD. In recent years the activity recognition has focused on the dementia environment providing valuable information about users' ADLs. New approaches to cover specific solutions take advantage of the latest technologies and others approaches refine previous solutions addressed to elderly such as reminders. In general, they aim at secondary users, despite their use of UCD techniques they seem to leave aside the primary users as an observer. Today's society, based on greater technology acceptance and powerful tools, can provide new AAL approaches that involve stronger PwD.

AnAbEL mixes different approaches to create an AmI system that involves the person living with dementia and guarantees safety by involving caregivers too. The AR process of AnAbEL provides a way to monitor the user's activities such as other AR solutions except that AnAbEL can provide warnings and reminders on-time to involve the users. The system also can check whether the user carries out the activity once advised in contrast to current reminders solutions whose alerts can be ignored by users. This feature allows the system to involve secondary users when needed. Thus, AnAbEL system addresses an AAL limitation to achieve real user autonomy.

This research also presents an approach to face two dementia behaviours: wandering and elopement. The system can detect both behaviours and warn the user and carer. These behaviours are usually out of solutions to monitoring ADLs but professionals in dementia

highlight both as important behaviours to comprehend and track since they present pieces of evidence of cognitive impairment of PwD.

Another contribution of this research is the technology to distinguish users by using BLE beacons. Although this research uses the user's mobile to identify the user, this technology is light thus can be developed in smartwatches, bracelets or other small devices that the user carries all the time.

The user's interface aiming to adapt the system to each user also differentiates this project from other AR systems wherein the information has to be analysed a posteriori. AnAbEL can provide user's activity information in real time.

This work describes the development and deployment process of a system ready to set up in a real house environment and thus test with PwD. The tests in the smart house have demonstrated the system work excellent computationally and have great activities recognition accuracy. The middleware developed has been tested proving fast communication among system parts.

Finally, the positive evaluations from users and professionals through real demos highlight the usefulness of this kind of system in dementia environments. Therefore it will be interesting to consider the ideas here described in future AAL projects that could solve its current limitations.

### **7.3. Research limitations**

Since it is not possible to test the system with the final target population of this thesis, that is PwD, the validation of this research is limited. Although the evaluation of this system has been very positive, future validations with PwD using this or similar systems, will show a real impact on the dementia environment.

Involving PwD also will have a significant impact on other decisions such as APP GUI and interface designs have the same limitations, which could be addressed by future works using co-design approaches. However, this work is based on previous researches that have contributed and validated their methods. The feedback from professionals specialized in dementia also has been relevant.



The accuracy of this AR system is based on an exclusive code of the MReasoner rules. That means I wrote the code to detect a precise action in the smart lab. However, an action can have several meanings and also can vary among users. Although AnAbEL provides an interface, this point reduces in some way the system versatility.

The middleware covers the communication needs of the system. An analysis of its performance in broader environments will help to refine it. However, currently, it is possible to find many solutions to work as this middleware does. The system could be evaluated using technologies such as distributed streaming platforms to provide the communication among the system elements.

## 8. Conclusions

The state-of-the-art in AAL is showing great advances in issues related to dementia. However, there are still limitations originating from human behaviours that are difficult to identify with precision. These issues are accentuated for PwD, which makes it more difficult to understand and anticipate some behaviours and, thereby, guarantee PwD safety using just a computer system. This reason makes that involving the caregivers a strong requirement. I believe the system AnAbEL proposed here is a good initial approach to work in this line. The extended consensus about enhancing PwD autonomy is a great step that can benefit all people involved and reinforces this belief. Thus, the system described in this work focuses on engaging PwD into the final product and on their autonomy and self-esteem, whilst it keeps the caregivers involved at the same time that also helps to reduce the burden of their role.

I have presented the final AnAbEL pilot which has been deployed to cover the concerns related to dementia and to improve some shortcomings within AAL.

The system provides an activity recognition infrastructure which has demonstrated a good accuracy detecting the studied situations and manages appropriately reminders to the users and/or alerts to caregivers. These are crucial desirable features to deploy the system in a real environment. In addition, the external positive viewpoints from Health professionals and other people who gave feedback about this system provide great expectations to the main aim of the system: to enhance autonomy of PwD.

The general design of the system and its graphical component is based on general requirements focused on elderly. This work does not try to survey a vast number of fields involved but explores and implements an idea using similar approaches to previous works addressed to enhance PwD autonomy.

This work provides a novelty idea to involve PwD and covers the current system limitation within dementia highlighted in section *Current AAL limitations*. The complete development of the system carried out in this work also shows the practical functionality and exhibits a whole system able to be tested and evaluated by people without technician

knowledge. Thus Dementia Care professionals can understand the system better and can provide better evaluations in contrast to a theoretical proposal.

Although AnAbEL is open to improvements at different stages, all the issues and future works offer interesting possibilities to improve the quality of life of PwD and the elderly in general. Although one of the main concerns is the low acceptance of technology by aged users, the current mid-age population, which will be the next elderly generations, already use technology in their daily activities. Thereby the initial milestone to propose and do research on this interactive technology is now by creating intelligent environments that consider PwD as the final user.

## 8.1 Future work

The number of fields related to this research such as IoT, AR, Context Awareness, etc. and cross-sectional areas, makes this system open to exciting future work based on its limitations in several fields.

Validations involving people living with dementia are crucial to expose the strengths and weaknesses of AnAbEL system and the PwD acceptance. The validation findings could lead to new scenarios by increasing the number of ADLs and detection accuracy. It also will involve novel analysis about using different types of devices addressed to detect activities. It is also newer devices which can be added to the system and evaluate the outcomes on it.

Besides, working with people living with dementia, it is possible to apply a UCD approach and use co-design techniques. It will provide fitter solutions in the interface and mobile application offering more friendly designs, options and statistics. It could also contribute with new ways of user's interactions that this research discarded such as using lights or smart speakers similar to Amazon Alexa or Google Go.

Work in a stable and efficient architecture which provides reliable communication among system elements can be interesting since this work does not measure the efficiency in a broader scenario or failure sensitivity. AnAbEL has excellent efficiency yet this research has limited the number of sensors and hence the activities to detect. Analysing the efficiency

of different architectures, e.g. based on Computing Edge, could be interesting to improve the system efficiency and reliability.

Related to the previous point and since AnAbEL is running either in a computer or in a laptop, the migration of the whole system to a small device like a Raspberry or Arduino will provide a fully independent gadget.

The lack of MReasoner versatility rules provides an exciting work by boosting the AR system using learning processes which could evaluate usual activities on-time and labelling them into the ADLs searched based on the learning processes. In this line, it could be also fascinating to develop friendly interfaces wherein users can define the activities to detect and to assess. Thus the system will be more autonomous and flexible to users.

It is also interesting to provide different approaches to wandering by adding other wandering definitions or using other types of devices.

AnAbEL provides several improvements based on its main specific contribution: Aiming the AAL system to people living with dementia.

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## Appendix A. Example of testing “goOut” case for elopement behaviour

EloCF1	Enablers	Assumptions Initial values	Test 1	Test 2
Expected Outcome(s)			The user receive an alert in the mobile app asking about the behaviour.	The user receive an alert in the mobile app asking about the behaviour.
Real Outcome(s)			The user do not receive an alert.	The user receive the alert.
Sensors	Main Door Motion sensor (MDM)	No movement. MDM=0	MDM=1	MDM=1
	Main Door Reed sensor (MDR)	Door is closed. MDR=0	MDR=1 two second after MDM changed to one.	MDM=1 when in the last 3 seconds MDM=1 has been one.
Network	Z-wave (Vera hub)	Vera has connection with sensors involved.	There is connection with MDM and MDR and updating their values.	There is a right connection.
Database	Preferences database	Timetable wherein the user is usual leaves the house.	Preferences has been stored correctly.	The times has been stored correctly.
	Monitoring database	Stores the context being monitored	Preferences has been loads correctly.	The times has been loads correctly.
Reasoner	Connection with Sensors and Server.	The tool connects with Vera and MReasoner.	The info from Vera is updating in the tool.  There is connection with the server.	The info from Vera is updating in the tool. There is connection with the server.
	Context-Aware Reasoner	The tool is running with all states loads. The action “goOut”, “goIn”, “elopementSchedule” and “elopementAlertUser” are false. detected and “goIn” is not detected before time alert user span (Tau)	The action “goOut” is false (it is not detected).  The action “goIn” is false (it is not detected).  “elopementAlertUser” is false.  “elopementSchedule” is false.	The action “goOut” is detected.  The action “goIn” is false (it is not detected).  “elopementAlertUser” is true.  “elopementSchedule” is false.
HCI (Human Computer Interaction)	User mobile app GUI	The APP is running without errors.	User has not received an alert in app GUI.	User has received an alert in app GUI.
Preferences	User web settings GUI	The schedule was setting from initial time Ta to final time Tb.		
Users	Person with Dementia (PWD)/Caregiver			User does not come back to house -> Elopement Context Feature 2

## Appendix B. Wandering code implemented in MReasoner.

1. *ssr*((*KitchenMotion* ^ *userKitchen*) -> *isKitchen*);
2. *ssr*((#*KitchenMotion* ^ #*userKitchen*) -> #*isKitchen*);
3. *ssr*((*LivingroomMotion* ^ *userLivingroom*) -> *isLivingroom*);
4. *ssr*((#*LivingroomMotion* ^ #*userLivingroom*) -> #*isLivingroom*);
5. *ssr*((*BedroomMotion* ^ *userBedroom*) -> *isBedroom*);
6. *ssr*((#*BedroomMotion* ^ #*userBedroom*) -> #*isBedroom*);
7. *ssr*((*ToiletMotion* ^ *userToilet*) -> *isToilet*);
8. *ssr*((#*ToiletMotion* ^ #*userToilet*) -> #*isToilet*);
9. *ssr*((<->[30s.]*isLivingroom* ^ <->[30s.]*isKitchen*) -> *pattern*);
10. *ssr*((<->[30s.]*isLivingroom* ^ <->[30s.]*isBedroom*) -> *pattern*);
11. *ssr*((<->[30s.]*isLivingroom* ^ <->[30s.]*isToilet*) -> *pattern*);
12. *ssr*((<->[30s.]*isLivingroom* ^ <->[30s.]*isShower*) -> *pattern*);
13. *ssr*((<->[30s.]*isKitchen* ^ <->[30s.]*isBedroom*) -> *pattern*);
14. *ssr*((<->[30s.]*isKitchen* ^ <->[30s.]*isToilet*) -> *pattern*);
15. *ssr*((<->[30s.]*isKitchen* ^ <->[30s.]*isShower*) -> *pattern*);
16. *ssr*((<->[30s.]*isBedroom* ^ <->[30s.]*isToilet*) -> *pattern*);
17. *ssr*((<->[30s.]*isBedroom* ^ <->[30s.]*isShower*) -> *pattern*);
18. *ssr*((<->[30s.]*isToilet* ^ <->[30s.]*isShower*) -> *pattern*);
19. *ssr*(([-][30s.]#*isKitchen* ^ [-][30s.]#*isBedroom* ^ [-][30s.]#*isToilet*) -> #*pattern*);
20. *ssr*(([-][30s.]#*isLivingroom* ^ [-][30s.]#*isBedroom* ^ [-][30s.]#*isToilet*) -> #*pattern*);
21. *ssr*(([-][30s.]#*isLivingroom* ^ [-][30s.]#*isBedroom* ^ [-][30s.]#*isToilet*) -> #*pattern*);
22. *ssr*(([-][30s.]#*isLivingroom* ^ [-][30s.]#*isKitchen* ^ [-][30s.]#*isToilet*) -> #*pattern*);
23. *ssr*(([-][30s.]#*isLivingroom* ^ [-][30s.]#*isKitchen* ^ [-][30s.]#*isBedroom*) -> #*pattern*);
24. *ssr*(([-][30s.]#*pattern* ^ *wandering*) -> #*wandering*);
25. *ssr*(([-][30s.]*pattern* ^ #*wandering*) -> *wandering*);
26. *ssr*(([-][1s.]*wandering*) -> *wanderingAlertUser*);
27. *ssr*(([-][20.]*wandering*) -> *wanderingAlertCaregiver*);

## Appendix C. Initial survey: Developing AAL system to support people with cognitive decline and dementia.

### General questions

1. What is your interest or involvement with a person living with dementia? *Mark only one.*

- ☐ Relative
- ☐ Caregiver
- ☐ Social Health
- ☐ Volunteer
- ☐ Other: \_\_\_\_\_

2. How long is your experience with a person living with dementia? *Mark only one .*

- ☐ Less than 1 year
- ☐ 1-5 years
- ☐ More than 5 years

3. Where do you give support to a person with dementia? *Mark only one.*

- ☐ At Home
- ☐ In a Hospital
- ☐ In a formal residential care home for people living with dementia
- ☐ In a formal residential care home not specifically for people living with dementia Occasional activities support (e.g.: as a volunteer)
- ☐ Other: \_\_\_\_\_

4. How much time do you spend with the person/s with dementia? *Mark only one.*

- ☐ Almost every day (a full time)
- ☐ Almost every day (a few hours)
- ☐ Some days a week
- ☐ Some distributed days per month
- ☐ Some distributed days per year

### Behaviours

If you have had contact with different persons with dementia, choose the more common option according to your experience and regardless of whether the person is at home or care centre.

These questions are addressed to know the frequency of elopement and wandering behaviour and assessment of the importance to develop the behavioural detection related as well as to pose new ones.

5. Have you attended episodes of wandering? *Mark only one.*

- ☐ Everyday
- ☐ Several times
- ☐ Occasionally
- ☐ Not much
- ☐ Never

6. How do you detect the person is wandering? *Check all that apply.*

- ☐ You notice the person has anxiety but stands still in a place.
- ☐ The person walks around the same room.
- ☐ The person moves among different rooms without staying in any them
- ☐ The person tries to get out of the building
- ☐ Other:

7. When the person is wandering, How do you interact with the person? *Check all that apply.*

- ☐ You ask the person where is going or what is doing
- ☐ You speak to the person and try to convince him/her stop
- ☐ You hold the person and conduct him/her to a place
- ☐ You use any special sound or visual action
- ☐ Other:

8. Have you attended episodes of elopement? *Mark only one.*

- ☐ Everyday
- ☐ Several times
- ☐ Occasionally
- ☐ Not much
- ☐ Never
- ☐

9. When the person is trying to get out, How do you interact with the person? *Check all that apply.*

- ☐ You ask the person where he/she is going and he/she realizes about his/her behavior
- ☐ You speak to the person and try to convince him/her to go back.
- ☐ You hold the person and conduct him/her to a place.
- ☐ You use any special sound or visual action to take him/her attention.
- ☐ Other:

10. Are there other common behaviours which imply physical motion or devices that you have observed regularly? *Check all that apply.*

- ☐ The person sits and stands up from the seat repeatedly.
- ☐ The person opens or closes a door (room or closet) repeatedly.
- ☐ The person changes the TV channel many times.
- ☐ The person starts an activity at inappropriate time. (according to his/her usual times)
- ☐ Other: \_\_\_\_\_

### Activities Daily Living. (ADLs)

ADLs are common activities such as eating, grooming, bathing, sleeping, exercise, drinking, etc.

The information extracted from these questions will help to show the importance and use of schedule in ADL as well as to determine the more common and complex one. It also helps to understand the caregiver intervention.

11. Does the person follow a schedule to carry out ADL's? *Mark only one.*

- ☐ Yes, very closely in general.
- ☐ Yes, in some of their ADL
- ☐ Freely.

12. What activities you think are more important to schedule? (choose 4 max.) *Check all that apply.*

- ☐ Sleeping
- ☐ Dressing
- ☐ Drinking
- ☐ Eating
- ☐ Grooming
- ☐ Bathing
- ☐ Entertainment
- ☐ Exercise
- ☐ Other:

13. Does the person need support to achieve ADLs? *Mark only one.*

- ☐ Continuously
- ☐ Sometime
- ☐ A little
- ☐ Never

14. What activities are easier to achieve for the person with dementia without help?*Check all that apply.*

- ☐ Sleeping
- ☐ Dressing
- ☐ Drinking
- ☐ Eating
- ☐ Grooming
- ☐ Bathing
- ☐ Entertainment
- ☐ Exercise
- ☐ Other:

15. What activities are harder to achieve for the person without help? *Check all that apply.*

- ☐ Sleeping
- ☐ Dressing
- ☐ Drinking
- ☐ Eating
- ☐ Grooming
- ☐ Bathing
- ☐ Entertainment
- ☐ Exercise
- ☐ Other:

## Interacting with people with dementia

These questions can help us to understand the common actions taken by the caregiver when detecting an unusual behaviour.

16. When you detect an anomalous activity (wandering, elopement, no ADL carried out), which action do you take first?

17. Do you use any sort of sounds or visual support (lights) to guide the person to the aim (room, seat, etc.)?*Check all that apply.*

- ☐ Lights
- ☐ Sounds
- ☐ Other:

18. Could you describe briefly which one and how you do it?

## Technology and dementia

19. Is the person living with dementia used to using technology (watch, mobile, tv) by his/her own? *Mark only one.*

- ☐ All time
- ☐ Every day
- ☐ Some days
- ☐ Rarely
- ☐ Never

20. Which devices is the person with dementia used commonly? *Check all that apply.*

- ☐ TV
- ☐ Radio
- ☐ Computer
- ☐ Mobile / tablet
- ☐ Watch/smart watch
- ☐ Other: \_\_\_\_\_
- ☐

21. Which activity for? *Check all that apply.*

- ☐ Entertainment (e.g. watching TV)
- ☐ Entertainment focus on dementia therapy
- ☐ Managing the person's daily routine (mobile apps, alarms, etc.)
- ☐ Using to support the person as a guide to achieve some task
- ☐ Other: \_\_\_\_\_

22. Do you regularly use some kind of digital device to interact with the person with dementia? (i.e. mobile games) *Mark only one.*

- ☐ Usually with everyone
- ☐ Sometimes with everyone
- ☐ Usually with some persons
- ☐ Sometimes with some persons
- ☐ No, Never

23. Could you briefly describe the activity?



## **Appendix D. System evaluation survey: Developing AAL system to support people with cognitive decline and dementia.**

1. Do you think this sort of technology (AAL / smart houses) can improve the people with cognitive decline (PCD) life?
  - ☐ Yes, pretty sure
  - ☐ Maybe
  - ☐ No too much
  - ☐ No at all
  
2. In your opinion, What are the more important points using these technologies in PCD life?
  - ☐ Safety guarantee
  - ☐ Supporting caregivers
  - ☐ Promote exercise
  - ☐ Medication management
  - ☐ Health tracking
  - ☐ Autonomy by guiding Activity daily living (sleeping, eating, grooming, drinking, etc.)
  - ☐ Other: \_\_\_\_\_
  
3. Do you think these sorts of technologies can have acceptance among PCD?
  - ☐ Yes
  - ☐ Maybe
  - ☐ No
  
4. What are your main concerns about the use of this technology in PCD life?
  - ☐ Risk of privacy (misusing personal information)
  - ☐ Risk of personal security due to system failures
  - ☐ System cost versus real benefits on PCD life
  - ☐ Misunderstanding diagnosis due to system failures
  - ☐ Other: \_\_\_\_\_
  
5. Do you think a smart house would be able to guide PCD in daily life?
  - ☐ Yes, pretty sure
  - ☐ Maybe
  - ☐ No
  
6. What sort of activities do you think could manage and support a smart house in PCD life?