FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Environment-Aware System for Alzheimer's Patients

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Mestrado Integrado em Engenharia Electrotécnica e de Computadores

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Abstract

The aim of this dissertation, developed at Fraunhofer Portugal, is to create a small electronic device able to check the environmental conditions in patients suffering from Alzheimer's disease (AD). This device is able to sense and monitor the environmental temperature and humidity, as well as the movements of the individual based on a free-fall detection system.

The equipment can be incorporated into a piece of clothing (such as a waist belt). It is able to indicate the real-time position of the patient using GPS navigation and employs GSM-GPRS communication to transmit data to the caregiver and logging it into a database. A prototype has been developed and tested in patients from a retirement home.

Resumo

O objetivo deste trabalho, desenvolvido no Fraunhofer Portugal, é a criação de um pequeno dispositivo eletrónico capaz de verificar as condições ambientais de pacientes que sofrem de doença de Alzheimer. Este dispositivo é capaz de detetar e monitorizar a temperatura e humidade ambiental, bem como os movimentos do indivíduo com base num sistema de detecção de queda.

O equipamento pode ser incorporado numa peça de vestuário (tal como um cinto) sendo capaz de indicar a posição em tempo real do paciente usando navegação GPS inclui também comunicação GSM-GPRS para transmissão de dados para o cuidador e para uma base de dados. Foi desenvolvido um protótipo testado em pacientes de um lar de idosos e de um centro de dia.

Acknowledgments

I would like to thank Artur Cardoso, Cândido Duarte and Renato Oliveira, for their guidance, help and critics which were important aspects that helped me to always try to do better.

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To my dear friends Joana Barra and Ana Ferreira, to my sisters Joana and Diana for their help and to my boyfriend Ricardo for his tolerance through all this process and most of all for his patience.

To my entire family that were always there for me during the hard times. But specially I want to thank my mother for her unconditional love and support and for the sacrifices she made so that I could be where I am today.

Ana Rita Barreto

Perseverance is the basis of success.

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Acronyms

AD Alzheimer's Disease

ADL Activities of Daily Living

ETSI European Telecommunications Standards Institute

EU European Union

GPRS General Packet Radio Service

GPS Global Positioning System

GSM Global System for Mobile communications

HTTP HyperText Transfer Protocol

IC Integrated Circuit

IIC Inter-Integrated Circuit

IDC International Data Corporation

MEMS Micro-Electro-Mechanical Systems

MySQL My Structured Query Language

NMEA National Marine Electronics Association

SC Serial Clock

SD Serial Data

SMS Short Message Service

SPI Serial Peripheral Interface

TSIP Trimble Standard Interface Protocol

URL Uniform Resource Locator

Chapter 1

Introduction

The population of Europe has been aging in these past few decades and Portugal is not an exception. Alzheimer's disease (AD) affects about 90,000 people in Portugal [1], which makes this disease a public health problem. As this is a neurodegenerative disease, patients gradually lose autonomy [2]. Alzheimer's is a type of dementia that origins problems with memory, thinking, discernment and behavior. Symptoms usually develop slowly and get worse over time, becoming sufficiently severe to interfere with daily tasks such as eating and performing daily hygiene.

In the beginning it is mainly characterized by memory loss, but in the advanced stages patients lose the capacity to carry on with a conversation with someone or even respond to the environmental stimulations.

With normal aging, people experience motor, cognitive and sensorial declines. These are common problems in the early stages of AD, and there are no completely accurate tests to detect it. As a result, it is very difficult to diagnose [3]. For that reason the diagnosis is done based on medical records, examining a certain set of symptoms and filtering out other diseases.

Alzheimer's has no current cure, but there are treatments available and research continues. The disease cannot be stopped yet from developing; the worsening of dementia symptoms can only be provisionally decelerated to improve the quality of the Alzheimer's patients' life and their caregivers. Currently, there is a global struggle underway to find better ways to treat the disease like delaying and even preventing it from developing.

The observation of patients with Alzheimer's disease demonstrates that patients present big difficulties in the execution of activities of daily living and these changes occur very early in the disease [4].

Another recognised problem are the disturbances during sleep, which worsen with the disease's progression: a patient at an early stage can sleep for long periods of time while a patient in an advanced state is only able to sleep for a short period of time, sometimes sleeping in the afternoon or waking up numerous times at night.

For the motives previously presented it is essential to monitor AD patients. For that reason the objective of this project is the creation of a non-invasive device for the patient in order to be able to register the environment temperature, humidity and body movements since Alzheimer's disease can cause sleep disturbances, nightmares and agitation [5].

1.1 Structure of the document

Beyond this chapter, the current report has six more chapters. The second chapter, "Alzheimer's and Aging" approaches the differences between normal aging and Alzheimer's disease, presenting some population data and statistics from Eurostat. It also contains an insight on the disease concerning the general term "dementia", its signs and symptoms, and its stages.

The third chapter, "State of the Art and Technical Approach" gives an overview on what has been made in the area so far by describing some already existing solutions in the market. In this chapter the dissertation statement can also be found.

The fourth chapter, "Prototype Development" describes all the components and technologies that integrate the final device, why they were chosen and it also provides an insight on the final program.

In the fifth chapter, "Android Application" the Android application made to support the main program and targeted at the caregivers of people with AD will be presented.

Chapter 6, "Validation and Discussion" details the validation methodology and the results discussion.

Chapter 7 concludes this report by making an overview of the status of the system and proposing possible future work.

Chapter 2

Alzheimer's and Aging

This chapter contains information regarding the aging problem in Europe, focusing on Dementia/Alzheimer's disease diagnosis, symptoms and how to handle the disease. It also describes the caregivers of people affected with AD and how these people are medically assisted.

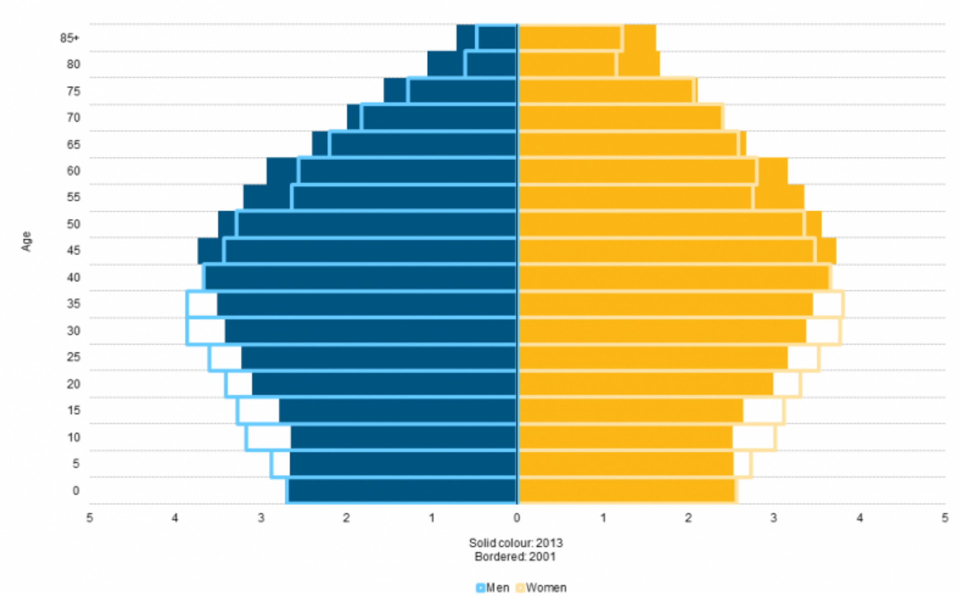
2.1 Progressive Aging Population

> *"In the coming decades, all EU countries will experience steep increases in the share of elderly persons in the total population and a significant decline in the share of young people and those of working age."* [6]

Longevity is an achievement of European societies; however the aging of the population also brings a big challenge for the economy and health systems.

Fig. 2.1a and Fig. 2.1b show graphs of the European Union (EU) population pyramids in 2001, 2013 and the prospection for 2080 [7].

With such a decrease in births it is understandable that eventually the elder group (+65 years) will exceed the younger one (-5 years). This brings serious financial and health issues. For that reason it is urgent to prepare the healthcare system.



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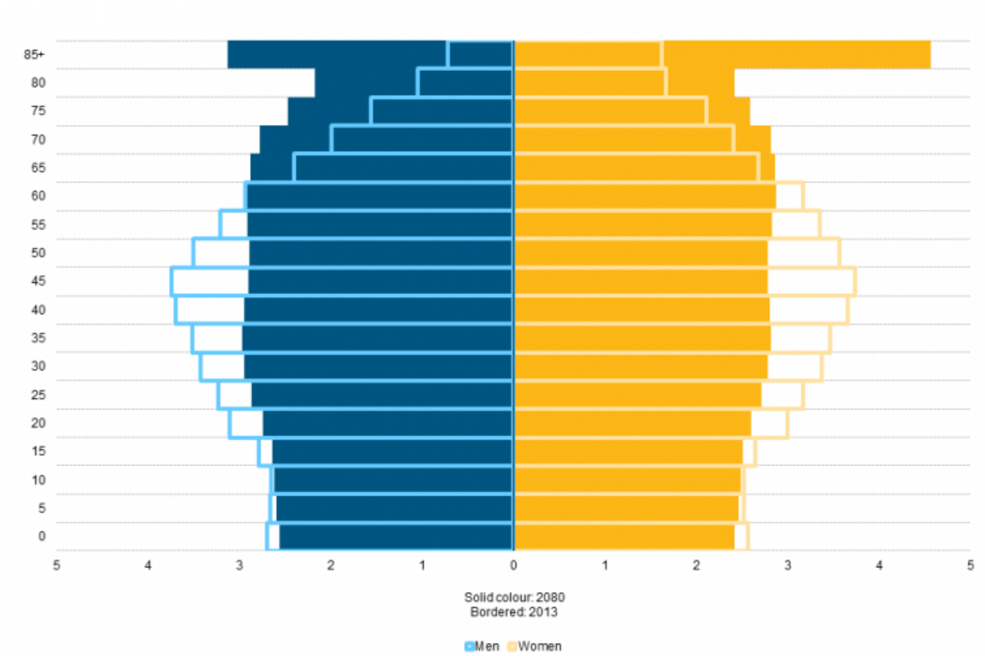


(b)

Figure 2.1: Population pyramids, EU-28, (a) 2001 and 2013, (b) 2013 and 2080 (% of the total population) [7].

2.2 Dementia

The word dementia comes from Latin “de” which means “apart” and “mentia”, which means “mind”. Dementia is the progressive decline of cognitive functions and the ability to process thoughts (intelligence) sufficiently severe to interfere with a person’s daily functioning [8].

Dementia is a term used to describe various symptoms of cognitive deterioration such as forgetfulness, vagueness and lack of memory, but is not a clinical diagnosis itself until a disease or disorder has been recognized and identified [9]. It is a collective term to entitle brain disorders such as memory, language, and discernment.

Cognitive losses happen as a normal part of aging, as we start to lose brain cells after our 20’s. This is known as age-related cognitive decline, and does not equal dementia. However when the loss of brain cells is noticeably and significantly heavy, and affects the daily life tasks, it is called dementia. Dementia designates more than one type of symptom that really affects daily activities.

All kinds of dementias are caused by brain cell death and that can be caused by a head injury, a stroke or even a brain tumor, among other causes.In these cases dementia is irreversible but may be in some cases reversible when triggered by drugs, alcohol, hormone or vitamin disproportions or depression [9].

Alzheimer’s is a type of dementia and is caused by progressive brain cell death. It is estimated that 60 to 80% cases of dementia are Alzheimer’s disease [2].

2.2.1 Dementia Signs and Symptoms

People with dementia may know or may not know that they suffer from it. Fig. 2.2 summarizes the symptoms presented in the following list, which was previously published by the American Academy of Family Physicians, which can help in identifying dementia [10]:

- “***Recent memory loss.*** *All of us forget things for a while and then remember them later. People with dementia often forget things but never remember them. They might ask the same question over and over, each time forgetting it that was already answered. They won’t even remember that they already asked that question.*”

- “***Difficulty performing familiar tasks.*** *People with dementia might cook a meal but forget to serve it, and might even forget that they cooked it.*”

- “***Problems with language.*** *People with dementia may forget simple words or use the wrong words. This makes it hard to understand what they want.*”

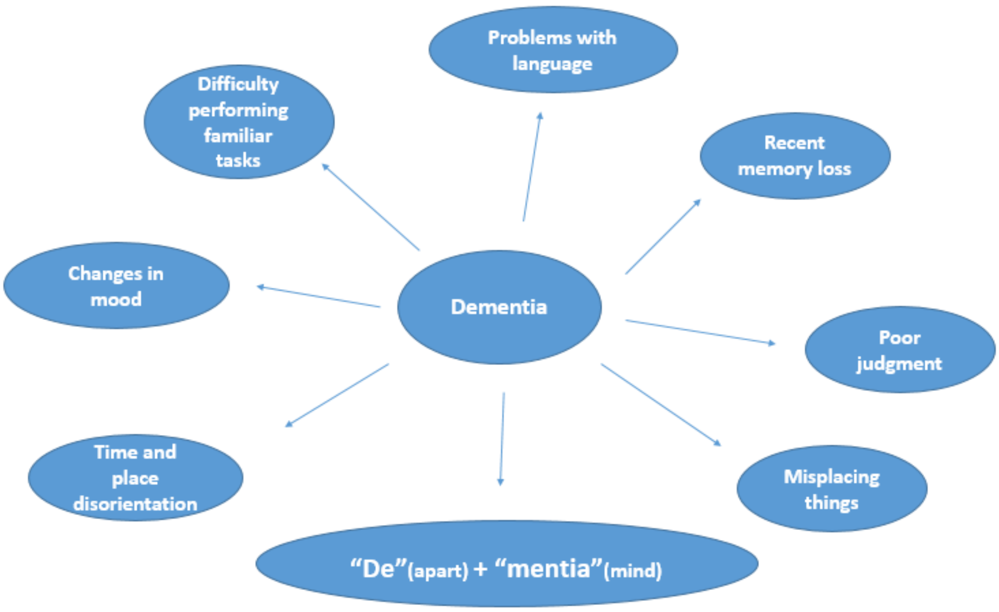


Figure 2.2: Dementia signs and symptoms.

- "***Time and place disorientation.*** *People with dementia may get lost on their own street, or forget how they got there and how to get back home.*"

- "***Poor judgment.*** *Even a person that is well might get distracted and forget to watch a child for a little while. People with dementia, however, might forget all about the child and just leave the house for the day.*"

- "***Problems with abstract thinking.*** *Anybody might have trouble balancing a checkbook; people with dementia can forget what the numbers are and what has to be done with them.*"

- "***Misplacing things.*** *People with dementia may put things in the wrong places. They might put an iron in the freezer or a wristwatch in the sugar bowl. Then they will not be able to find those things later.*"

- "***Changes in mood.*** *Everyone is moody at times, but people with dementia could have fast mood swings, going from calm to tears to anger in a few minutes.*"

- "***Personality changes.*** *People with dementia may have drastic changes in personality. They might become irritable, suspicious or fearful.*"

- "***Loss of initiative.*** *People with dementia may become passive. They might not want to go places or see other people.*"

Nevertheless, it is important to note that although people do tend to become forgetful and oblivious as they age, a great portion of people over 80 stay mentally alert. This means that even though the probability of suffering from any kind of dementia increases with age, old age does not cause the disease itself.

2.3 Alzheimer's Disease

AD is a neurological disorder caused by the death of brain cells which causes memory loss and cognitive decline. It was named after a German psychiatrist, the doctor that first identified the disease, Alois Alzheimer in 1906. It is a neurodegenerative type of dementia, the disease starts slow and with time gets progressively worse.

The following list displays some early indicators that can help identify AD [12]:

- Memory problems;
- Language/communication difficulties;
- Lapses in judgment;
- Problems completing familiar tasks;
- Disorientation;
- Decreased capacity to think abstractly;
- Misplacing things;
- Changes in mood and/or behavior;
- Shifts in personality;
- Apathy/Loss of initiative.

Although AD is a major cause of disability in older people it should not be mistaken for normal aging. Only one person out of twenty over the age of 65 and less than one person in a thousand over the age of 65 years suffers from AD [13]. In the Table 2.1 are some cases that might be mistaken for Alzheimer's.

2.3.1 Stages of the disease

This disease progression can be divided in several stages of cognitive decline based on the severity of the symptoms – from a state of no impairment, through mild and moderate decline, and eventually reaching "very severe decline" [14, 15].

For further detail on each stage and the symptoms associated with it, please see Appendix A.1 and A.2, which represent three stage and seven stage models, respectively.

Table 2.1: Alzheimer's *versus* normal aging [11].

Signs of Alzheimer's	**Normal aging**
Poor judgment and decision making	Making a bad decision once in a while
Inability to manage the budget	Missing a monthly payment
Losing track of the date or season	Forgetting which day it is and remembering later
Difficulty having a conversation	Sometimes forgetting which word to use
Misplacing things and being unable to retrace steps to find them	Losing things from time to time

With the progression of the disease, AD patients start to lose their autonomy and get increasingly dependent on others.

In the **earliest stages**, before it can be detected with the current tests, the first areas affected are involved in:

- Learning and memory;
- Thinking and planning.

In the next stage, **mild to moderate** the previous areas continue to suffer deeper changes. As a result, individuals develop problems in memory and thinking, serious enough to interfere with work and social life. Patients also may get confused and have trouble handling money, communicating and organizing their thoughts.

This stage is when great part of AD patients are diagnosed due to the increasing symptoms that start to show.

The areas that are affected next are:

- Speaking and understanding speech;
- Their sense of space like where their body is in relation to objects around then. This increases even more the risk of falling [31].

As Alzheimer's develops, individuals may experience changes in personality and behavior and have trouble identifying friends and family. For this reason the caregivers must be people in whom the patient can trust and depend on.

In **severe stages** of Alzheimer's disease most of the cerebral cortex is extremely damaged. The brain shrinks dramatically because of progressive cell death. Patients become unable to recognize their family, communicate and care for themselves [16].

2.3.2 Diagnosis

Diagnosing AD is not simple and achieve the correct result can take time and patience.

There is a blood test developed in the Georgetown University School of Medicine this year (2014) with a 90 percent certainty of whether a person will suffer from dementia such as Alzheimer's disease in the next few years. Meaning that up to one in ten people could be wrongly diagnosed with a disease that has no effective treatment yet. For that reason, this test is raising some ethical concerns among the medical community [17].

Diagnosing Alzheimer's disease requires a detailed evaluation of the patient, including [14]:

- *"A thorough history of symptoms from the patient and spouse or family, including past and present functioning.*

- *"A physical and neurological exam, including cognitive tests to assess such things as orientation (ability to recall details about self, place, and time), attention span, speed of information processing, working memory, and mood and personality.*

- *"Other tests, such as brain imaging and blood tests, to rule out other medical causes.*

"The symptoms that a doctor will look for to diagnose AD are:

- *"Significant memory problems in immediate recall, short-term, or long-term memory;*

- *"Significant thinking deficits* in at least one of four areas:
  - *"expressing or comprehending language;*
  - *"identifying familiar objects through the senses;*
  - *"poor coordination, gait, or muscle function;*

- *"Executive functions of planning, ordering, and making judgments;*

- *"Decline severe enough to interfere with relationships and/or work performance;*

- *"Symptoms that appear gradually and become steadily worse over time;*

- *"Other causes to be ruled out to ensure memory and cognitive symptoms are not the result of another medical condition or disease, such as mild cognitive impairment.*

After the tests, the doctors will make a judgment about whether Alzheimer's is the most likely cause of the patient symptoms or not because Alzheimer's disease can only be diagnosed with complete certainty after death, when microscopic examination of the brain reveals the characteristic changes.

2.4 Brain Changes

A brain with AD will suffer profound changes over time. The brain of a healthy adult weighs about 1,300 grams while a brain from an Alzheimer's disease patient can lose up to 10% of its size, which would make it 1,170 grams [18, 19]. The differences between a normal adult brain and a brain with AD can be seen in Fig. 2.3.

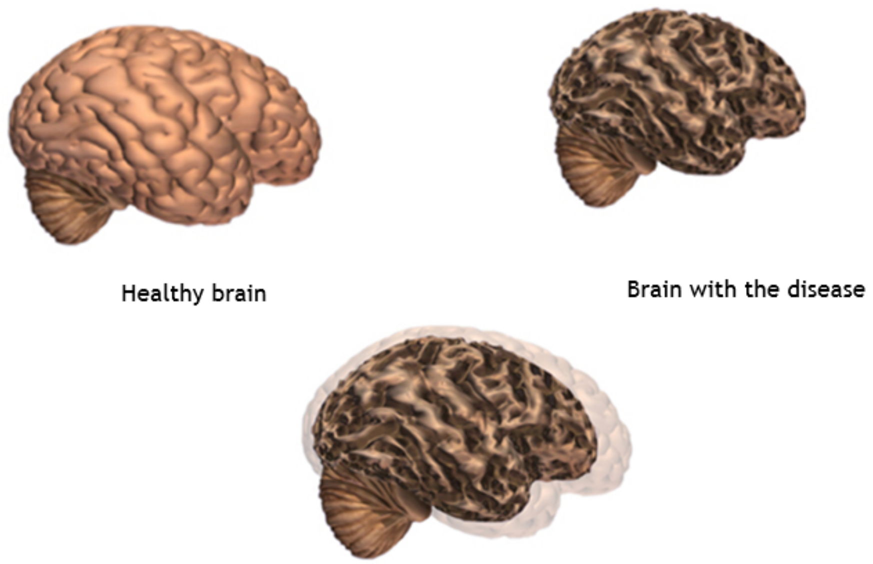


Figure 2.3: Comparison between an healthy brain and a brain with AD [16].

The brain has three main parts (Fig. 2.4) [16]:

1. *"The **cerebrum** that fills up most of the skull. It is involved in remembering, problem solving, thinking, and feeling. It also controls movement."*

2. *"The **cerebellum** sits at the back of the head, under the cerebrum. It controls coordination and balance."*

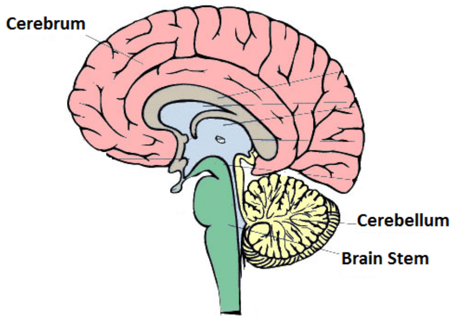


Figure 2.4: The three main parts of the brain [20].

3. *"The* ***brain stem*** *sits beneath the cerebrum in front of the cerebellum. It connects the brain to the spinal cord and controls automatic functions such as breathing, digestion, heart rate and blood pressure."*

Cells called neurons are the part of the brain where the work is centralized. An adult has about 100 billion neurons with subdivisions that connect to other neurons creating a complex network made of brain cells [16]. Alzheimer's disease destroys mainly neurons. Signals that form memories and thoughts move through the nerve cells as electrical charges and nerve cells connect to each other through synapses. When a charge reaches a synapse, it triggers the release of chemicals called neurotransmitters that travel across the synapse carrying the signals to other cells. AD interrupts electrical charges from travelling within cells and the activity of neurotransmitters and that changes the whole brain [16]. AD leads to nerve cell death and tissue loss throughout the brain. Over time, with the progressive cell death, the brain shrinks dramatically, affecting nearly all its functions.

Fig. 2.5 shows how massive the cell loss is in advanced stages of AD. The figure is a transverse cut through the middle of the brain between the ears.

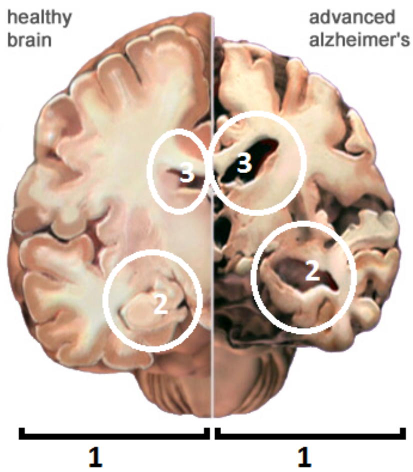


Figure 2.5: 1-Cortex; 2-Hipocampus; 3-Ventricles [16].

In the Alzheimer's brain [16]:

- *"The cortex shrivels up, damaging areas involved in thinking, planning and remembering."*
- *"Shrinkage is especially severe in the hippocampus, an area of the cortex that plays a key role in formation of new memories."*
- *"Ventricles (fluid-filled spaces within the brain) grow larger."*

A big difference can be seen between both sides looking at brain tissue under the microscope. Alzheimer's tissue has fewer nerve cells and consequently less synapses than healthy brains.

2.5 Caregivers

There are two different kinds of caregivers, formal and informal, a friend or relative that helps a disabled individual with his or her daily activities. Usually, formal caregivers are paid workers and informal caregivers are relatives that assist the patient at home.

It is really important that caregivers establish a good relation with the patient because irreversible dementia requires an increasing level of care as the disease progresses.

Many families provide care at home for a person with dementia, and although it might be a very rewarding experience, it can also be stressful; studies have demonstrated that caring for someone with a brain disorder can be more stressful than caring for someone with a physical disability [21].

Patients who do not have access to home treatment, are treated in medical facilities and in this case the caregivers can be also doctors or nurses.

2.5.1 Application targets

The device created in the scope of this dissertation can give assistance to caregivers since it will provide data about the physical state and whereabouts of the patients.

It can be useful in a variety of places and situations:

- In a house environment if for example the caregiver is able to access the condition of the patient even when the caregiver is not around.

- In locations such as day care centers to facilitate the control of both the persons with dementia as well as the environment that surrounds them.

- In a clinical environment to allow health professionals to follow the state of each patient in the unit.

2.6 Summary

Alzheimer's disease is the main cause of disability in older people and because of its nature and symptoms it is a huge weight on the caregivers and health system. As the European population is aging fast the number of individuals suffering from the disease is expected to increase dramatically in the next years.

There is still no treatment for this disease and its diagnosis is difficult to do as it is based on medical records, family history, neurological exams and analyzing disease symptoms.

This chapter gave an insight on Alzheimer's disease with special attention to its symptoms, the current tests to diagnose it, brain changes during the progression of the disease and how it is handled by the caregivers.

Chapter 3

State of the Art and Technical Approach

This chapter will present the state of the art in the scope of this dissertation and the already existing technical approaches. Some advances have been made in the area of monitoring patients for medical health, some of them focused in patients with dementia to improve their autonomy during the disease, or even to make their life easier through monitoring.

3.1 Studies made in the area

Sleep Monitoring Project

In Singapore in the project "G.P.S." [22] (which stands for "Grid-based Pipelined-parallel processing of Sensor data" for circadian pattern identification and validation of manual recording) their objective was to monitor the activity of individuals especially at night, using a simple wearable accelerometers to extract information related to sleep activity patterns [22]. The device was designed to track the signals in indoor and outdoor environments being wirelessly connected to a smartphone through the Bluetooth interface. The smartphone acts as a gateway between the sensor and a remote server, transferring data collected from the sensor to the remote server through the internet.

Fig. 3.1 shows the data flow of the processing sensor [22].

The Homecare Project

In the Caussade hospital (in France) infrared, ultrasonic and pressure sensors were used in the care unit to help the caregivers monitor their patients. This was an indoor system to control the movements of the patients that tried to be as less invasive as possible [23]. The main objective of this project was to follow patient's activities in their living environment. The patch system

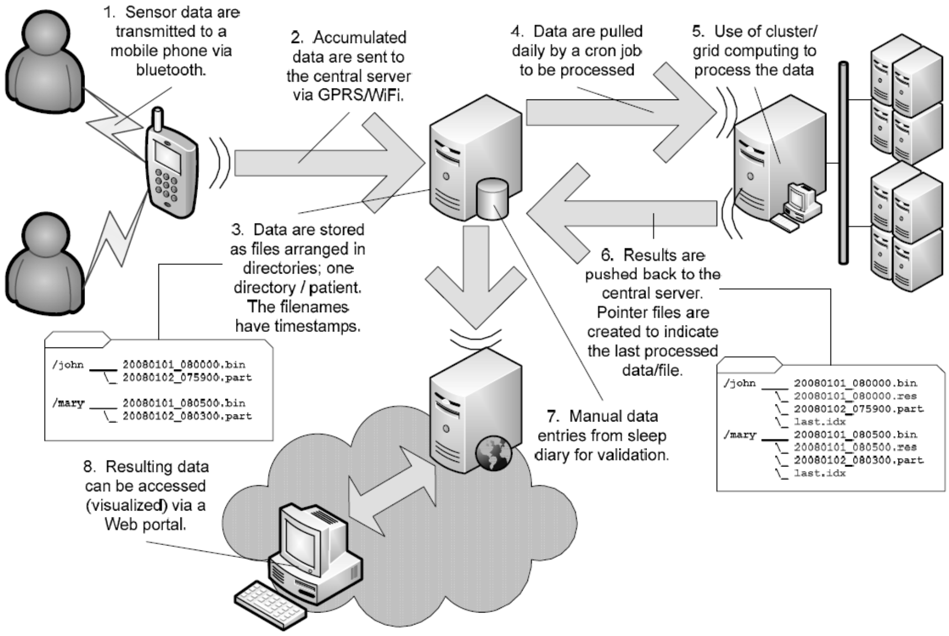


Figure 3.1: Grid-based pipelined-parallel processing of sensor data flow [22].

includes an accelerometer, a microcontroller and a wireless transceiver, where the accelerometer was used to install a fall detection system. The electronic patch was inside a hydrocolloid badage (avoids redness) to secure it on the subject's back as shown in Fig. 3.2.

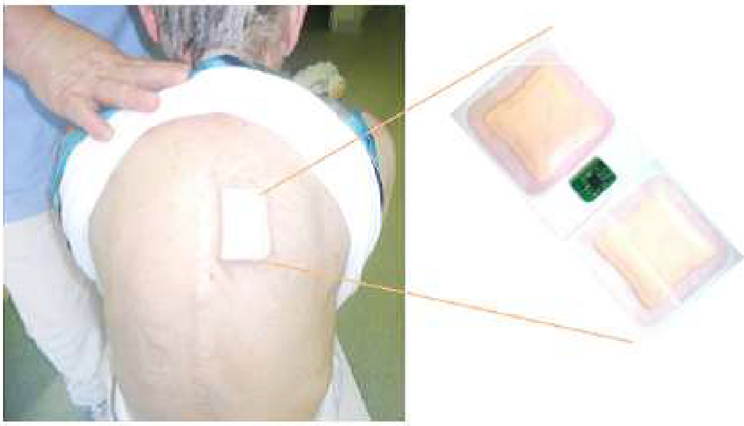


Figure 3.2: The patch applied on a patient [23].

The system was created to help caregivers monitor their patients suffering from Alzheimer's disease. Fig. 3.3 shows the areas that are being monitored with the sensors and their range [23].

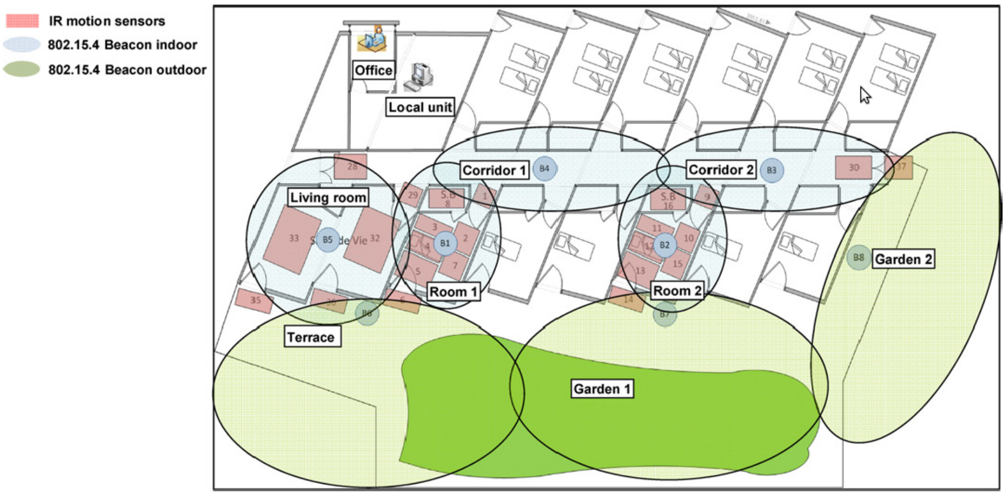


Figure 3.3: Sensors distribution in the care unit [23].

Activity Recognition Project

Another study on this subject made in the Staffordshire University in UK and the Chiang Mai University, Thailand had the aim to create a device that could recognize and classify activities of daily livings (ADLs) of an elderly person using small, low-cost, non-intrusive and non-stigmatizing wrist worn sensors [24]. The main characteristics are represented in Fig. 3.4.

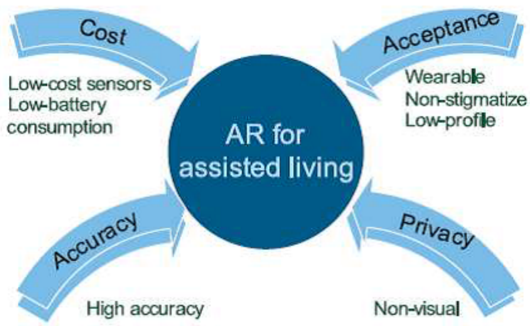


Figure 3.4: Activity recognition for practical assisted living system [24].

To achieve the desired goals, they used sensors like accelerometers, gyroscopes and a magnetometer as well as bio-sensors such as electrodes for measuring changes in skin conductance. This work investigated three types of sensors, namely accelerometer, temperature and altimeter. These sensors were integrated on a normal sports watch as shown in Fig. 3.5.

The aim of the project was to identify daily activities; for that, each subject had to use two watches, one in each wrist. In Fig. 3.6 we can see the subjects in their normal activities with one watch in each arm so the activities can be identified correctly. The processing of sensor data flow is presented in Fig. 3.7.

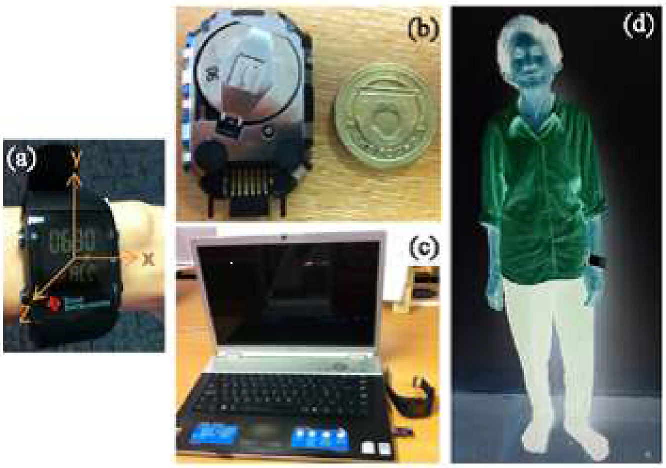


Figure 3.5: Experiment equipment and setup. (a) Acceleration axis. (b) A watch module compared to a pound coin. (c) Equipment used for experiments. (d) Sensor location on a participant [24].

Figure 3.6: Participants carry out activities naturally [24].

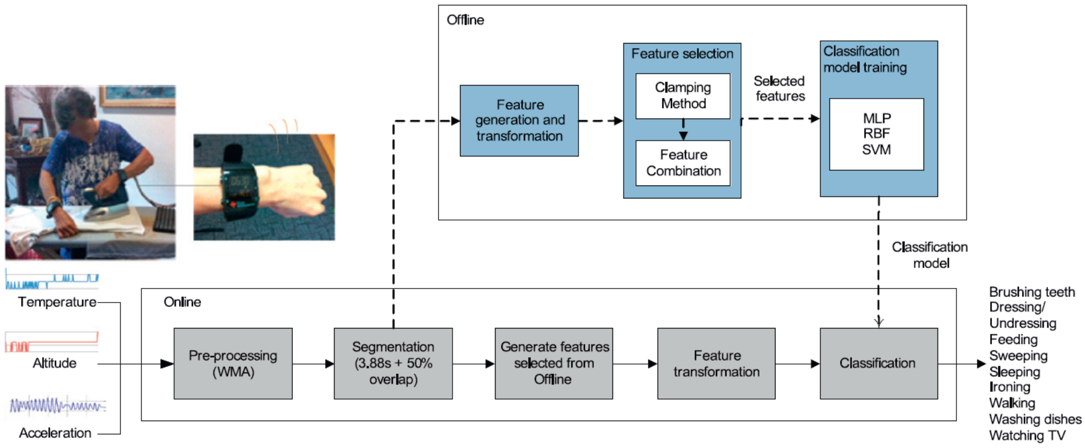


Figure 3.7: The proposed activity recognition method to detect elderly ADLs using wrist-worn multi-sensor [24].

Continuous Monitoring Project

Another study from the University of Toulouse and University Pierre Mendè, France had the objective of monitoring an Alzheimer's care unit.

The system developed consisted in a motion sensor network placed on the ceiling of the clinic. Each patient had to wear a patch so the system could identify them and detect falls (Fig. 3.8).

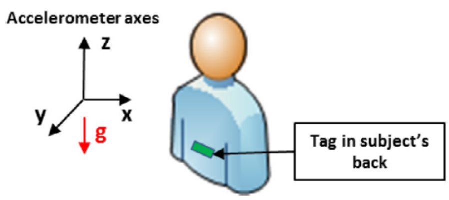


Figure 3.8: Position of the tag and axis of the accelerometer [25].

The medical staff also had access to real-time data through a web application [25].

This system has been functioning for several months now monitoring two patients twenty-four hours a day. This system allowed the detection of seven falls out of eight.

3.2 Available commercial solutions

In the market there are already some solutions. Most of them are directed towards locating goods and people. Some examples will be presented next.

Geolocsys NS100

NS100 is a small device capable of sending its location to a cellphone and to a computer via GPRS with an autonomy of 15 hours in GPS/GPRS mode (Fig. 3.2) [26].

Figure 3.9: Geolocsys NS100 [26].

Suricare

The Suricare GPS Tracker is a small equipment with a simple user interface. It has one red HELP button right in the center for when the user needs assistance while the other features as GPS trackers work without any interaction (Fig. 3.10) [27].

Figure 3.10: Suricare [27].

MagicTracking

Magic Tracking is a device developed in the polytechnic institute from Guarda, Portugal [28]. It contains a GPS receiver and a GSM card which allows data (coordinates) transmission to the "Magic Key" server (Fig. 3.11). The user can then easily access the person's location in a web environment through Google Earth.

Figure 3.11: MagicTracking [28].

My locator

My Locator is a GPS system from Inosat (a Portuguese company specialized in location solutions) that allows the user to track any important object like a laptop, suitcase or a musical instrument (Fig.3.12). With this device the user will know in real time where each one of these objects is at any time. It has a power supply that can last until 15 days maximum [29].

Figure 3.12: My Locator [29].

Car locator

Car Locator also from Inosat was created in order to decrease the phenomenon called Carjacking and the theft of cars (Fig. 3.13). The location of the car is always available via Internet access, or through a short message sent to the user cellphone [29].

Figure 3.13: Car Locator [29].

Pet locator

Pet Locator, which is also a solution from Inosat, allows the users to track their pets, simply by accessing the Internet (Fig. 3.14). The device has a power supply that can last about 5 days depending on the mode of operation. This allows the users to have more control over their pets [29].

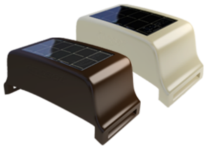


Figure 3.14: Pet Locator [29].

Gaffashion

In partnership with Inosat, GAFFASHION created the BACKPACK LOCATOR. It is a backpack with a locator in it. The objective of this creation was directed for children location (Fig. 3.15) [30].

Figure 3.15: Gaffashion [30].

3.3 Dissertation statement

After analyzing what has been made in the area and realizing what care should be taken when dealing with the well-being of Alzheimer's disease patients, the author assembled a list of topics that needed attention.

- Danger posed by falling in older adults (as mentioned in section "Stages of the disease") [31];
- The loss of memory in Alzheimer's patients that can create confusion, misperception of time and place;
- The lack of clarity;
- Most of the emergency devices created needed to be activated by the user, which could be a problem in case of fall and unconsciousness.

None of these issues is resolved by the technological approaches presented earlier in this chapter.

For that reason the presented work is based on the author's belief that:

Creating a new mobile device with remote communication capabilities and sensors to monitor the patients' environment and to know their location will ease the care of Alzheimer's patients by supporting caregivers in their work.

This device provides a solution that comprises four kinds of sensors, with a focus on the usage of the accelerometer to give more confidence to the AD patient and the caregiver regarding falls and on the GPS tracker that ensures the caregiver that even if the patient gets lost, the caregiver will know his/her location. The other two sensors, temperature and humidity are used to detect cases of environmental events like fires.

3.4 Summary

Throughout this chapter, some studies approaching the Alzheimer's disease technologically were analyzed. As we are dealing with patients that frequently experience episodes of confusion and disorientation, it is very important that the device created is as less intrusive as possible. That way, it can be used transparently, lessening the impact on the patient's daily routine as much as possible.

Chapter 4

Prototype Development

Each component of the device will be presented in this chapter. As said previously, one of the main problems inherent to Alzheimer's patients is the loss of memory, not just about the people they used to know, but also about current events, time, and place. Individuals with Alzheimer's disease in the middle stage usually experience episodes where they get disoriented and consequently get lost. This is the main reason why the GPS was necessary for this device. With this system, the family or other caregiver of the person who is wearing the device can always know his/her last position. And at last but not least to address the problem concerning falls, a fall detection system with an accelerometer is needed. In order to monitor the environment in which the patient is, the sensors used are temperature and humidity to detect any anomaly that occurs.

To fulfil the objective and aggregate various sensors in one unit the microcontroller used was the Arduino Uno.

4.1 Arduino

> *"Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists and anyone interested in creating interactive objects or environments."* [32]

It was chosen for its price, versatility and size, which are important and helpful in the creation of an initial prototype.

The various sensors chosen besides the Arduino to integrate the circuit were the accelerometer ADXL345, the HTU21D digital humidity and temperature sensor breakout board and the communication module GPS/GPRS/GSM Shield V3.0, which communicate using the inter-integrated circuit (IIC) bus and protocol.

4.1.1 IIC

The communication protocol used to establish communication between the various sensors is the IIC.

The IIC bus was invented by the Philips semiconductor division, today NXP Semiconductors, and is used for attaching low-speed peripherals to a motherboard, embedded system, cellphone, or other digital electronic devices [33].

The IIC protocol allows multiple “slave” digital integrated circuits to communicate with one or more “master” as present in Fig. 4.1.

It is only intended for short distance communications within a single device and only requires two signal wires to exchange information, a serial data (SD) and a serial clock (SC).

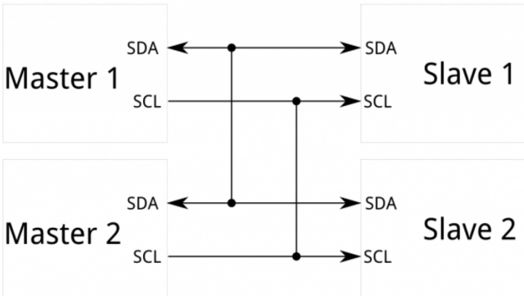


Figure 4.1: IIC protocol with multiple masters and slaves.

Each device connected to the bus is software addressable by a unique address and simple master/slave relationships exist at all times; masters can operate as master-transmitters or as master-receivers [33].

For further details on IIC communication procedure [31], refer to Appendix B.

4.2 Accelerometer

Accelerometers sense movement changes. Human movement analysis is a field of wide interest since it enables the assessment of a large variety of variables related to quality of life.

This kind of sensors offer a practical and low cost method of objectively monitoring human movements [34].

Accelerometers based on micro-electro-mechanical systems (MEMS) technology have become the most used sensors in the study of human movement because they are small, light and wearable, and these are actually some of the characteristics that we were looking for. Commonly these sensors are used with a microcontroller to process the measurements and also modules to enable communication with other devices [35].

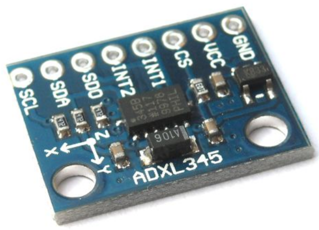


Figure 4.2: ADXL345 [36].

The accelerometer seen in Fig. 4.2 was chosen for the prototype development for its size, price and its IIC communication.

4.2.1 Implementation

The ADXL345 is an IIC 3-axis accelerometer with user-selectable sensitivity and 10-13 bit resolution (depending on sensitivity). This device already has some libraries available suitable for detection of certain movements or stimulations, like:

1. Tap
2. Double tap
3. Free fall
4. Activity
5. Inactivity

For this project only Free fall, Activity and Inactivity detections are important and will be used.

These special detection features have the ability to trigger 2 interrupt pins, making the pin go HIGH the moment one of the events is sensed. For this project only the 3th, 4th and 5th features will be selected to trigger the interrupt 1.

An interrupt, when sensed on the Arduino, pauses the system immediately, even if it is in the middle of some task, responding to that interrupt. Then the program returns to the normal routine.

The ADXL345 supports both serial peripheral interface (SPI) and IIC communication, but in this project only IIC will be used.

IIC is a 2-wire serial connection, so only the SD (data) and SC (clock) lines to Arduino need to be connected for communication.

On the Arduino Uno, SD is on pin 4, and SC is on pin 5.

The connection diagram is shown in Fig. 4.3.

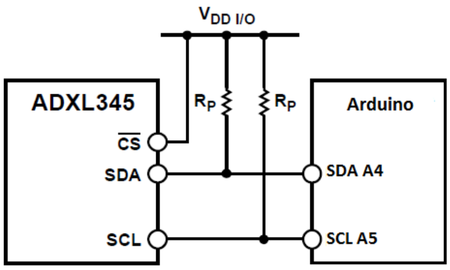


Figure 4.3: Connection between ADXL345 and the Arduino where the R_p resistors represent pull-up resistors necessary for IIC communication ($R_p = 10$ kΩ).

4.2.2 Device location on the body

The accelerometer was the main sensor taken into account to decide which position the device would take. When we want to measure the movement of the whole body there are two options:

- Multiple accelerometers;
- One accelerometer placed in the center of mass as shown in Fig. 4.4.

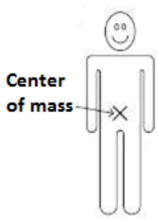


Figure 4.4: The center of mass of a person is located within the pelvis when standing upright.

As with this device we aim to detect falls but also understand when the individual is active and inactive with the accelerometer, it will be placed close to the center of mass of the patient with the help of a waist belt.

However, in conversation with a professional in the area we were advised not to create a device that would be attached to the skin because as people get older their skin becomes more fragile, less elastic and thinner, so to keep an object holding against their skin, even for a short period of time, would have the potential to damage it.

For that motive the device could not be directly attached to their skin, so it was decided to put the device into a bag fixed on a waist belt instead.

4.3 Humidity and temperature sensor

Humidity is the amount of water vapor in the air and that amount can condition a person‘s well-being, as it affects the transpiration of the skin which regulates body temperature.

For that purpose the sensor present in Fig. 4.5 was chosen for being a low-cost, easy to use, highly accurate and small digital humidity and temperature sensor.

Figure 4.5: HTU21D [37].

4.3.1 Implementation

As said previously when IIC is used, it is really easy to add more devices to the system since different addresses are attributed. The simple connection of the HTU21D can be seen in Fig. 4.6.

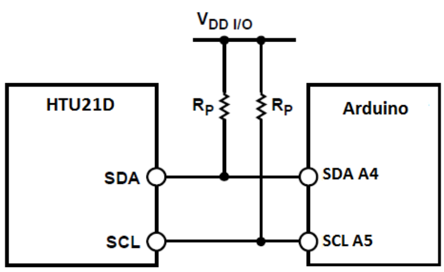


Figure 4.6: Connection between HTU21D and the Arduino where the R_p resistors represent pull-up resistors necessary for IIC communication ($R_p = 10\ k\Omega$).

This sensor already has a library in the Arduino store, and the main functions are:

- myHumidity.ReadHumidity() which will return a float containing the humidity. Ex: 54.7;
- myHumidity.ReadTemperature() which will return a float containing the temperature in Celsius. Ex: 24.1;
- myHumidity.SetResolution (byte: 0b.76543210) which sets the resolution of the readings;
- myHumidity.check_crc (message, check_value) which verifies the 8-bit CRC generated by the sensor;
- myHumidity.read_user_register() which returns the user register. Used to set resolution;
- SetResolution() which allows the developer to change the humidity and temperature resolution.

4.4 Communication Module

The data from the sensors regarding the environment and state of the patient is sent to a server (described in a next section "Server database") and the caregiver's phone.

With that in mind the module for communication chosen was the GPS/GPRS/GSM Shield V3.0 available from DFRobot (Fig.4.7).

Figure 4.7: GPS/GPRS/GSM shield [38].

This is a GPS/GPRS/GSM shield with a Quad-band GSM/GPRS engine. It also supports GPS technology for satellite navigation.

This module is controlled via AT[1] commands and the design of this shield makes it possible to drive the GSM and GPS function directly through the Arduino Board. It includes a high-gain antenna for GPS and GSM.

This GPS/GPRS/GSM shield uses an embedded SIM908 chip from SIMCom. Featuring an industry-standard interface and GPS function, the combination of both technologies is a suitable solution to track people at any time and any location with signal coverage.

4.4.1 AT commands

AT commands, also known as "Hayes command set", consist of a series of short text strings which combined together produce complete commands for operations such as:

- Send text messages;
- Change between modes;
- Dialing;
- Hanging up;
- Changing the parameters of a connection.

For further detail on the AT commands used in this program with the GPS, GPRS and GSM module, please see Appendix C.

4.5 GPS

GPS is a navigation system based in 24 satellites placed into orbit by the United States Department of Defense [39]. This system was first created for military applications, but since the 1980s this technology is available for civilian use.

GPS provides the ability to locate an object everywhere on earth with signal coverage. This aims to make the caregiver job easier and provide a more comfortable life for them and the patients.

[1] Stands for "attention", a command usually sent to wake up the communication module.

Each satellite circles the earth twice a day in a very precise orbit and transmits signal information to earth. GPS receivers use the time the signal was transmitted with the time it was received to calculate distance. They then use that information to do triangulation to calculate the user exact location, latitude and longitude and for that at least three satellites are needed. However if altitude is needed a fourth satellite has to be used.

The GPS consists of a set of 24 operational satellites and land-based control stations [40].

GPS receivers offer information about position, altitude, velocity, time, and can be controlled by standardized protocols like NMEA-0183 (National Marine Electronics Association), TSIP (Trimble Standard Interface Protocol), etc.

4.6 GSM and GPRS

GSM is the European standard for cellular communications developed by the European telecommunications standards institute (ETSI) [41].

It makes available services like short message service (SMS), voice calls and GPRS.

GPRS is one way of data transmission in GSM, this is the major development in the GSM standard that benefits from packet-switched techniques; it was designed by ETSI to be implemented over the existing infrastructure of GSM without interfering with the already existing services, and that was possible because GPRS uses the same frequency bands, the same radio modulation and burst structure as GSM.

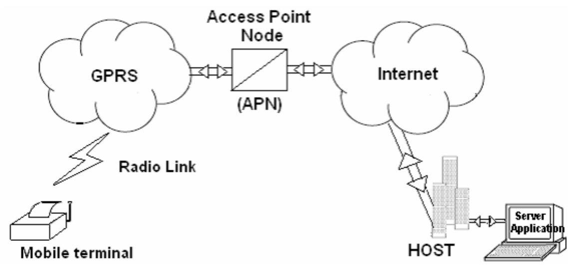


Figure 4.8: GPRS connection via the Internet [42].

Fig. 4.8 represents a scheme of GPRS connection via the Internet.

The package system allows a more efficient use of resources since the network is only being used when there is something to transfer. The advantage of the GPRS connection is the higher data rate than the circuit switched data and the permanently ON connection to the network.

4.7 Flow chart for microcontroller tasks

The main structure of the program is presented in Fig. 4.9. The central sensor, in which we are focused on, is the accelerometer.

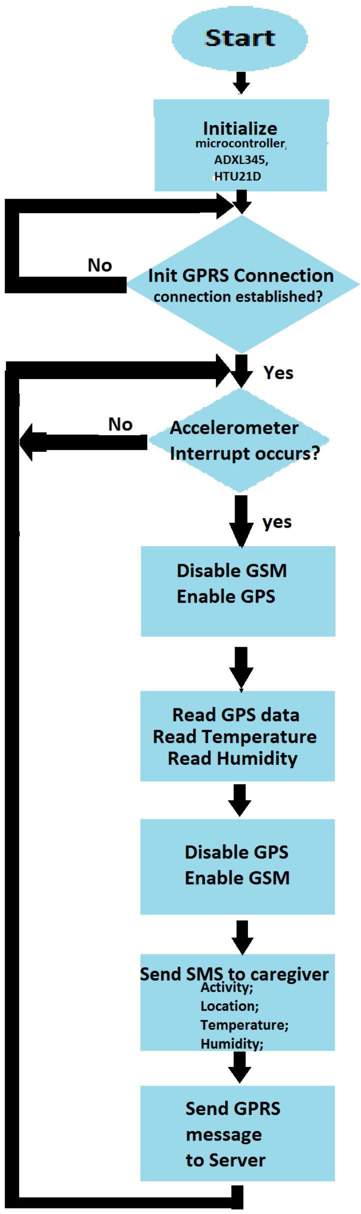


Figure 4.9: Flow Chart.

The next step is to initialize the GPRS connection and if it succeeds the program is running just waiting for the accelerometer interrupts to be activated, i.e. once one of the three activities is sensed:

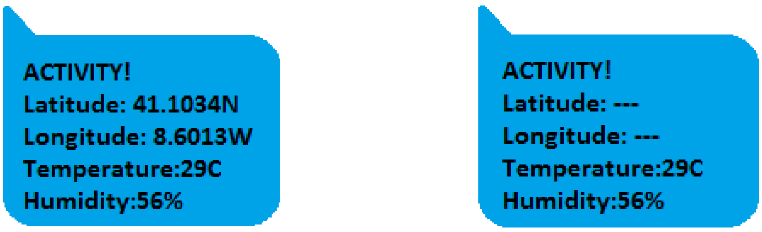
- Free fall;
- Activity;
- Inactivity.

GPS is enabled as the GSM is disabled because the two modes cannot work at the same time in the device used.

Subsequently the system asks for its coordinates and reads temperature and humidity values.

Then GSM is activated and GPS deactivated so the information can be sent to the caregiver phone, and also to the server's database through GPRS.

The caregiver will receive an SMS with the information seen in Fig. 4.10a, where the first line "ACTIVITY" in this case can also be "INACTIVE" in case the individual is not doing any activity or "FREE FALL" in case the individual has suffered from a fall.



(a) (b)

Figure 4.10: Information received by the caregiver (a) with and (b) without GPS coordinates.

In the scenario in which the patient is indoors, as the GPS data are not available, the SMS will be presented as shown in Fig. 4.10b.

After being sent to the caregiver the information is also sent automatically to a server database (please refer to the next section) where data is stored.

4.8 Server database

To support the system and also save data collected, a MySQL database was created.

The database relates all patients' data, not just the data collected by the device but also their personal information. For instance, the clinic each patient frequents and its address. The database structure can be seen in Fig. 4.11. For further information on database structure see Appendix D.

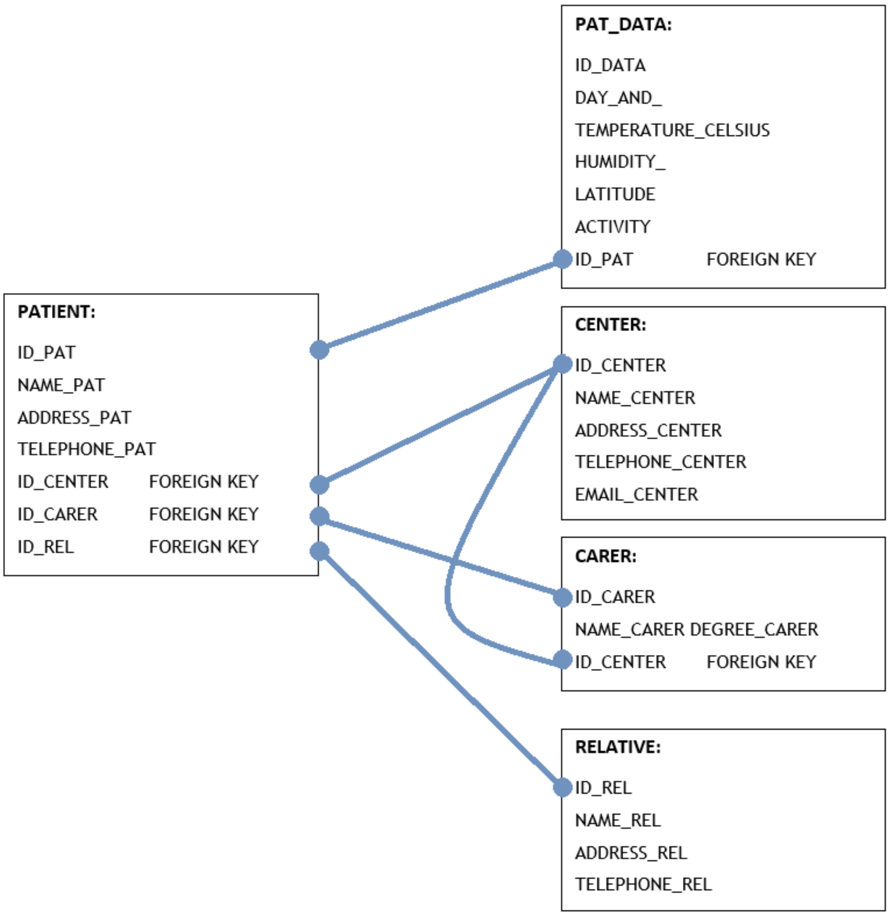


Figure 4.11: Database structure.

The information is directed to the server sent through HTTP string where data is sent as URL parameters as follows:

http://alzsense.projects.fraunhofer.pt/api/index.php?patient_id=**100**
temperature=**29**humidity=**56**activity=**Activity** latitude=**41º10’34"N**longitude=**8º60’13"W**

The server will get the information as shown on Fig. 4.12, where ID_PAT is the identity number of the patient in the system.

DAY_AND_HOUR	TEMPERATURE_CELSIUS	HUMIDITY_PERCENTAGE	LATITUDE	LONGITUDE	ID_PAT	ACTIVITY
2014-06-12 17:11:21	29	56	41º10'34"N	8º60'13"W	100	Activity

Figure 4.12: Server data.

This way the information regarding the patient will be sent to two places, the caregiver’s phone and the server where data can be posteriorly accessed by the caregiver.

4.9 Final product

After gathering all the sensors (accelerometer, humidity and temperature sensor, GPS and GSM/GPRS) the result was a single unit that can be seen in Fig. 4.13. The autonomy achieved was around one hour and a half.

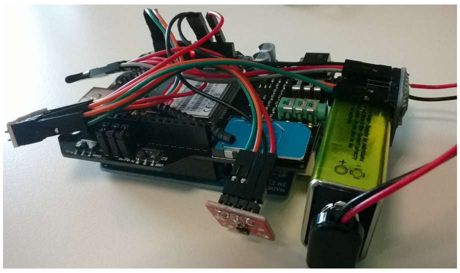


Figure 4.13: Device outside the box.

For the proper use of the device, it was important to design a box in which all the sensors could fit. Its dimensions are:

- Length = 11,5cm;
- Width= 7,6cm;
- Height=5,4cm.

To design the box the software used was SketchUp, and the sketch can be seen in Fig.4.14.

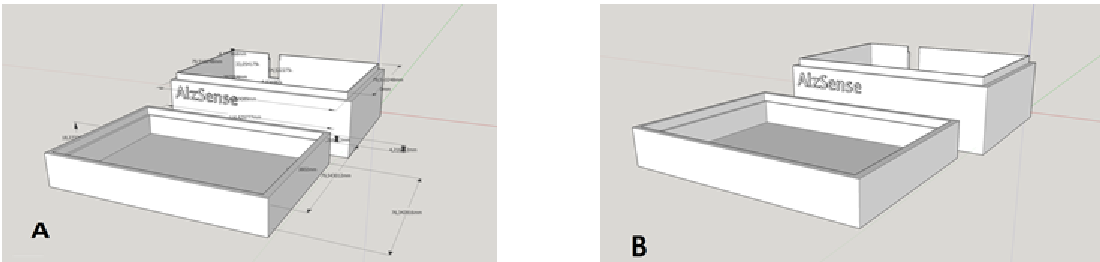


Figure 4.14: A – The sketch of the box; B – Final version of the box.

The name *AlzSense* presented in the box design was decided because we are approaching Alzheimer's disease (Alz) through sensors (Sense).

After the box was designed, it was converted to a MakerWare file and then printed out in the 3D printer MakerBot Replicator 2x and the result is in Fig. 4.15. Then the device is inserted in a small bag and used in a waist belt as seen in Fig. 4.16.

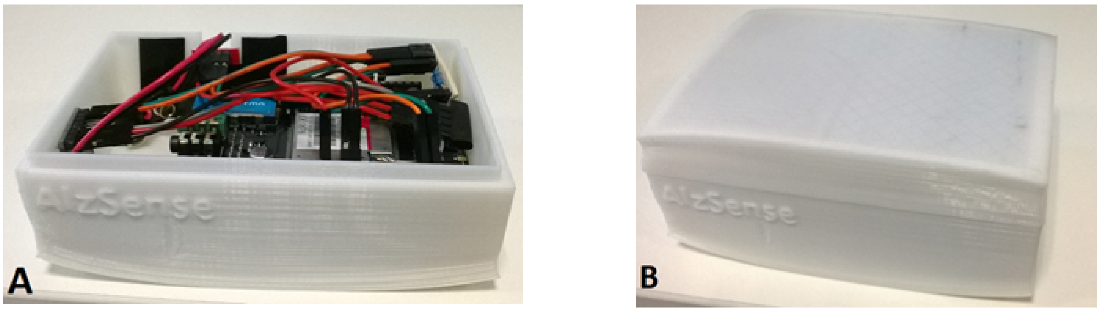


Figure 4.15: A – Open box with the device inside; B – Closed box.

Figure 4.16: The device on a waist belt on the left and a patient using it on the right.

4.10 Summary

Throughout this fourth chapter, the specification and implementation process was detailed. The prototype is a system composed by one accelerometer, one humidity and temperature sensor and one location sensor (GPS), capable of communicating through GSM and GPRS.

This device is meant to be used by Alzheimer's patients and to be remotely connected to their caregiver.

The system provides data regarding the patient's environment, such as humidity, temperature data and its location.

The final product appearance is a box with the following dimensions: 11,5×7,6×5,2 cm.

Chapter 5

Android Application

In this chapter, the Android application made to support the caregiver will be presented. In the application, it is possible to see the current and past data in real time. With the application the user is able to access past and current data like temperature, humidity and activity history.

5.1 Android

Android is a Linux-based operating system in general designed for mobile devices. It is used mainly in smartphones and tablet computers. It is developed by Open Handset Alliance, a consortium of companies led by Google.

According to the International Data Corporation (IDC) [43], Android currently holds 95.7% of all smartphone shipments in the fourth quarter of 2013, and 93.8% of all smartphone shipments for the year.

Besides the highest market portion, Android also provides some characteristics that were important in the choice of selecting it as AlzSense's mobile platform:

- Open source;
- Fully customizable application interfaces;
- Low price and high accessibility devices.

5.2 Application Interface

The Android application AlzSense was developed with the aim to provide the caregiver the possibility of accessing the patient's information when Internet access is available. The application retrieves the patient's data from the server.

The application has a simple design with only two screens. First the main menu with three options, "Check Temperature", "Check Humidity" and "Check Activity" (Fig. 5.1), where each one of them opens the second screen displaying different data according with the choice made here.

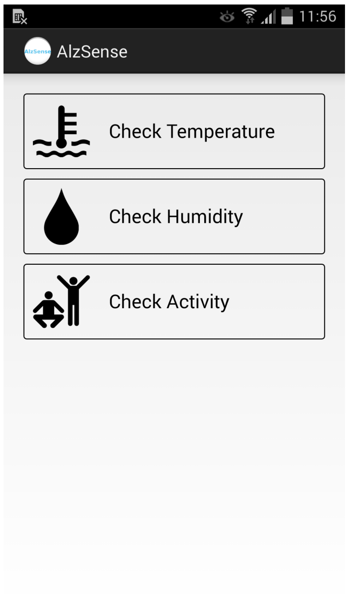


Figure 5.1: The main options menu.

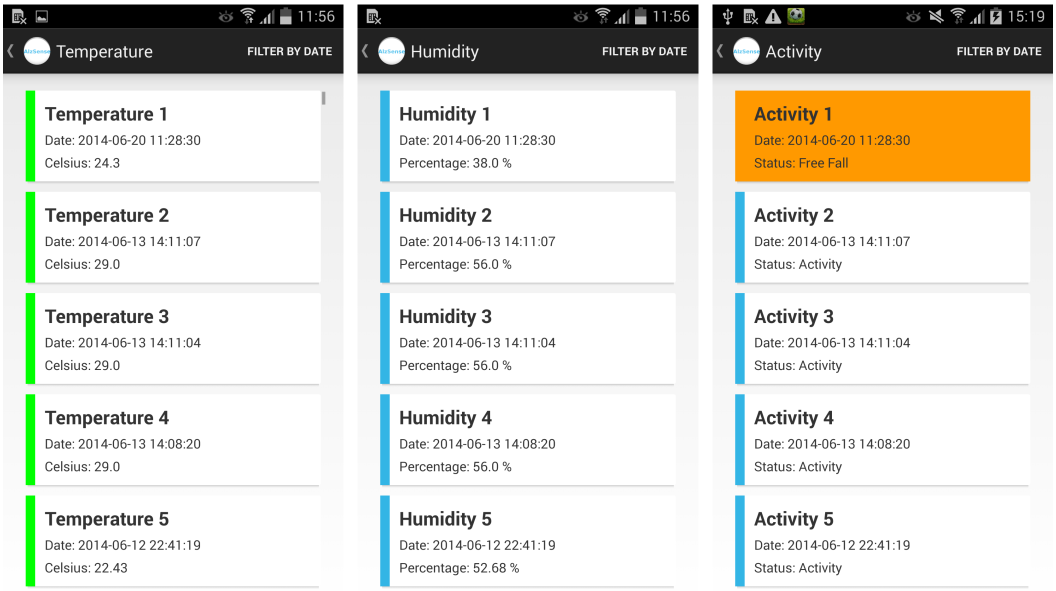
The user interface is shown in Figs. 5.1–5.3.

Two things deserve to be described here:

- The temperature data list will display a different color based on the temperature value. When the temperature is too cold or too hot the information card will present a blue or red edge respectively instead of the green one.

- The activity data list will display as normal except for the case when a free fall is detected. In this case the information will appear with an orange color to get the caregivers' attention.

There is also a date filter, because that way not only the user can choose only the data from today but also to other days data. With that in mind, different dates can be selected through the dialogue box presented in Fig. 5.3.



(a) (b) (c)

Figure 5.2: Information regarding (a) temperature, (b) humidity and (c) activity.

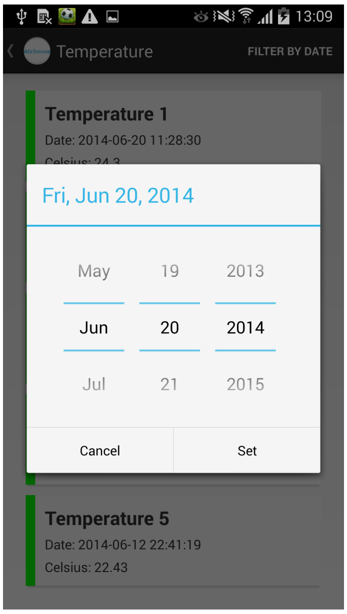


Figure 5.3: Filter based on the day of the test.

5.3 Summary

The Android application AlzSense was presented in this chapter. It is a mobile application to be used by the caregiver to access the patients' data stored in the AlzSense database. The caregiver can access temperature, humidity and data referring to the patient's activities.

The search can also be filtered by date to have an easy and intuitive access to data.

On the next chapter it will be possible to see the results obtained when testing the system, as well as an analysis thereof.

Chapter 6

Validation and Discussion

An appropriate validation of a system like this would be performed during a week 24 hours a day in a home or clinic environment, where the subject involved in the test would wear the device and live his/her normal daily routine.

However due to time and battery constraints such validation was not possible. Nevertheless tests with three Alzheimer's patients and two patients without AD were performed. Each patient had to wear the device on a waist belt for one hour while doing their normal daily routine (for further detail refer to Appendix E).

The results of the tests performed will be detailed and analyzed throughout this chapter.

6.1 Results of the tests

The tests were performed with five individuals, all women of ages above 75 years as can be seen in Table 6.1, which contains some information about each one and their caregivers.

Table 6.1: Patients and caregivers personal data.

Subject	Age	Already suffered a serious fall?	How long with the disease?[12]	How many hours spent in the clinic?	How much time by yourself?	The subject's caregiver uses a smartphone?	Caregiver's age?
A	80	No	1 year	5	0	–	60
B	85	No	8 years	24	0	No	73
C	90	No	1 year	8	0	Yes	65
D	79	No	–	3	20	No	60
E	75	Yes	–	4	0	No	76

The question *"Already suffered a serious fall?"* was made because fear of falling increases if the person already had suffered one and that seriously affects their gait and increases their fear of walking alone or without other physical support [31].

The question *"How long with the disease?"* was made to understand in which stage the subject was in, however none of them were able to say the stage, only how long they were diagnosed.

The next two questions *"How many hours spent in the clinic?"* and *"How much time by yourself?"* were made to see how long the subjects were alone and if in case of emergency or falling, assess how much time they would be without assistance.

The final question *"The subject caregiver uses smartphone?"* was made to understand if an application for a smartphone would be useful for caregivers to have access to all their AD-affected relative's information.

Each test had the duration of one hour and the data was sent every three minutes, so for each test, approximately twenty samples were acquired.

As seen in the table, only subject E had already suffered from a serious fall, only subject C caregiver's used a smartphone, and only subject D spent time on her own outside the daily center. This last subject already had an emergency system.

That system consisted in one little device with an "Emergency" button, that once pressed contacted a caregivers company, and someone would be sent to subject D house.

The following sections describe the subject results.

Subject A

Context: Subject A was the first patient to do the test, she had been diagnosed with the disease for a year and was still very active, participated regularly in the gym class and interacted with other people in the day care center.

She showed some reluctance in using the device because she was not feeling comfortable with it since she thought it was too big and unaesthetic. For that reason she only wore it for 30 minutes which explains the fact that only half of the normal number of data was acquired. The test was performed at 4:20 p.m. (Fig. 6.1).

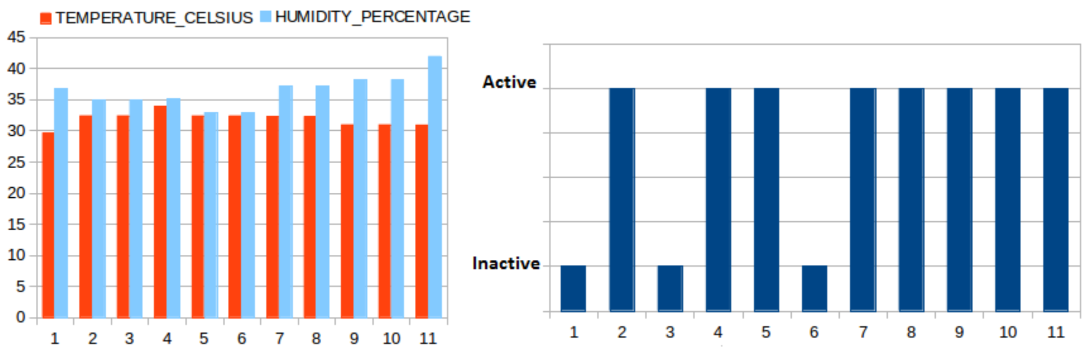


Figure 6.1: Subject A (temperature and humidity, at the left; activity records, at the right).

Subject B

Context: Subject B had Alzheimer's disease diagnosed for approximately eight years now, however the caregiver was unable the say which stage she was in. She spent most of the day sitting on a sofa with certain moments when she was awake but most of the time, just sleeping.

The device did not seem to bother her as she kept her normal routine. The test was performed at 11:40 a.m. (Fig. 6.2).

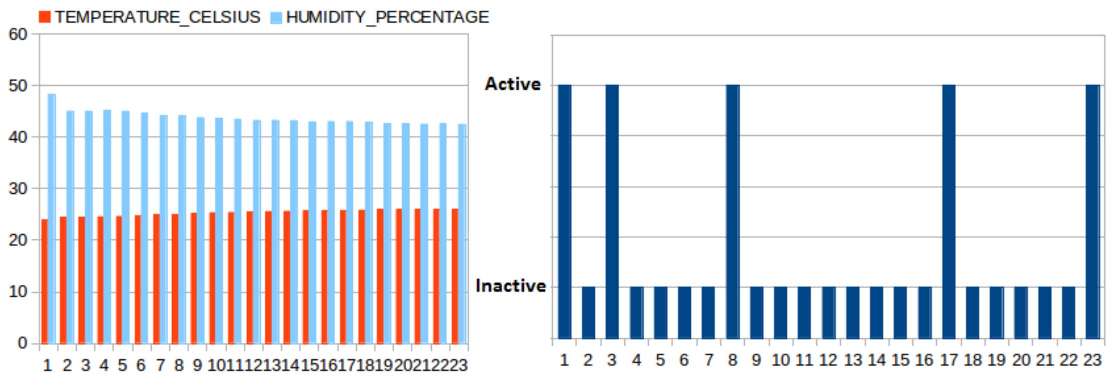


Figure 6.2: Subject B (temperature and humidity, at the left; activity records, at the right).

Subject C

Context: Subject C had only been diagnosed with AD for one year but she was much less active then subject A (which was diagnosed with AD for about as long). She spent most of the time sleeping on a sofa near subject B. The device did not seem to bother her since she was sleeping all the time just waking up for some time now and then.

The test was performed at 9:30 a.m. (Fig. 6.3).

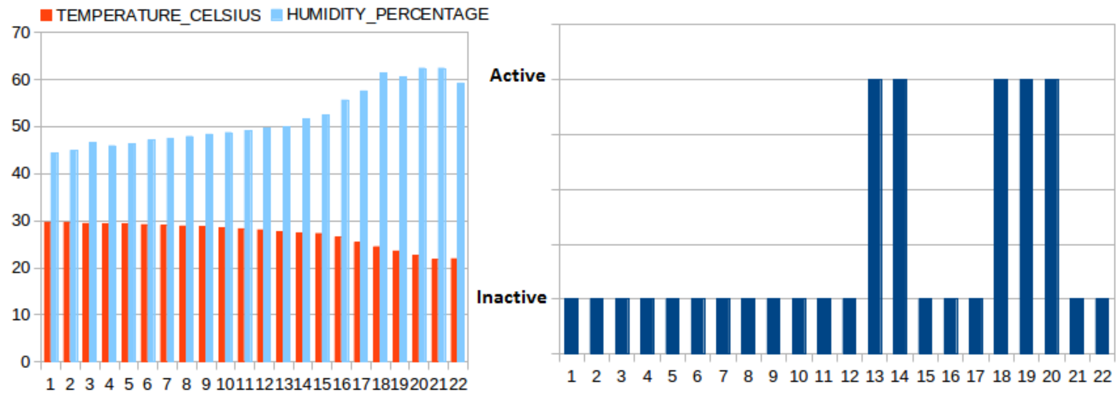


Figure 6.3: Subject C (temperature and humidity, at the left; activity records, at the right).

Subject D

Context: Subject D was the fourth one to do the test and one of the subjects that did not had the disease. She gave a positive feedback since the device did not bother her at all. At the time of the test a group of people in the center including her were having a Boccia game.

The test was performed at 3:20 p.m. (Fig. 6.4).

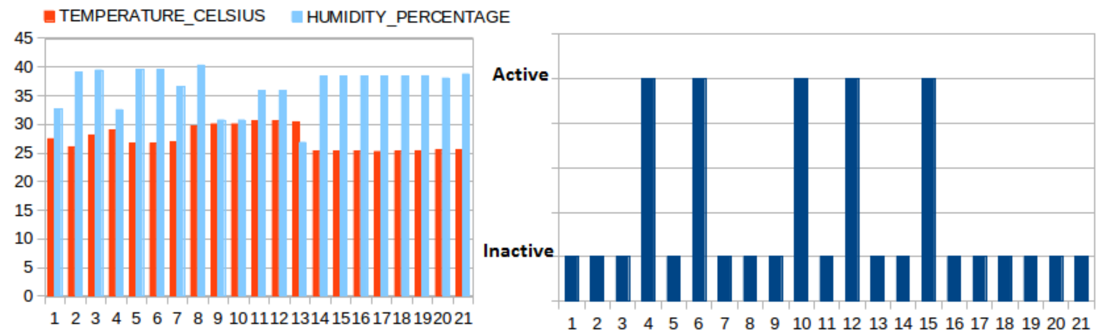


Figure 6.4: Subject D (temperature and humidity, at the left; activity records, at the right).

Subject E

Context: The last subject also did not have the disease; however she suffered from falls frequently which made her a suitable subject for a fall detection system. For that reason she spent most of the time sitting on a chair.

The test was performed at 4:00 p.m. (Fig. 6.5).

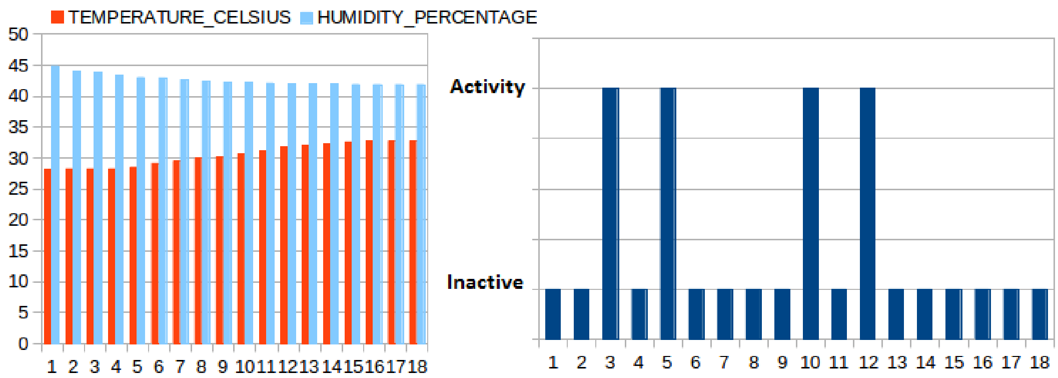


Figure 6.5: Subject E (temperature and humidity, at the left; activity records, at the right).

6.1.1 Feedback from the patients

After the test each patient answered some questions about the test and the device to see if it was intrusive or uncomfortable for them. Those answers are shown in table 6.2.

6.2 Result analysis

Results obtained indicate that most of the patients did not feel disturbed by the device. Only one said it was uncomfortable.

The results were also consistent with the subjects' movements and environment measures.

This was positive as the technical approach described in chapter 4 revealed to be useful, and can be a first step for a good starting point for a system with the same purpose as AlzSense.

Regarding the patients, as the device did not require any interaction from them, it was easy to test and acquire the necessary results. One of the subjects suggested that the device should be smaller and more discreet.

Table 6.2: Feedback from patients after the test.

Subject:	Was the device heavy?	Did the device keep you from doing any regular task?	Other observations:
A	No	No	Too big and uncomfortable
B	No	No	Unable to respond
C	No	No	Unable to respond
D	No	No	Felt normal
E	No	No	Felt normal

With this in mind, some adjustments are needed regarding mainly the size of the device and also its autonomy.

Generally the results show that a device like this, capable of detecting falls, measuring the environment parameters in which the patient is and having a wireless connection could be used as a tool to monitor AD patients, supporting caregivers and helping in the data acquisition since the measurements do not need to be done in person.

6.3 Summary

While an ideal test was not possible due to time and battery constraints, a series of smaller tests were done with five different subjects.

The feedback given from subjects was positive, and the device identified correctly which activity was the individual performing, if **Active** or **Inactive**.

In none of the tests did the activity **Free Fall** activate as none of the subjects fell.

The results gathered evidenced of the usefulness of the device in older AD affected people as well as of its ability to support caregivers by warning them in case of an emergency like a fall.

Chapter 7

Conclusion

Alzheimer's disease is not just a burden to the patients but also to their family, caregivers and also the health system as it is an irreversible type of dementia, difficult to diagnose and until now without cure. Patients suffering from this disease need special care twenty-four hours a day.

After researching the disease and the technological state of the art in the related patient care, several issues were identified, like the lack of location solutions adapted to this type of patient, bearing in mind their tendency for memory loss, disorientation and risk of fall.

So a decision was made to create an electronic device to solve those issues by providing a solution capable of 1) monitoring an AD patient regarding environment temperature and humidity, and body movement, 2) detecting falls, 3) provide constant support to the caregivers.

The system was validated with a group of subjects showing promising results because it responded correctly to environment stimulations and most of subjects did not feel disturbed when using the device.

7.1 Future work

For future work the author proposes:

- Decrease the size of the device;
- Create an interface where the caregiver can insert the personal data of the patient in the database;
- Include an emergency button on the device;

- Perform additional tests, both with AD-affected people and their caregivers (testing the application);
- Increase the device's autonomy;
- Integrate the device's existing intelligence with external sensors which would allow for instance for indoor positioning.

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Appendix A

Different Alzheimer's disease stage models

A.1 The three stage model [15]

Stage 1: *Mild/Early (lasts 2-4 years) – Frequent recent memory loss, particularly of recent conversations and events. Repeated questions, some problems expressing and understanding language. Mild coordination problems: writing and using objects becomes difficult. Depression and apathy can occur, accompanied by mood swings. Need reminders for daily activities, and may have difficulty driving.*

Stage 2: *Moderate/Middle (lasts 2-10 years) – Can no longer cover up problems. Pervasive and persistent memory loss, including forgetfulness about personal history and inability to recognize friends and family. Rambling speech, unusual reasoning, and confusion about current events, time, and place. More likely to become lost in familiar settings, experience sleep disturbances, and changes in mood and behavior, which can be aggravated by stress and change. May experience delusions, aggression, and uninhibited behavior. Mobility and coordination is affected by slowness, rigidity, and tremors. Need structure, reminders, and assistance with the activities of daily living.*

Stage 3: *Severe/Late (lasts 1-3+ years) – Confused about past and present. Loss of ability to remember, communicate, or process information. Generally incapacitated with severe to total loss of verbal skills. Unable to care for self. Falls possible and immobility likely. Problems with swallowing, incontinence, and illness. Extreme problems with mood, behavior, hallucinations, and delirium. In this stage, the person will need round the clock intensive support and care.*

A.2 The seven stage model [14]

Stage 1: *No impairment (normal function). The person does not experience any problems. An interview with a medical professional does not show any evidence of symptoms of dementia.*

Stage 2: *Very mild cognitive decline (may be normal age-related changes or earliest signs of Alzheimer's disease). The person may feel as if he or she is having memory lapses – forgetting familiar words or the location of everyday objects. But no symptoms of dementia can be detected during a medical examination or by friends, family or co-workers.*

Stage 3: *Mild cognitive decline (early-stage Alzheimer's can be diagnosed in some, but not all, individuals with these symptoms). Friends, family or co-workers begin to notice difficulties.*

During a detailed medical interview, doctors may be able to detect problems in memory or concentration. Common difficulties include:

- *Noticeable problems coming up with the right word or name.*
- *Trouble remembering names when introduced to new people.*
- *Having noticeable greater difficulty performing tasks in social or work settings.*
- *Forgetting material that one has just read.*
- *Losing or misplacing a valuable object.*
- *Increasing trouble with planning or organizing.*

Stage 4: *Moderate cognitive decline (mild or early-stage Alzheimer's disease). At this point, a carful medical interview should be able to detect clear-cut symptoms in several areas:*

- *Forgetfulness of recent events.*
- *Impaired ability to perform challenging mental arithmetic.*
- *Greater difficulty performing complex tasks such as planning dinner for guests, paying bills or managing finances.*
- *Forgetfulness about one's own personal history.*
- *Becoming moody or withdrawn, especially in socially or mentally challenging situations.*

Stage 5: *Moderately severe cognitive decline (moderate or mid-stage Alzheimer's disease). Gasp in memory and thinking is noticeable, and individuals begin to need help with day-to-day activities. At this stage, those with Alzheimer's may:*

- *Be unable to recall their own address or telephone number or the high school or college from which they graduated.*
- *Become confused about where they are or what day is it.*
- *Have trouble with less challenging mental arithmetic.*
- *Need help choosing proper clothing for the season or the occasion.*

- *Still remember significant details about themselves and their family.*
- *Still require no assistance with eating or using the toilet.*

Stage 6: *Severe cognitive decline (moderately severe or mild-stage Alzheimer's disease). Memory continues to worsen, personality changes may take place and individuals need extensive help with daily activities. At this stage, individuals may:*

- *Lose awareness of recent experiences as well as of theirs surroundings.*
- *Remember their own name but have difficulty with their personal history.*
- *Distinguish familiar and unfamiliar faces but have trouble remembering the name of a spouse or caregiver.*
- *Need help dressing properly and may, without supervision, make mistakes such as putting pajamas over daytime clothes or shoes on the wrong feet.*
- *Experience major changes in sleep patterns – sleeping during the day and becoming restless at night.*
- *Need help handing details of toileting.*
- *Have increasingly frequent trouble controlling their bladder or bowels.*
- *Experience major personality and behavioral changes, including suspiciousness and delusions or compulsive, repetitive behavior like hand-wringing or tissue shredding.*
- *Tend to wander or become lost.*

Stage 7: *Very severe cognitive decline (Severe or late-stage Alzheimer's disease). In the final stage of this disease, individuals lose their ability to respond to their environment, to carry on a conversation and, eventually, to control movement. They may still say word or phrases. At this stage, individuals need help with much of their daily personal care, including eating or using the toilet. They may also lose the ability to smile, to sit without support and to hold their heads up.*

Reflexes become abnormal. Muscles grow rigid. Swallowing impaired.

Appendix B

IIC procedure [33]

One integrated circuit (IC) that wants to talk to another must:

1. *Wait until it sees no activity on the IIC bus. SD and SC are both high. The bus is "free".*
2. *Put message on the bus that says "it's mine" – I have STARTED to use the bus. All other ICs then LISTEN to the bus data to see whether they might be the one who will be called up (addressed).*
3. *Provide on the CLOCK (SC) wire a clock signal. It will be used by all the ICs as the reference time at which each bit of DATA on the data (SD) wire will be correct (valid) and can be used. The data on the data wire (SD) must be valid at the time the clock wire (SC) switches from "low" to "high" voltage.*
4. *Put out in serial form the unique binary "address" of the IC that it wants to communicate with.*
5. *Put message (one bit) on the bus telling whether it wants to SEND or RECEIVE data from the other device.*
6. *Ask the other IC to ACKONOWLEDGE (using one bit) that it recognized its address and it is ready to communicate.*
7. *After the other IC acknowledges all is OK, data can be transferred.*
8. *The first IC sends or receives as many 8-bit words of data as it wants. After every 8-bit data word the sending IC expects the receiving IC to acknowledge the transfer is going OK.*
9. *When all data is finished the first chip must free up the bus and it does that by a special message called "STOP". It is just one bit of information transferred by a special "wiggling" of the SD/SC wires of the bus.*

Appendix C

AT Commands

```
GPS AT commands

AT + CGPSPWR used turn on GPS power supply
AT + CGPSRST used to reset GPS in autonomy mode

Then ask for data and treat it.


GPRS AT commands

AT + CREG //used for network registration
AT + SAPBR //used for bearer settings for applications based in IP

After enabling the GSM mode, set the module to send a SMS

AT+CMGF=1
AT+CMGS="91*******” //the receiver phone number
"HELLO" //the message you want to send

GSM AT commands

After sending the message, set the module to send the data through GPRS to the s

AT+HTTPINIT
AT+HTTPPARA="CID”
AT+HTTPPARA="URL","http://alzsense.projects.fraunhofer.pt”
```

Send the data.

```
AT+HTTPACTION=0 //now GET action
AT+HTTPTERM //end connection
```

Appendix D

Database Structure

```
Entity:

PATIENT  (ID_PAT, NAME_PAT, ADDRESS_PAT, TELEFONE_PAT)

RELATIVE (ID_REL, NAME_REL, ADDRESS_REL,
         TELEFONE_REL)

CARER  (ID_CARER, NAME_CARER, DEGREE_CARER, TELEFONE_CARER)

CENTER (ID_CENTER, NAME_CENTER, ADDRESS_CENTER,
         TELEFONE_CENTER, EMAIL_CENTER)

PAT_DATA (ID_DATA, DAY_AND_HOUR, TEMPERATURE_CELSIUS,
          HUMIDITY, PERCENTAGE, LATITUDE, LONGITUDE, ID_PAT, ACTIVITY)

Associations:
goes_to (patient, center); 1:1
has (patient, relative); 1:N
work (carer, center); N:1
take_care_of (carer, patient); N:N
dada_from (patient, pat_data) 1:N

Rational model:
PATIENT | ID_PAT   || NAME_PAT | ADDRESS_PAT
| TELEFONE_PAT | # ID -> CENTER | # ID -> CARER | # ID -> REL |
```

```
RELATIVE| ID_REL   || NAME_REL   | ADDRESS_REL  |TELEFONE_REL |

CARER | ID_CARER || NAME_CARER | DEGREE_CARER
| TELEFONE_CARER |#ID -> CENTER|

CENTER | ID_CENTER || NAME_CENTER | ADDRESS_CENTER
   | TELEFONE_CENTER | EMAIL_CENTER |

PAT_DATA| ID_DATA || DAY | HOUR
        | TEMPERATURE_CELSIUS | HUMIDITY_PERCENTAGE
        | LATITUDE | LONGITUDE | #ID -> PAT | ACTIVITY |


Table creation:

CREATE TABLE CARER(
ID_CARER TINYINT PRIMARY KEY AUTO_INCREMENT,
NAME_CARER VARCHAR(50) DEFAULT NULL,
DEGREE_CARER VARCHAR(50),
TELEPHONE_CARER VARCHAR(9) DEFAULT NULL,
ID_CENTER TINYINT DEFAULT NULL,
FOREIGN KEY (ID_CENTER) REFERENCES CENTER (ID_CENTER)
);



CREATE TABLE CENTER (
ID_CENTER TINYINT PRIMARY KEY AUTO_INCREMENT,
NAME_CENTER VARCHAR(50) DEFAULT NULL,
ADDRESS_CENTER VARCHAR(50) DEFAULT NULL,
TELEPHONE_CENTER VARCHAR(9) DEFAULT NULL,
EMAIL_CENTER VARCHAR(50) DEFAULT NULL,
);



CREATE TABLE PATIENT (
ID_PAT TINYINT PRIMARY KEY AUTO_INCREMENT,
NAME_PAT VARCHAR(50) DEFAULT NULL,
ADDRESS_PAT VARCHAR(50) DEFAULT NULL,
```

```
TELEPHONE_PAT VARCHAR(9) DEFAULT NULL,
ID_CENTER TINYINT DEFAULT NULL,
ID_CARER TINYINT DEFAULT NULL,
ID_REL TINYINT DEFAULT NULL,
FOREIGN KEY (ID_CENTER) REFERENCES CENTER (ID_CENTER),
FOREIGN KEY (ID_CARER) REFERENCES CARER (ID_CARER),
FOREIGN KEY (ID_REL) REFERENCES RELATIVE (ID_REL)
) ;


CREATE TABLE PAT_DATA (
ID_DATA TINYINT PRIMARY KEY AUTO_INCREMENT,
DAY DATE NOT NULL,
HOUR TIME NOT NULL,
TEMPERATURE_CELSIUS FLOAT DEFAULT NULL,
HUMIDITY_PERCENTAGE FLOAT DEFAULT NULL,
LATITUDE VARCHAR(20) DEFAULT NULL,
LONGITUDE VARCHAR(20) DEFAULT NULL,
ACTIVITY VARCHAR(20) DEFAULT NULL,
ID_PAT TINYINT NOT NULL,
FOREIGN KEY (ID_PAT) REFERENCES PATIENT (ID_PAT)
);


CREATE TABLE RELATIVE (
ID_REL TINYINT PRIMARY KEY AUTO_INCREMENT,
NAME_REL VARCHAR(50) DEFAULT NULL,
ADDRESS_REL VARCHAR(50) DEFAULT NULL,
TELEPHONE_REL VARCHAR(9) DEFAULT NULL
);

Views:

 CREATE VIEW VIEW_PAT_CONTACTS AS SELECT NAME_PAT,
NAME_CARER, TELEPHONE_CARER, NAME_REL,
TELEPHONE_REL FROM PATIENT JOIN CARER
USING(ID_CARER) JOIN RELATIVE USING (ID_REL);

CREATE VIEW VIEW_PAT_CONTACTS AS SELECT NAME_PAT,
```

```
NAME_CARER, TELEPHONE_CARER, NAME_REL,
TELEPHONE_REL FROM PATIENT JOIN CARER
USING(ID_CARER) JOIN RELATIVE USING (ID_REL);
```

Appendix E

Tests Protocol

E.1 Consent for the caregivers to sign

The Fraunhofer Research Portugal does research work aimed at finding solutions to promote well-being of the senior population. With that in mind the research project AlzSense was created. The objective of this project is to create a small device suitable to be transported without interfering with the daily tasks of the patient, being the least intrusive possible.

The device will record the physical conditions in which the individual is and send them to a control center and will also be able to send an alert in case of fall or emergency.

It consists of sensors and communication modules existing in the market and therefore do not present any risk or danger to the patient who uses it.

We would like to have your authorization to get your relative involved in the tests with the device. The patient will only use the belt for one hour. Participation does not involve any injury or property damage and there will not be any payment. The data collected is confidential. The Fraunhofer Portugal Research Association shall take all necessary measures to safeguard and protect the data collected in order to avoid that may be accessed by unauthorized third parties measurements.

Participation is voluntary, and it may cease at any time without any consequence. Thanks very much, your contribution is vital to our research!

Representative of the participant:

I have read and understood this document, as well as the verbal information provided and accepted my relatives participation in this investigation. I allow the use of the data provided on a voluntary basis, trusting it will only be used for research and with guarantees of confidentiality and anonymity that are given to me by the investigator. I authorize the disclosure of information anonymously to other entities who establish partnership with Fraunhofer Research Portugal for academic purposes and scientific research.

Participant name: ________________________
Participant age: ________________________
Representative of the participant: ________________________
Signature of the Representative of the participant:________________________

Date: ___ / ___ / ______

E.2 Table to fill in with the caregivers

N.º	Patient's name	Caregiver's Age	Uses smartphone?	What is the stage of the patient's AD?
01				
02				
03				
04				
05				
06				
07				
08				
09				
10				

E.3 Table to fill in with the patients before the test

N.º	Patient's name	Age	Already suffered a serious fall?	How many hours spent in the center?	How many hours by yourself?
01					
02					
03					
04					
05					
06					
07					
08					
09					
10					

E.4 Table to fill in with the patient after the test

N.º	Patient's name	Was the device heavy?	Did the device keep you from doing any regular task?	Observations
01				
02				
03				
04				
05				
06				
07				
08				
09				
10				