Universidade do Minho
Escola de Engenharia

Tiago José Fernandes de Sá Araújo Ribeiro

Mobile Intelligent Sensoring System

Tese de Mestrado

Trabalho efectuado sob a orientação do
Professor Doutor Paulo Novais

Junho de 2012

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Resumo

Tendencialmente as pessoas idosas têm problemas cognitivos e físicos que potencializam a queda. Estudos revelam que 30% das pessoas com idades á volta dos 65 anos cai pelo menos uma vez por ano, piorando o cenário para 50% a partir dos 80 anos de idade. Quando a assistência á pessoa que caiu tarda em chegar surge evidentemente o agravamento do estado de saúde e das condições de cura e recuperação. Recorrendo a técnicas dos Sistemas Inteligentes, neste trabalho pretende-se estudar e analisar formas computacionais de deteção da queda. Para que a deteção seja correcta é necessária a utilização de sensores, e software que interprete a informação proveniente dos mesmos. Será ainda necessário estudar diferentes abordagens na utilização dos dados dos sensores para optimizar a eficácia do sistema. Neste trabalho dá-se ênfase ao uso de dispositivos de fácil aquisição e uso, e a uma abordagem não invasiva. Especificamente, estuda-se a utilização dos acelerómetros de plataformas móveis Android para a aquisição de dados sobre os padrões de movimento dos utilizadores por forma a detetar quedas e minimizar o tempo decorrido entre a queda e a chegada de ajuda.

Abstract

In a general way, elder people suffer from cognitive and physical disorders that potentiate falls. Studies show that 30% of people aged around 65 falls at least once a year, with this number worsening to 50% after 80 years of age. When the help to the person that fell takes time to arrive, there is an evident risk to the health of the person and a worsening of the healing and recovering conditions. Using Intelligent System techniques, in this work we aim to study technology-supported ways of detecting falls. In order for the detection to be correct, there is the need to use the appropriate sensors as well as software that correctly interprets the data generated. It will also be necessary to study different approaches on the use of the sensory data in order to optimize the efficacy of the system. In this work we focus on the use of easy to use and easy to acquire devices, and on a non-invasive approach. Specifically, we study the use of the accelerometers that make part of mobile Android platforms for data acquisition concerning user movement patterns in order to detect falls and minimize the time between a fall and the arrival of help.

Acknowledgements

It is not living that matters, but living rightly.

Socrates

I would like to thank to everyone who helped me in this journey.

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Acronyms

A

`AmI` Ambient Intelligence, p. 8.

C

`CBR` Case-based reasoning, p. 31.

`CSV` Comma Separated Values, p. 35.

E

`eHeath` Electronic Health, p. 15.

`EHR` Electronic Health Records, p. 15.

G

`GDSS` Group Decision Support Systems, p. 16.

`GPS` Global Positioning System, p. 19.

`GSM` Global System for Mobile Communications, p. 25.

H

`HSDPA` High-Speed Downlink Packet Access, p. 25.

I

`ITS` Intelligent Transportation System, p. 19.

K

`KNN` K-Nearest Neighbour, p. 41.

M

`MAS`	Multi-agent Systems, p. 30.
`MISS`	Mobile Intelligent Sensing System, p. 23.
`MIT`	Massachusetts Institute of Technology, p. 18.
`MMS`	Multimedia Messages, p. 27.

R

`RFID`	Radio-frequency identification, p. 12.
`RS`	Recommendation Systems, p. 15.

S

`SDK`	Software Development Kit, p. 27.
`SMS`	Short Text Messages, p. 27.

U

`UMTS`	Universal Mobile Telecommunications System, p. 25.

W

`WHO`	World Health Organization, p. 2.

To my mother La Salette Sá,
For the support, encouragement, and constant love throughout my life.

Chapter 1

Introduction

A prudent question is one-half of wisdom.

Francis Bacon

The elderly population is the fastest growing population in the world with consequences that demand for changes in social and health policies. As people get older their health condition naturally becomes weaker. Although there is already a variety of medications for a variety of diseases, there are not reliable solutions for other problems that the elderly face. One of the greatest problems that the elderly face in their day-to-day living is the risk of falling, which may have a significant impact on their health, quality of life and safety. This problem may be attenuated using emerging technologies that can provide key information and solutions for a better fall detection.

1.1 Motivation

For several years now, world population is aging as many studies reveal: the elderly population is increasing more than the young one [28].
This means that in a short period of time, the elderly population will constitute a bigger percentage in the population distribution. This group of people does not generate richness. Moreover, they are retired and benefit from the social security systems of their countries. Worsening this situation is the fact that the working population and labour force is declining [49]. As the situation grows, these economical costs will be too expensive to be supported by the active population, leading to the bankruptcy of the social security systems.
According to the United Nations report, the number of older persons has tripled over the last 50 years and will triple or more again over the next 50 years, as depicted in Figure 1.1.

More than economic costs, this phenomenon has social costs. As people get older, their health condition worsens, the bones get weaker and denser (being osteoporosis a frequent condition) and the organism gets more susceptible to infections. One

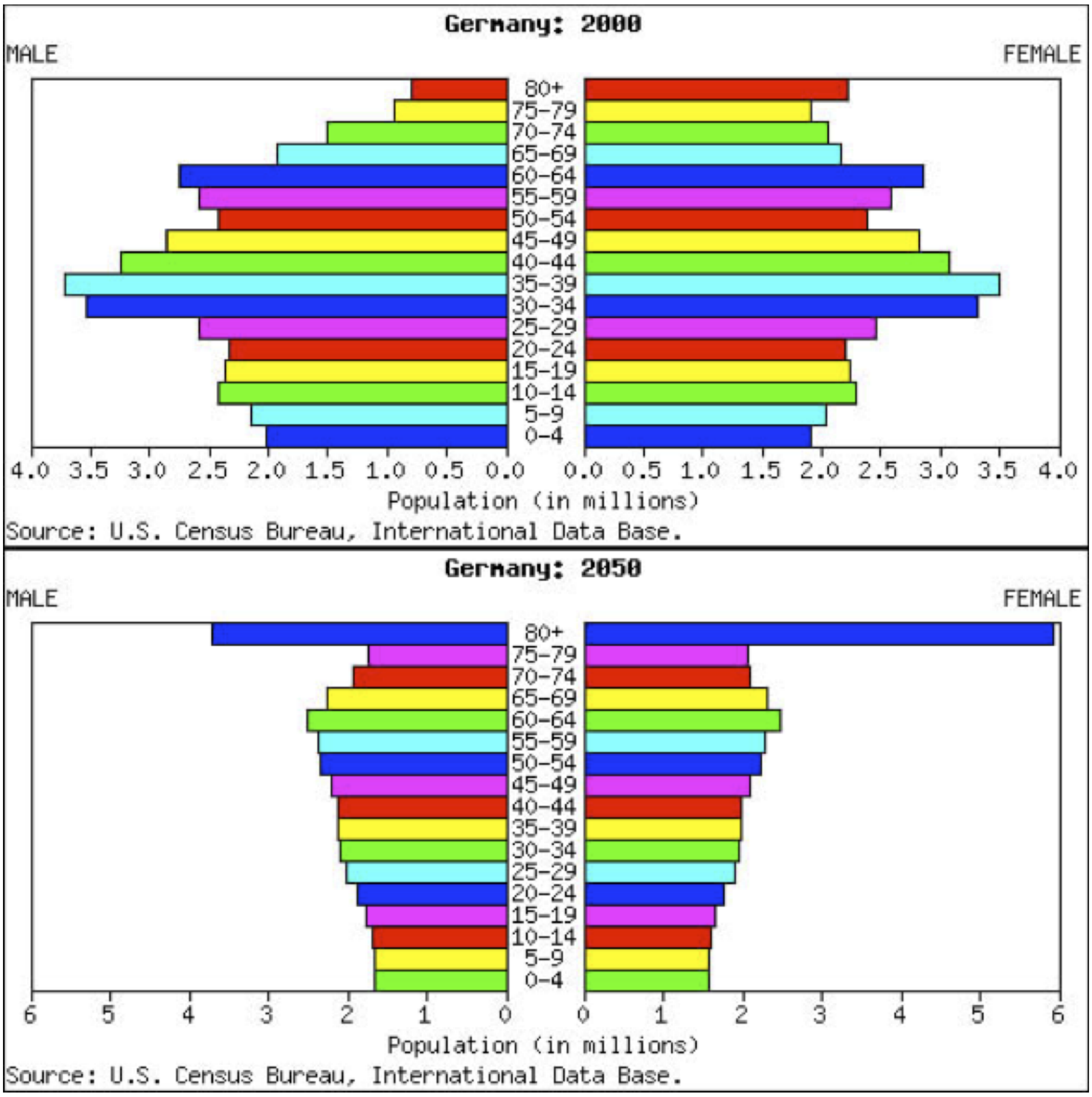

Figure 1.1: Prevision of the changes in the demographics between 2000 and 2050 in Germany.

of the main catalyst worsening the health state is the fall. Falls are common and happen because of disorientation and lack of mobility [39]. A study by *World Health Organization* (WHO) reveals that 30% of the people aged 65 years fall at least one time per year, with this number increasing to 50% after the age of 80 [21, 45]. Falling can have drastic physical and psychological repercussions in the life of an elderly person. Physically, the fall frequently results in femur fractures. Moreover, due to the time that the body is laying down while the person is not assisted, it is subject to infections, myocardial infarction, pneumonia and pulmonary thromboembolism. The older person can develop mobility impairments, become bedridden or require equipment for mobility aid. The psychological aspect results of the recovery time as the inaction due to these cases can cause other underlying problems such as the fear of falling again, isolation or chronic conditions. Without any kind of assistance the health condition worsens, healing and recovering takes a longer time, perpetuating the illness state. People that fall frequently need hospitalization so addressing this issue is also interesting for governments from an economical point of view.

1.2 Scope of the Dissertation

The facts depicted in the previous section raise some challenges that must be faced. There is the need to find new solutions that ensure that all elderly people will have the deserved care. It is not correct or human to advise people older than 60 years to face the fall problem using mobility aids: it is the same as to say that they cannot move. Thus being, one of the solutions may be to provide specialized monitorization every time that a person moves. This could have great advantages since it would keep the elder moving, without restricting any movement, and at same time take care of him/her. But how to provide this care?

In order to answer to this question, this work proposes an application able of monitoring a person's movement, based on the concept of Ambient Intelligence, more specifically Ambient Assisted Living. This application should be able to watch over the elderly by monitoring his movements, reacting every time it is in need, assisting it in a fall. By doing so, the elder can have a more efficient support, avoiding health complications by staying longer periods of time in extreme conditions, increasing the odds that the older person can live safely while maintaining their routine as much as possible.

1.3 Ambient Intelligence

The computers have been a useful tool for humans but our interaction with them has always been computer-centred: when we need to use a computer we have to go to the computer and interact with it where it is, by its means. With the evolution of the technology the way of interacting with computers is changing rapidly, leading to what is nowadays know as Ambient Intelligence.

Ambient Intelligence (also known as Intelligent Environments) is a relatively new field of Artificial Intelligence. Artificial intelligence may be defined as the branch of the computer science that is concerned with the automation of intelligent behaviours while in Ambient Intelligence, computers are defined as proactive tools that adapt autonomously for assisting us in our day-to-day tasks, making our lives easier. In this new paradigm of Ambient Intelligence we do not need to interact with computers like we used to, using ways that were not natural for us. One of the main characteristics of this paradigm is that computers can interact with us through user-friendly interfaces such as gestures or our natural language. Intelligent Environments also tend to be as pervasive as possible, which is possible since computational power and communication technologies are present in almost every device we use nowadays. The trend is therefore to have more powerful and smaller devices. The ultimate aim of Intelligent Environments is to achieve more safety, comfort and well-being in our day-to-day living.

1.4 Related Approaches

In the following section some projects that were analysed during this work are presented. All of them are related to falls and all of them have benefits for the users of assisted environments. The number of on-going or finished projects proves that many other researchers believe that the new technologies can be part of the solution for the fall problem. These projects can be organized according to the equipment used and the extracted features.

The first approach studied uses accelerometers: an accelerometer is a device that uses a single axis or multiple axes to detect the magnitude and direction of the acceleration. The second approach uses the gyroscope, which can measure the orientation. It consists of a spinning wheel whose axel is free to take any orientation in one or more axis, making it possible to exactly determine an object's orientation and respective changes. The third approach studied is the visual detection: without posture reconstruction this is based on extracting input data from still images or video; with posture reconstruction it is based on 3D localization of markers placed on the human.

There are also some commercially available solutions on the market for fall detection, most of them based on emergency buttons: a wireless panic button attached to a necklace that is pressed by the user after a fall. This approach has range limitations, and is supposed to be only used indoor. Moreover, it is completely useless if the users is not wearing the necklace or if he is unconscious or unable to move after the fall.

Accelerometers

The most common and simple methodology for fall detection is using a tri-axial accelerometer with threshold [8]. This type of algorithms simply raises an alert when the value of the measured acceleration goes over a threshold value. There are already several devices with built in sensors and fall detection algorithms [29]. Zhang [58] designed a fall detector based on a Support Vector Machine. The equipment used for detecting the fall was a waist-worn accelerometer. The data used for the machine learning algorithm included the acceleration in each axis and changes in direction. Tapia [47] developed a different approach using a real-time algorithm for an automatic recognition of physical activities and their intensity using five wireless accelerometers and a wireless heart rate monitor. The equipment is attached to the body of the user in the shoulder, wrist, and ankle. The accelerometers were placed at shoulder, wrist, hip, upper part of the thigh and ankle. The features, e.g., FFT peaks, variance, energy, correlation coefficients, were extracted from time and frequency domains using a predefined window size on the signal. The classification of activity was done with C4.5 and Naïve Bayes classifiers into three groups: postures (standing, sitting etc.), activities (walking, cycling etc.) and other activities (running, using stairs). The results of this solution vary between a subject-dependent training and a subject-independent.

Gyroscope

Bourke and Lyons [7] introduced the idea of using a threshold to be able to distinguish normal activities like sitting down and standing up, lying down and standing up, getting in and out of a car, walking from abnormal activities and a fall. The discrimination of activities was achieved using a bi-axial gyroscope fixed on the torso, measuring pitch and roll angular velocities. A threshold algorithm was applied to detect peaks in angular velocity signal, angular acceleration and torso angle change.

Visual Detection

Vishwakarma [51] presented an approach for fall detection without posture reconstruction based on video analysis. In the first step the background is eliminated and a set of features from the remaining objects is extracted such as the aspect ratio or horizontal and vertical gradients. Next, the fall detection is performed based on the angle between an object's bounding box and the ground. The final step is the fall confirmation, which is rule-based (e.g. the angle had to be less than 45 degrees). This method shows better results for a single object than for multiple objects.

Another approach based on visual detection is with posture reconstruction. Wu [56] studied unique features of the velocity during normal and abnormal activities, to be able to detect falls during the descending phase of a possible fall. Normal Activities include walking, rising from a chair and sitting down, descending stair, picking up an object from the floor, transferring in and out of a tub and lying down on a bed. The study was made by three markers placed on the posterior side of the torso, recorded by three cameras at a 50 Hz rate, providing velocity parameters for fall detection. This study aimed to suggest velocity characteristics, so the author did not implement the solution.

1.5 Monitoring in Ambient Assisted Living

As the older population grows and social problems worsen, new solutions for this challenge must be devised. The possibility of homecare may be a solution that can benefit patients, informal caregivers and health service providers. However, limiting the patient to a restrict area is not a desirable solution. So, in this work, we take the solution a step forward by constantly monitoring the user anywhere. To pursue this goal we rely on mobile devices and telecommunication technologies, always making the person in need of care feel that there is actually something taking care of them, constantly watching over their health status. Ambient Assisted Living approaches can be of value to people in a wide range of application scenarios: in a work environment to assist workers on their tasks, in a medical facility to support staff and patients or in a home environment, assisting people in their day-to-day living. This growing interest in Ambient Assisted Living is also visible in the present scientific meetings, many of them fully dedicated to this topic (e.g. Symposium of Ubiquitous

Computing and Ambient Intelligence [57] , International Workshop of Ambient Assisted Living [35], European Conference on Ambient Intelligence [48] or the Journal of Ambient intelligence and Smart Environments [25]. In the specific scope of this work, the indoor and outdoor environments are going to be studied for the advantages they can bring to people, narrowing down to the problematic of the falls. We believe that it is possible to detect falls while the person is allowed to maintain the usual routine. This work is intended to contribute, as much as possible, to making this vision a reality.

Technological Challenge

A mobile Ambient Assisted Living system can be made of many different components. These components can include the latest generation of mobile devices which are now equipped with sensors and feature-rich operative systems. However, each mobile device may provide a different operative system, raising the first challenge to address: which operative system will be chosen to support the possible solution? Firstly, there is the need to find which mobile device is suitable for this kind of development since we aim for live tests and simulations. Secondly, it is also important to know what others technologies are supported that can facilitate integration.

Nowadays, with the democratized use of mobile devices, they are seamlessly merged with our environments, appearing perfectly normal. This is directly related with the acceptance of such solutions: people tend to accept better such systems if they seem to change nothing in their lives, mainly when we talk of elderly people. If such an approach encompasses significant changes in their routine, the acceptance will diminish and, despite the system being a very good one, it is likely to fail. Thus, such an approach for such a target population must be non-intrusive, intuitive and integrate seamlessly into the environment.

Another challenge is related with the architecture of the solution, which must be dynamic. In fact, with the rate at which new devices appear, there will be interesting features to be added to the architecture in the future. The user may even want to change the mobile device for a new one, which may have different functionalities and characteristics. This is also a challenge that must be taken into consideration. It is also desirable that such a project is not a closed one: being open source enables interconnection with similar systems so that functionalities and advantages can be shared.

1.6 Objectives

The main objective of this work is to develop a system that can provide fast and accurate fall detection services for users in their daily activities and in any environment, with the aim of fighting the social and health-related problems depicted before, using already existing and commercially available technologies. In order for this main objective to be accomplished, the following secondary objectives are established:

- Design an architecture for a Mobile Intelligent Sensing System that respects the following features:
  - Use of mobile devices with sensors;
  - Be dynamic, being ready to adapt in time to different situations as they occur
- Implement the architecture defined;
- Design a software, based on statistical methods or machine learning, to detect falls. As a secondary objective we aim to classify other activities (e.g. walking, running).
- Design software that allows for the system to be tested and its effectiveness assessed. This is important for validating the architecture and the approaches used, increasing the reliability of the final version;

1.7 Investigation Methodology

To accomplish the objectives enumerated before, the Action-Research methodology was followed [43]. This is the kind of social search, or resolution of collective problems, in which the research and the representative participants of the situation or the problem are involved in a cooperative or participative way. The action-research follows a routine composed by four main stages:

- Exploration;
- Main;
- Action;
- Evaluation.

The first stage of the process is of importance since it will lead all the subsequent stages of research. The main focus is on collecting the most meaningful and relevant information given the requirements of the project in order to study the main problems and existing solutions.
After the concluding that there is clarity of ideas and consensus in the priority

points, research moves to the next phase. In the Main phase, the theme is defined, priorities are established, scenarios are set, the research hypotheses is defined, the activities are coordinated (possibly with other research teams/works), information is centralized with the support of tools for information management, solutions are searched and actions proposed, results are interpreted, evaluated and divulged.

The Action phase includes practical measurements based on previous stages, results diffusion, definition of reachable objectives by real actions and proposal presentation to be negotiated between stakeholders. The last phase is the Evaluation. In this final step the action-research includes two main objectives: verification of the results from the actions in short and medium term and extracting information that will be useful to continue the experiment applying it in future studies.

1.8 Structure of the Document

This document is organized as follows: Chapter 2 contains detailed descriptions of `AmI`, starting by emphasizing its main characteristics and showing its general high-level architecture. It continues by detailing some important components of an intelligent device, such as sensors or actuators, as well as the advantage of having such devices working for Humans. It also exposes the context of service providing from the `AmI` particularly in the Health Care Sector and the expected future of Ambient Intelligence.

In Chapter 3 the concept of Mobile Intelligent Sensing System is introduced in terms of the main paradigms behind it and its relation with healthcare.

Chapter 4 details the architecture needed for a Mobile Intelligent Sensing System. It starts with a comprehensive description of the existing technologies, continues enumerating devices that can be used for implementing the proposed solution and concludes by specifying the architecture for supporting Mobile Intelligent Sensing System, the application is tested and analysed. It emphasizes the importance of testing, details how the equipment, sensors, actuators and users are composed and how it shapes the final architecture. The monitorization device is detailed in this chapter too. It is described in terms of the sensors and actuators that were used. This chapter also details how the system can analyse the data and support the decision on the best approach to be used.

The document ends with Chapter 5, where a Synthesis of the work done is presented as well some important contributions and work generated. It finishes with the conclusions obtained and the future work that is planned.

Chapter 2

Ambient Intelligence

Computing is not about computers any more. It is about living.

Nicholas Negroponte

Ambient Intelligence (AmI) is a central concept in this thesis and a guiding line in all the work performed. In this section the main components of AmI are depicted as well as the main usage scenarios and the predicted future of AmI applications.

2.1 What is Ambient Intelligence

Ambient Intelligence [16, 22], as defined by the IST Advisory Group is a new paradigm born from the junction of three key technologies: Ubiquitous Computing [53] Ubiquitous Communication [50, 53] and Intelligent User Interfaces [40] . Nowadays computers have been like a tool, doing the tasks we program them to do. There is nothing to distinguish them from a shovel, a wrench or any other tool, except for the fact that computers can be programmed to do different tasks while other tools can usually perform only one. With this new paradigm the way of interacting with computers changes: instead of working with them we have the computers working for us. This new approach completely changes the way we see them.

Ambient Intelligence is like imagining a tool such as a shovel digging when you want, where you want, without anyone having to grab and balance it. That is what is happening with Ambient Assisting Living: computers are no longer mere tools but are learning what we like, what we do, out habits and our preferences to simplify our lives. Moreover they are disappearing and hiding in common devices so that we do not even notice them when we use them.

Physically, an intelligent environment is composed by the ambient itself (e.g. a house, a room, a car, a school) and the devices on it. These devices are common devices like our mobile phones, laptops or a desktop, media servers, air-conditioning systems, micro-waves or PDA's, all of them common these days. The new thing about them is that they are connected to a control network so that they can be controlled or control other devices from any point of the network. But this is not Ambient Intelligence, this is Domotics or Home Automation. In domotics, the devices are connected so that we can control them from distance and this is not what `AmI` is about. Ambient Intelligence goes further as we will see in this section. What makes Ambient Intelligence more than just a group of components connected together is the focus on hiding components and equipment as must as possible, making the environment appear perfectly normal, embedding its component in common devices, noticeable only by its actions. That is why Ambient Intelligence depends on ubiquitous computation, to try to integrate computational power into small devices, so that they can pass unnoticed but, nevertheless, do their job. This distributed architecture makes agent technology very fit to implement intelligent environments, as well will see hereafter.

The job requested from the devices in an intelligent environment is to ensure people's well-being and safety. In order to do that, they must be aware of the needs and the preferences of the person. Preferences and needs can be set manually, when configuring the system. Moreover, the routine and the preferences can be learned as the person does its day-to-day [41]. This is a characteristic of `AmI`, it learns just by interacting with the user: without him even noticing the system is studying his behaviour, learning what he uses to do and when he uses to do it. This implies that every environment will be unique, depending on the person who interacts with the system. This make us conclude that one important characteristic of Ambient Intelligence is that it is personalized [42]. Moreover if we change our routine, the system will adapt and learn the new habits, so we can also say that it is adaptive.

The advantage of learning the user habits is to use that information in favour of the user, to predict what the user will need and take measures that assist the user in that action. So, if a person every day eats toasts when waking up, the system learns and turns on the toaster when the alarm clock sounds. So, Ambient intelligence can also be proactive.

In order to correctly choose how and when to provide some service, the system must be aware of the context. Context is a very complex concept and may include the action that some person is performing and where it is being performed, what is the state of the environment at that time, what is the emotional and physical state of the person and eventually other factors like the weather or the traffic depending on the location of the person. This means that Ambient Intelligence must know the current situation of the person and the environment around, therefore, it is also described as context-aware [2].

Summing up, `AmI` can be defined as an electronic environment that is sensitive and responsive to the presence of people. This sensibility comes from the intelligence, much like in real life: a trained nurse that can identify symptoms can proactively provide better care. Furthermore, if she knows the patient and its preferences or needs, she can be sensible towards the user. In order for Ambient Intelligence to show these characteristics, it makes use of several fields of Computer science being the most notorious: Artificial Intelligence, Human Computer Interaction, Sensors, Networks and Ubiquitous Computing.

2.2 Ambient Intelligence as Service Providing

Ambient Intelligence can be seen as the continuous providing of services to the users. As an example: a company owner when entering his office might have as services the control of the lights, the air conditioning and a computer. When workers enter the same room they might not have access to the same services, given their role. So, with this in mind, we can identify some important requirements for an intelligent environment to work.

First of all, information. The system must have as much information about the user in the environment as possible. It must identify the user and know its role in the environment. Identifying who is who and their roles is central. The system must also know the limitations or preferences of each user. We can think of an impaired user which cannot reach a certain object: there is no use on the system telling the user where the object he needs is, if the user cannot reach it. As for preferences, it is very important to try to meet the preferences of the user when one of the objectives of Ambient Intelligence is to provide well-being. Both this cases mean that the system must be non-static, therefore dynamic, and adapt its services to the users.
When having all this information about the user, the system will decide which services to provide, when to provide and how to provide, and it must know the availability of the devices eventually needed for providing the services: it should not announce a service if it is not possible to provide it. Other important characteristic about the services are the geographic location. The system must be context-aware relatively to the users and their environment and have a strong description of the services to support an efficient and autonomous use.

The adaptation of services is especially important for elderly people [19, 26] with specific limitations. This group of people usually has physical impairments like mobility limitations, partial or total blindness or deafness and other issues that prevent them to use the appliance or devices in a regular way. As said before, services in Ambient Intelligence must be adapted to meet the needs of the users, mainly when the users have these particular problems. This is a very interesting field of investigation and significant work can still be done here. If a service is correctly adapted, the elder or impaired person may have much to gain with Ambient Intelligence since it can empower their lives providing autonomy and security.

2.3 Sensors

Sensors are the basis of `AmI`. In fact, how could `AmI` work without sensors the information provided by sensors? We have been describing some of the main features, we said that it learns out behaviours, it adapts to us, it hides in common devices, it is aware of out context and it is able to predict our actions. However, without sensing this would be just impossible. Thus, let us now analyse what is behind Ambient Intelligent, what are the devices upon which these characteristics can be achieved.

As stated, Ambient Intelligent depends on sensors: a large sensorial network is indispensable for correctly reading as much data as possible from the environment and from the user, constituting the basis of any decision from the system. So, we

can think of the use of the nowadays common smoke, flood or gas detectors or intrusion alarms. This would take care of the safety in the environment. Adding sensors for luminosity, temperature or humidity, makes it possible to read environmental parameters with the objective of maintaining some degree of comfort or energetic savings.
Locating a person inside the house is a more complex subject that can be addressed through the combined use of several types of sensor since one, by itself, is generally not enough for such a task. For determining in which room the person is, AmI solutions make use of motion detectors or technologies such as *Radio-frequency identification* (RFID) . For determining exactly where the person is inside the room, it is possible to use weight sensors on furniture like sofas or beds or even detect the activity in some devices (e.g. if the person just turned the television on, this means that it is close to the device). More complex location systems can also be built using triangulation and RF-technology.
Another very important use of sensors in Ambient Intelligence is for monitoring the user's vital signs. There is nowadays a panoply of ways for doing it. There are wristwatches, jackets and other implementations of what is called wearable computing [44], using clothes that have sensing capabilities. This equipment's share the information read from the sensors through wireless protocols, mostly Bluetooth.

There are many more types of sensors that can be used to enrich the information that a system can acquire from the environment, such as an outside weather station, which, when connected to the system provide information about the exterior environment. This can be important not only to inform the user but also to make recommendations regarding what to wear or what to do, depending on to the weather.

Sensors are very important in this work as well. Given the device chosen, the available sensors to achieve our main objective are the accelerometer and the gyroscope. An accelerometer sensor measures the acceleration it experiences relative to a free-fall and is the acceleration felt by people and objects. Gyroscope measures the orientation, based on the principles of angular momentum [55]. In essence, a mechanical gyroscope is a spinning wheel or disk whose axel is free to take any orientation.

2.4 Acting

The objective of Intelligent Environments is to act in order to achieve some goal. The effects of these actions are visible mainly on the environment but they may also be visible on the users or even on external entities. Generally, an Intelligent Environment takes action for two main reasons: a reaction to an event or an action to prevent or cause an event. These are called reactive or proactive attitudes.

In the first case, the system detects a predetermined event and reacts to it in a predetermined way, e.g., the lights being turned off when the user leaves the house or the heat being turned to minimum when he is sleeping. In the second case, the system has the initiative to take an action, e.g., the system turning on the coffee machine at the usual hour the person wakes up or turning on the heat at home at the usual hour the person arrives. Actions can be classified according to its purpose:

the system can take an action concerning the safety of the user, its well-being or for assisting him.

The most important actions are obviously the ones that concern the user's safety. An intelligent device can constantly monitor the state of the user and rapidly react in case of danger. An Intelligent Environment can even react when the user is not at home. If there is a fire, a flood, or gas is detected inside the house, the Intelligent Environment has enough autonomy to automatically call for help and prevent the situation to get worst, without interacting with any user.

Actions that concern conflicts at a user-level are probably the ones more used in an Intelligent Environment. They are mainly intended to interact with all components in a house that can change the environmental parameters. The objective is for the system to be able to change the environmental parameters through the use of these devices so that the user's preferences or needs can be met. Evidently, when acting this way, the objective can also be to save energy while at the same time maintain or increase the comfort of the inhabitants [4]. Once again, this type of actions can have more significant advantages for elder user suffering from chronic respiratory diseases and in need of specific environmental settings.

2.5 Communicating

All the devices mentioned in the previous sections must be connected since they need to share information. Several communication technologies suitable for use in Ambient Intelligent are explained in detail here. We want to emphasise the importance of the network in the architecture of any intelligent environment or device. Devices with lower mobility use the wired connection working as a backbone for other networks. We have the example of the widely used Ethernet protocol, which uses a dedicated line for data transmission, or the less common Powerline, which uses the electric signal of the power line as a carrier of data, while at the same time providing power to the devices. Devices with high mobility use the wireless technology. Moreover there should also be a gateway through which devices and users inside the environment access the outside network. Regarding the sensorial network, there are several protocols for connecting sensors, which are oriented for low power consumption and low bandwidth, since sensors do not need to transmit much data. The result of all these different protocols working together is a heterogeneous network that allows very different types of devices to communicate.

When there is a large number of different devices communicating, there must be a common language to be used by all, i.e., to communicate we need more than the air that carries our voice: there is the need to use a common language so that we understand each other. The same need exists with devices. There are already some possible solutions for fulfilling this goal. The most promising one relies on the so-called Service Oriented Architectures [38]. This paradigm consists in giving visibility not to the device itself but to its capabilities or functionalities, i.e., what it can offer to the architecture. It does not matter how the device works or what it is, it only matters what it does. Services are announced in a common language that every device knows and every device in the architecture can use these same services. This is a solution for dealing with the heterogeneity that is visible nowadays with the increased use of so different networking devices.

2.6 Usage

User interfaces are another important component of intelligent environments. Traditionally, user interfaces have never been very user friendly. In the first years, interaction was performed through a keyboard. A few years later the mouse was invented improving interaction but not necessarily making it more natural. These interfaces, however, are not very intuitive, especially for people that are not used to use them or have no significant experience with computers. In Ambient Intelligence interfaces tend to be much more user friendly so that everyone can use them intuitively, independently of their experience with computers. This is even more important for people with some mobility impairment for whom using the traditional common interfaces may be a challenge or may even be impossible.

Interfaces can be made of very different devices, depending on the type of environment and the target users, i.e., in a house the interface could be a touch screen or a handheld device, while outside it could be a mobile device. The trend is that interfaces get as natural for us humans as possible. Therefore, it is expected that in the future our hands and our body will no longer be stuck to the computer and probably our interaction will be with our voice, in our natural language, with gestures or even with our behaviour. This way we can be doing other things and, nevertheless, interact with computers.

Other important aspect that is often forgotten or ignored about interfaces is that the interface is the visible face of the system. One can have an amazing intelligent application but if its interface does not explains to us what it does, if it is not friendly and easy to use, we feel that we have no control and the acceptance of the system decreases. Furthermore, it should also be adaptive, adapting to who is using it. As an example, an interface for an older person should be kept simple, giving less information and in a more explicit way. On the other hand, for a younger user more experienced with computers, the interface could provide more information and in a more rapid way. Interfaces are therefore a very important part of any intelligent application.

2.7 Ambient Intelligence and Health Care

As already seen in this chapter, `AmI` has many uses in a wide range of domains. However, when we think of the specific case of healthcare, Ambient Intelligence can really make the difference on the users. The evidence is the number of projects that keep appearing merging Ambient Intelligence in the healthcare sector.

Assisting people can have significant advantages, mainly for impaired, convalescent, pregnant and elder people. In fact this sector and the people involved have much to profit from the use of this approach. With a constant monitoring from an intelligent device or environment, it is possible to provide to these persons the most important: safety. The fact of knowing that, despite being alone, should something happen to them and help will come fast, it surely brings along a feeling of safety for the persons and their relatives. With a constant monitoring and efficient response in case of need, these persons can stay in their homes, living their routines and, nevertheless, live with security.

However, Ambient Intelligence in the healthcare sector is not only about care at home. These kinds of system can and have been successfully applied in environments like hospitals, leisure centres or care centres. These systems do not only benefit the users, but also the persons working there, resulting in an increase in the quality of the care provided. We can think of a hospital environment where the vital signs of the patients can be constantly monitored and alarms can be raised in case of danger, or we can think of a system scheduling tasks for nurses in a dynamic way, according to the patient's state or location. More important than all this is the fact of knowing, at each time, the context of the user. For the medical personnel, having real-time access to knowledge about the patient's location, the state of the environment or the medical condition is very important. As we can see, the possibilities are wide and result in many significant improvements that affect all the persons involved. These potential improvements should be exploited so that we can make the best use of the technologies we have available nowadays.
There are many paradigms or approaches nowadays in which technology is used for providing healthcare services, with varying levels of autonomy. However, AmI can build on them to provide value-added services, with embedded intelligence and decision-making capabilities. *Electronic Health* (eHeath) designates the generic use of IT [5] for the provision of healthcare services. ITs have a wide range of services that can support the health care sector and make it more efficient, cheap and closer to the patients such as *Electronic Health Records* (EHR), Telemedicine, Recommendation Systems, Group Decision Support Systems or mHealth [24].

EHR is a data file that contains all medical information about patients. Different professionals in different institutions can access that information; by being electronic this information can easily be shared and does not depend, as before, on the physical location of the patient's file. Telemedicine is the use of telecommunication technologies to bring doctors, patients and relatives closer together. The main technologies used are the telephone, videoconference and other internet-based communication means. The objective is to provide remote consulting or even remote examinations so that the patient does not have to travel to the medical facility so often, saving costs for both parts, i.e., patient and health care system. In the simplest case, telemedicine is a patient calling its doctor to solve a doubt and in a complex and futuristic case it would be a surgery locally executed by a robot, which is remotely controlled by a doctor. Telemedicine is the most known concept, perhaps because it builds on technologies which are nowadays very common and available. Still, in this field, we can also talk about teleradiology, which is the ability to send radiographic images from one point to another. This means that a patient does not have to go to its doctor to take radiography if it has a closer institution where he can do it.

Recommendation Systems (RS), as the name suggests, are meant to assist the user in a given task being done. They are used in a wide range of domains but in this area they generally support the doctor narrowing down the possible choices of a specific group of symptoms of a patient to a smaller number, decreasing the time wasted in choosing. In a *Group Decision Support Systems* (`GDSS`) [30] Recommendation Systems can also be used, making suggestions according to the situation. A `GDSS` is a system that provides support in cases in which a group of entities gets together to take a decision. There are different types of entities, each one with a different field of expertise, and at the end a decision is taken. Moreover, the participants may not be in the same location, they may even meet in different times. Thus, these systems need to support distributed and synchronous or asynchronous decision making processes.

2.8 The VirtualECare Project

The VirtualECare Project [13, 14] main objective is to present an intelligent multi-agent system able to monitor, interact and provide its customers with health care services of the utmost quality [14]. This system will be interconnected, not only to other healthcare institutions, but also with leisure centres, training facilities, shops and patient relatives, just to name a few.
The VirtualECare Architecture is a distributed one with their different modules interconnected through a network (e.g. LAN, MAN, WAN), each one with a different role, a top-level description of the architecture machinery is given:

- Supported User - elderly people with special health care needs, whose clinical data is sent to the CallCareCenter and redirected to the Group Decision Support System. This user should be constantly monitored, outside and inside its environment so the data must be provided in real time to the interested parts. It is the central component of the architecture and all the other components must work together to ensure its safety and well being;

- Environment - the elderly natural environment, provided with sensors, with the clinical data being sent to the Group Decision Support System through the CallCareCenter, with the remaining ones being redirected to the CallServiceCenter. The data provided by this module must also be constantly available and analyzed so a reliable network connection is mandatory. The environment can be the user home, a hospital room, a day centre, just to name a few. The main actions of the other components towards the environment are to maintain the comfort and security parameters;

- Group Decision - This module is responsible for the long term planning regarding the health care of the patients. It should be composed of specialized staff like nurses and doctors as well as Recommendation Systems and tools for time and space distant meetings. In the overall this module should be able of planning all the issues related to visits to doctors, tests, automatically scheduling all this according to the user agenda;

- CallServiceCenter - Entity with all the necessary computational and qualified personal resources, capable of receiving and analyze the diverse data and take the necessary actions according to it;

- CallCareCenter - Entity in charge of computational and qualified personal resources (i.e. healthcare professionals and auxiliary), capable of receiving and analyze the clinical data, and take the necessary actions according to it. The user may make voice calls to this service and request assistance or advises and the service should respond and, if necessary, contact other modules like the Group Decision;

- Relatives - individuals that may have an active role in the supervising task of their love ones, being able to give precious complementary information about them and being able to intervene, in a complementary way, in specific crises (e.g., loneliness). By being an important part of the equation, the relatives should also have access to the health status of the patient so that they are constantly aware of its situation.
  In order to the Group Decision Support System to make its work, it has to collect the opinion of specialized staff (e.g., nurses, paediatrics, cardiologists). There is also the need to have a digital profile of the Supported User, allowing a better understanding of his/her special needs. In this profile we can have several different kinds of relevant information, ranging from the patient Electronic Clinic Process to their own personal preferences (e.g. musical, gastronomic) passing by their own personal experiences, which can be used to better understand and satisfy their needs and expectative.
  This solution will help healthcare providers to integrate, analyze, and manage complex and disparate clinical, research and administrative knowledge. It will provide tools and methodologies for creating an information-on-demand environment that can improve quality-of-living, safety, and quality of patient care.

Related Projects

In the following sections some projects that were analyzed during this work are presented. All of them cover complementary areas and all of them have benefits for users in assisted environments. They are the evidence that many other researchers believe that new technologies are the solution to this problem.

Amigo - Ambient Intelligence for the networked home environment

This project was a consortium of fifteen European companies who joined efforts to exploit the potential of the nowadays common home networks and improve peoples lives. The idea was to take profit of the fact that nowadays almost every equipment comes with a network connection. But still, there are lots of different

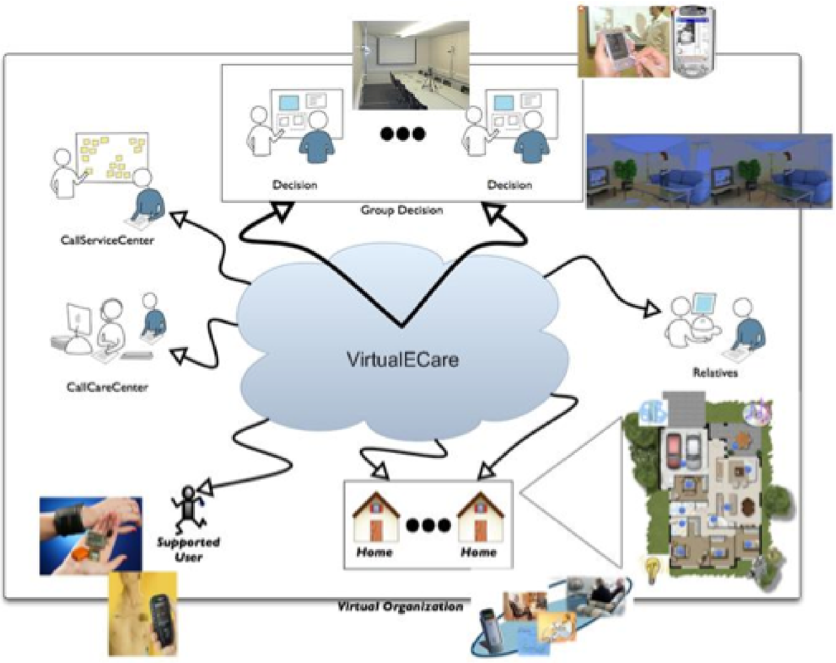

Figure 2.1: The VirtualECare architecture.

standards which make more difficult their interoperability so they wanted to make that possible. This project ended in September 2004.

It is common that a house has several networks such as the electrical, Ethernet or wireless networks. The Amigo project [17] interconnects these networks thus enabling communication between all devices. Over this "Hardware" layer, Amigo implements services so that people's environments are empowered. From any point of the house or even from outside the house, people can change house parameters, watch the surveillance cameras, put their TV to record some program, etc. This is in fact the main purpose of the project, to empower the environment it is in, releasing people from boring activities as the person is the center of the system. This project used "home laboratories" across Europe including Philips Research's "HomeLab", France Telecom's "Creative Studio Lab" and the Fraunhofer Institute's "InHaus".

Oxygen

This project from *Massachusetts Institute of Technology* (`MIT`) [31] has as main objective to make technology as available everywhere as the air we breathe. Since the beginning, computers are closed in rooms, and we have to get to them, interact with them using their means, work with them the way they want. Meaning that until now, we have been living for the computers instead of the computers living for us. `MIT` vision is that in the future, "computers" are available everywhere, so that everyone can use them and we do not need to carry our own devices. "Computers" will also be very generic, configurable to fit all our needs in every moment.

In order to do that, this project wants to make interactions between person and computer as natural as possible, using people's natural language or gestures. Computers will live for us, expanding our possibilities, simplifying our lives. They will learn our preferences, learn what we like, providing an even more natural interaction. They will be everywhere, watching our safety, taking automatically care of our needs, fetching information before we asking for it.

Several modules necessary for such a project to work have been developed. The Intelligent Room has a speech recognition system which receives and executes orders from people in the room. Imagine you are in a meeting, you can ask the room to read what is scheduled for today, show some video of the last meeting, show or read some document, etc. Another interesting technology is the Cricket/INS. This is a people location system inside a building that uses a badge carried by the people being traced. The main advance here is that the services someone is using follow the person as he or she travels from a room to another. Imagine you are listening to some music in your bedroom. When you walk into the living room, the system locates at each time where the nearest speakers are and automatically the sound starts playing there and stops playing in the bedroom. The same is possible for lights, air conditioning, TV or any other service.

I.L.S.A. - The Independent Lifestyle Assistant

This initiative from University of Minnesota [23] has as main objective to study the response of elderly to a monitoring computer system inside their houses and determine how such systems can help this people. They not only determined which are the main problems of elder people living alone, but they also implemented parts of a monitoring system in some test houses in real conditions. This application of AmI is not only good for the elder living alone but also for their caregivers as everyone maintains its autonomy.

A group of sensors was placed in each house (eleven houses during half year) according to what was being monitored (behavioural patterns, medication taken, etc). The information from the sensors was read and sent to a central where it was studied. From this central, alerts where emitted if the person in question did not take the medication or if the behaviour during the day was very unusual. The main features implemented included passive monitoring (mobility, occupancy, sleeping patterns), cognitive support (like reminders), alerts and notifications, reports (summary reports of client behaviour) and controlling remote access to information. Clients had a portable device from where they could check their agenda, change some system parameters and even communicate with caregivers. This is a project that directly interacted with a specific public: elder people living alone. This public of course has its own needs and creates specific problems or challenges that must be addressed and that was the target of this project.

Intelligent Transportation System

Intelligent Transportation System (`ITS`) is an initiative that intends to join information and communication technologies with the transportation system and the vehicles on it. It was created after the boom of vehicles in our roads as a way of fighting problems such as congestion, pollution or fuel consumption.

It comprises several technologies from simple `GPS` or traffic light control systems to CCTV circuits and Parking Guidance and information, all interconnected wirelessly. This would be a "simple" monitoring system if it did not have some predictive capabilities. In fact, using additional information like weather forecasts or current congestion level, it is now possible to predict future congestions for example. The system can also communicate with our car navigation device and inform it of some accident ahead and change our course. Hence, by detecting congestion and automatically deviate traffic through less congested roads, the system improves the efficiency of the transportation system. As every car is connected and visible to the traffic system, if an emergency vehicle approaches a traffic light that is red, the ITS can control the light signs so that the ambulance can continue safely.

These kind of systems are now being implemented and have already some history, namely in the USA and in Europe. ITS is by itself an amazing project with huge possibilities that can be even more expanded when integrated with other AmI projects.

ReachMedia

This project from MIT [18] consists on an RFID equipped wristband to provide us with on- the-move interaction with everyday objects. Usually, there is a lot of information related to the objects we deal with every day, mainly on Internet but it is normally only accessible through a computer. This project aims to present us that information wherever we are, in real time, without driving our attention from what we are doing.

The wristband contains an RFID reader that will read the information from RFID tags in objects close to our hands. After this, information is fetched from the Internet and presented to the user in some interface. At this moment a phone is being used to fetch the information and the user listens to what is found. Imagine you are in a book store and you grabbed some book you want some information about. When your hand approaches the book's RFID tag, the system beeps notifying you that some services are available for that object. For a book, there can be reviews or ratings that some store or book specialist put on-line. You can then choose, while you are flipping through the books pages, what you want to listen about that book.

The navigation between the several choices is also done using the wristband. As it is equipped with accelerometers, with small gestures of the wrist, the person can navigate through the several options for the object in question and select what to listen to. The uses for such a technology are wide. When meeting people with the same wrist, we could know what their interests are, their hobbies or what their personality is like. When shopping, we could know the characteristics of every product we grab (e.g. calories of alimentary products) while we are walking and looking at other products instead of having to stop and read the product specification.

Telecare

The objective of the Telecare [11] project is to develop a configurable framework for assisting elder people, based on the integration of a multi-agent and a federated information management approach. The result are services likely to be offered by the emerging ubiquitous computing and intelligent home appliances, which are useful for elderly people. With this approach, the project expects to address issues like elderly people being moved from their homes, providing them with autonomy and independence. To achieve these objectives, this project is based on tele-supervision and tele-assistance technologies. A virtual network is created, which connects the elderly home, the relatives office, the care or leisure centres, a virtual shop among others. It is thru this virtual community that the elderly makes use of the services. The project states that it is possible nowadays to create such a network that can provide cheap health care to elderly, namely because of the current development of internet-based infrastructures. The development of such projects is one important step towards countering the problems of ageing population and possible elderly marginalization.

2.9 Summary

Ambient intelligence is a relatively new concept as the technologies it is based on are also recent. This is probably the main reason for its low commercial implementation nowadays. On the other hand, the growing number of `AmI` research projects proves that this is a very interesting field with a promising future. There are many different ways of looking at this field. One of them, probably the most significant one, is to look at `AmI` as the providing of services to its users. This is the vision used in this work. The type of `AmI` described in this section is about monitoring and caring in indoor environments. We however believe that is possible to extend the intelligent environment to outdoors, providing the user with an increased safety range. This will be implemented with dynamic and interoperable intelligent applications, as we will see ahead.

Chapter 3

Mobile Intelligent Sensoring System

Once we accept our limits, we go beyond them.

Albert Einstein

Mobile Intelligent Sensing System (MISS) can be considered a sub-field of Ambient Intelligence. They are more specifically dedicated to assist people on its day to day in an outdoors environment, while on the move. These systems are generally lightweight, run on battery power and can easily be worn or carried by their users. Moreover, these systems are supported by communication technologies, interoperable services and small devices with significant embedded computational power. In this chapter, these technologies are detailed. By bringing together all these technologies in an AmI context, the result is a paradigm that works to assist the user independently of location [12].

In this new paradigm, people are empowered through digital mobile equipment that is aware of their location and movement, being this equipment sensitive, adaptive and responsive to their actual needs. Specifically, in the case of this work, the main objective is to monitor the activities of the person and respond accordingly in the event of a fall. Such motion aware systems combine ubiquitous information, communication, natural interaction and intelligence. The path to pursue in order to achieve this goal relies on a merge of different insights from Artificial Intelligence, Physics or Mathematical Logic, just to mention some of them, coupled with different computational paradigms and methodologies for problem solving.

3.1 Pervasive computing

Technology is moving beyond the standard personal computing to mobile devices with embed technology and connectivity as computing devices become progressively smaller and more powerful. Pervasive Computing is more than Ubiquitous Computing: its objective is to create environments that join in an integrated way humans and computers, minimizing as much as possible the awareness of our interaction with them. Traditionally, computers have always been a tool that has its own environment, its own reality and humans have to transfer themselves to that reality and interact with them according to their ways. With this new paradigm computer

and human environments are seen as a single one.
Pervasive Computing is the most recent result of the exponential speed at which technology is advancing. The evolution started when computers began to be interconnected through networks, being the Internet the most visible example. At this point computers started to be ubiquitous but still were not pervasive. When mobile technologies evolved, mainly in the areas of wireless communication and with the advances on miniaturization, Ubiquitous Computing became pervasive. Pervasive Computing is related to Mobile Computing and all the necessary support for interoperability and scalability, as well miniaturization. Therefore we can say that Pervasive Computing is made of four main areas, which are: devices, network, middleware and applications. Devices are the most common pieces of equipment that we use nowadays; they tend to have enhanced computational power, be small and have a significant range of functionalities. All these devices nowadays have wireless networking capabilities and increased embedded intelligence (e.g. the navigator assistant of our *Global Positioning System* (GPS) telling us the most economic path to our destination). Networks are nowadays common and generally available and are needed as a backbone for all devices to be interconnected. However, as devices are growing in number and functionalities, networks need to grow too. This means that more than the necessary bandwidth, networks need to provide tool for achieving the interoperability that is necessary between the devices. The Middleware layer is generally forgotten when one talks about Pervasive Computing. However it is of great importance since it allows developers to build more powerful and better applications. The objective of this layer is to hide all the heterogeneity beneath so many different devices and show, instead of that, a unique programmable environment. One does not see the devices one by one, but rather sees the services that these devices can provide. Applications using the middleware layer are user centred, which means that these pervasive environments will tend increasingly to assist us. The range of possibilities of interconnecting so many devices raises significant expectations. However, new challenges also arise. How should we deal with so many different devices and functionalities? Will our network be enough? Another consideration is the evolution needed in the miniaturization of batteries. In almost every mobile device batteries are by far the biggest component, significantly decreasing the possibilities of hiding these devices in the environment. Other important challenge to address is how to deal with so many different architectures and types of devices, each one having its own characteristics, communication protocols or interaction mechanisms. One cannot create high-level APIs for interconnecting each new device with the existing ones. Probably the best solution is the adoption of standards, as long as there are no more no less than the needed standards. Perhaps one of the main contributions of Pervasive Computing to Ambient Assisted Living is the creation of enhanced environments that look just like normal environments. This is very important when our focus is on older people, which are frequently technophobic, i.e., are very reluctant to accept new technologies and to use them. Pervasive environments could thus be a promising way of an elder person having such a computer system monitoring its life, with minor interference.

3.2 Mobile Computing

Computing devices that can be used while moving make up what is known as Mobile Computing [12]. This paradigm is evidently opposed to what happened until now when computing devices resumed to computers standing still in our houses. The change started in the 90's, with the emergence of the first mobile phones, later originating the smart phone.

This field started with the need to move devices to better locations (e.g. with better resource). This movement can be either physical or digital: one can move a computer to a better location or change an instance of a user or an application to a better location. The difference is that a physical system can move anywhere while a logical one can only move to a different computer system. This computer however, can be a mobile one, raising a lot of challenges to address. Entities must be identifiable while changing geographical location or while changing networks. And how to deliver a message to an entity that is constantly moving? When an entity is not in a network did it finish its execution or it just changed its digital location? Nowadays these are the main subjects of research in this area [20, 46].

However, it is nowadays possible to take computational power with us everywhere we go so that we can use it when needed, the same as we do in our homes or in our workplace. The most common examples are the laptops and PDA's, which have considerable computational power and portability. These devices can be used anywhere and even on the move (e.g. while in the bus or in the car) and they can even be connected to a wireless network and have access to the Internet. The most recent advances in this field are in the area of Wearable Computers, which intend to merge computers in our clothing so that it has embedded computation power. This will be the most natural way of transporting computational power since it releases our hands from any device and enables us to freely perform our tasks.

All Mobile devices depend however on a limited energy supply. In fact, the battery, that enabled Mobile Computing, is nowadays its biggest limitation as batteries did not follow the pace of evolution of other technologies, being big and without significant capacity, decreasing the uptime of some mobile devices. Another important technological advance for Mobile Computing was the communication technology. It evolved to a point in which we can have a connection to a network almost everywhere. It is a common thing that public buildings, private houses or workplaces have wireless networks that the devices can connect to. When these are not available we still have wider are networks with varying speeds and functionalities such as the *High-Speed Downlink Packet Access* (HSDPA), *Global System for Mobile Communications* (GSM) or *Universal Mobile Telecommunications System* (UMTS) network.

Given the scope of this work, we also need to stress the importance of wireless sensors, a sub-field of Mobile Computing. It would be impossible to constantly monitor a person if one did not have wireless sensors. With this technology, a person can be doing its day to day freely, while being monitored. Another important development in this field is the GPS sensor. One can nowadays have a GPS sensor embedded in a PDA which has also wireless networking capabilities and this way implement a wide range of location aware services. These services can be very useful to know where the person is, namely to react in the case of an emergency.

The on-going evolution in this field will generate smaller devices with enhanced capabilities and portability, which will enrich our experience with computer systems. These devices are already radically changing the way we use computers: they will get so smaller that we will wear them and even use them inside our body.

3.3 Generic MISS Architecture

When designing a Mobile Intelligent Sensing System there are some challenges that are raised by the heterogeneity of the devices and technologies used. The devices must behave equally and compatibility must be ensured between the different technologies and components. More than that, each device in the `MISS` must behave in a way that facilitates the achievement of the main objective of the `MISS`, being in this case the fall detection. In this section we describe the main technologies that can be used in a `MISS`, always bearing in mind the main objectives of this work.

3.4 Architecture

As seen in this section, the architecture of a Mobile Intelligent Sensing System must, first of all, be able to accept a very heterogeneous group of devices and technologies. This means that the architecture must provide means for these components to coexist and work together. It is therefore mandatory that the architecture provides a communication and information sharing mechanism that all different components can take profit of, as communication is a key component in cooperative systems. Architecture like this must also be highly expansible since new technologies appear every day. If it is expansible, it is also expected to be easy to expand, i.e. it should be easy to add new features or components to the architecture without having to mess with the architecture itself. With new features added, the architecture must ensure the compatibility between all of them. It is also important that this architecture is scalable so that it can grow or even be included in higher-level architectures like the ones already mentioned. At last, with all these features we can also say that the architecture cannot be static since many changes can occur so the architecture should also be described as dynamic. We can therefore enumerate the main expected characteristics of a Mobile Intelligent Sensing System:

- Dynamic
- Expansible
- Flexible
- Scalable
- Compatible

These are the features that we will have in mind when developing this architecture. The architecture will also be conditioned by the operating system. There are three main mobile operating systems, as we have described before. All of them are capable of supporting our application but there are certain specifications that we need to consider before choosing one. First, previous knowledge on some of them could save development time- This time could thus be better used for understanding and finding solutions for the main goals of this work. Secondly, we must also consider the equipment in the devices. Most of the devices have similar equipment, giving a significant freedom of choice. In third place we also have to consider the monetary issue since some of the development platforms are paid. Being this an academic work, a free-of-charge approach is more appealing. Thus being, according to our criteria, we decided on using the Android platform for the development of the mobile device.

Android is a software stack for mobile devices that includes an operative system, a middleware layer and key applications. Moreover, it provides a *Software Development Kit* (`SDK`), which has the tools and APIs needed to develop applications on the Android platform using the Java programming language.

The Android platform on the mobile device will thus support the application developed in terms of acquisition and communication of sensor data. It will be responsible for sensing the user movements in terms of the acceleration felt on the three axes and communicating it, in real-time, to a remote computer acting as a server. The Android device will be the core of the application since it will be carried by the user at all time, allowing the constant real-time monitoring.

3.5 Technologies Overview

The new technologies that are appearing allow for new ways of providing care to the elderly. They must be studied and classified according to the extent to which they can be useful on fall detection.

Communication Technologies

Communication technologies are, as we have already seen, of major importance in a `MISS`. They must be able of not only interconnecting equipment but also of providing security features, since some of the information transmitted is sensitive. This section is devoted to technologies that support the communication between the devices in a Mobile Intelligent Sensing System.

Mobile Technologies

In today's world, mobile devices are faster than computers from 10 years ago. The traditional view of a mobile device to make and receive phone calls only gets replaced by a mobile device that can be expanded through additional applications, offering limitless possibilities. One can read mail, take pictures, listen to music, send *Short Text Messages* (`SMS`) or *Multimedia Messages* (`MMS`), play games or edit documents. To support these features, rich operative systems and powerful hardware were developed. Currently, the three most important mobile operating systems are the iOS, Android and Windows Mobile. Below, each of these operating systems is explained in detail.

The iOS is a mobile operating system developed by Apple and first released in March 6th, 2008. It is a closed operating system so only Apple mobile devices can use it. The main objective behind the development of this OS was to change the way the user interacts with the mobile device, focusing on the touch. In that sense, the innovation was to remove keyboards and hard pointers, creating simple touch-based user interfaces. Apple mobile devices are equipped with several sensors: accelerometers, proximity sensor, ambient light, compass, moisture and gyroscope on the latest models. Development for iOS is only possible with Apple computers running its operative system, the OSx. The programming language used to develop applications is objective C. Furthermore, submitting the applications developed has a cost of 79 euros per year.

Android Inc. was purchased by Google in 2005 [52] and in 2007 the Android Distribution was released, with the funding of the Open Handset Alliance [36]. Android is a Linux-based operating system for mobile devices and the code is open-source. The vision behind Android is to create a successful real-world product that improves the mobile experience for end users [3]. Android is distributed for several models of mobile devices and each device has its own equipment, and different number and types of sensors. Generally, the most basic mobile devices are equipped with accelerometer and compass while the most advanced ones have these sensors plus gyroscope and proximity sensor. Developing for Android is free of charge and it can be done in any computer. The programming language used to develop is Java.

Windows have been developing his mobile operating system since 1990 and it was officially released in 1992. Since then Windows has released several new versions, in line with the new tendencies of technological evolution. The most recent versions of this operating system have changed so much that the user interface has nothing in common with the older ones. The current Windows devices have only three sensors: accelerometer, proximity and compass. Developing for Windows mobile has an annual cost of 99 euros, and the development tools are restricted to the ones that Windows offers. This means than it can only be done in a Windows operating system and the programming language is C#.

Ubiquitous Computing

Ubicomp or Ubiquitous Computing is a new paradigm of human-computer interaction. Until now, this interaction has been very computer centred. A human had to go to the computer and use in its location, consciously and willingly. Due to miniaturization and the development of communication technologies, that is now changing. The Ubicomp paradigm spread computational power everywhere, embedding it in common devices. Ideally, a user would not even notice that he is interaction with a computational system. Quoting Mark Weiser: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." [54].

This way, we go from a paradigm in which the human interacts with only one device consciously to one in which he interacts with a multitude of devices, possibly without noticing it. This kind of environments empowers our living since they extend the capabilities of common devices or objects that we use. These devices tend to be inexpensive, small, networked processing devices. The common interfaces that have been used until now (e.g. command line, keyboard, GUI) are no longer suitable to be used in these new environments. There is therefore the need to evolve the interfaces and make them more user-friendly and natural. This gap is filled with intelligent interfaces, described in the next section.

Intelligent Interfaces

Intelligent Interfaces are the evolution of the common interfaces. Besides making the bridge between human and computer, they can provide additional features. Namely, they can guide the user when he does not exactly know how to use the feature he wants, or even when he does not know exactly what he wants. The request to the computer can be incomplete, incorrect, or not very specific and there must be ways to assist the user on reformulating the request or trying to guess what the user wanted. In order to achieve this behaviour, the interface should be adaptive, anticipate the needs of the user, be proactive and always explanatory of its actions. The best examples nowadays are search engines like Google or Yahoo: they often do successful searches although we have misspelled the word, or suggest similar words or concepts in order for us to improve our search. They also filter the information, deciding which is closer to what we want and which is useless for us, in an attempt to meet our needs. Note that sometimes, even when we do not know what or how to exactly make a search, the search engine must try to conduct us to more specific subjects to narrow our search.

The way these interfaces are implemented is also changing. Human interaction with computers first started with batch interfaces, evolving then to command line interfaces and later to graphical user interfaces. Neither of those adapts to the new computer paradigms. As computation is starting to be less centred and more distributed, interfaces will also have to change from being in the computer itself to be in the environment. Traditional keyboard and mouse will no longer be useful. The future of interfaces includes technologies such as speech, gesture or facial expressions recognition. These technologies are based on pattern matching algorithms used to map a voice or a gesture to a programmed action. We can also think of the new multi-touch screens and, more futuristic but already with some implementations, the direct neural interface, which is a direct communication pathway between a human brain and an artificial system. Any of these new ways of interacting with computers will be more natural to us, therefore more passive of being used by people which are not familiarized with computers or that have some impairment that prevents them to efficiently use the common interfaces. Moreover, such technologies will increase our productivity and efficiency since we will be able to interact with computer systems without having to stand in front of them, and having our hands free for doing other tasks.

Multi-agent Systems

The combination between Artificial Intelligence and distributed computational models generated a new paradigm: distributed artificial intelligence called *Multi-agent Systems* (MAS). There are several valid definitions for a multi-agent system so we will try to define a multi-agent system from the Ambient intelligence point of view. A MAS is a group of entities, software or hardware, which will interpret the application requests and make intelligent decisions in order to achieve some common goal, in this case detect a fall, based on knowledge from every agent in the system. For an agent to be considered so, it must show some basic abilities; autonomy, reactivity, pro-activity and sociability which means agents must operate on their own actions and be able to relate to other agents in order to achieve their goals. Additionally, an agent may show characteristics such as mobility, learning, veracity or emotions.

In this paradigm it is expected that with simple agents or modules, each one responsible for some part of the application, the global objective is achieved through cooperation [34]. They are able of taking their simple individual decisions completely independently and we see the result of these decisions as a global intelligent behaviour. This paradigm rapidly started to play a major role in the design of any intelligent system. A lot of research has also been done in the field of argumentation with agent technologies [30]. In argumentation, agents debate, defend their beliefs and try to convince the other agents into believing the same they do.

An example might be using a multi-agent system for monitoring a user. Let us assume we have an agent sensing the movement of the user and another monitoring a weather station. When the motion agent senses that the user is leaving home, he asks the weather agent how's going to be the weather, suggesting the user what kind of clothes to wear. However, in cases in which there are several agents, the decision-making process may be more complex. This happens for example in an indoors environment in which an different agents control the temperature, the lights, the air-conditioning system and others control the level of comfort and the level of energy consumption. When a person leaves some room the energy agent will argue to turn off the lights and every agent might agree on that. However, the power saving agent may also argue that the heat should also be turned off because the room is empty. But, the comfort agent may argue that it should remain on because someone could return to the room and will feel more comfortable if it is hot. Obviously, there is a contradiction: agents in the same system may have conflicting objectives. Situations like this are common in multi-agent systems. Not all the agents have the same objectives or, if they do, not all of them agree in the way they should be achieved. This is solved by modelling human negotiation techniques, in MAS it is called automated negotiation [10, 33].

Context Awareness

According to Dey [15], context is "any information that can be used to characterize the situation of the entities". This concept has been around since ever and is rather difficult to define. It is however constantly used by us, most of the time, without noticing it, e.g. a conversation or gesture sometimes is complemented by the context on which it is used, this way, we do not have to explain or detail everything since much information is contained in the context and does not need to me mentioned: it is implicitly perceived.

In computer science, context awareness means that a system has sensors that are able to read the environment and through that, understanding what is happening and constructing its own representation of the environment. The concept is very important since only accurate representations of the environment allow the system to take the right decisions. Using context, the system can adapt the services provided accordingly. For example, if there is a reminder scheduled of low importance and the user is sleeping, the reminder will be delayed until the user wakes up.

Machine learning [32] and reasoning come along with context awareness: they are deeply related in Ambient Assisted Living. In order for an intelligent environment to reason and choose what action to take, he must learn the characteristic or habits of the persons in that universe, possibly from decisions he made in the past. For correctly learning about the persons habits, the system must be aware of the context.

Machine learning [32] is a subfield of artificial intelligence that aims to develop algorithms that allow computers to learn. This can be defined as the acquiring of new useful information. With us Humans this happens since we are born until we die: our brain constantly adapts and absorbs new information. In computers, learning has the same objective: to acquire new information that can later be used to improve the system. This learning can be done using a wide range of methods: by assimilating new cases in a *Case-based reasoning* (`CBR`) model [1], by modifying the weight in the node of a neural network or through evolutionary computation, just to name a few. `CBR`, models our own way of learning from a high point of view and because it is possible to understand its decisions, it has been a widely used method in many research projects involving learning.

Reasoning [27], in a rudimentary way, is defined as a mental process by which one goes from a premise to a conclusion. This has been since ever a characteristic associated to Humans. Automatic reasoning is the name given to the implementation of reasoning methodologies in a computer. The objective is that a computer shows reasoning skills without Human interaction, in a completely or almost completely autonomous way.

3.6 Communication with the Mobile Device

The functionalities of mobile devices, that depend on a limited supply of energy, should be used with rules. In fact, an excessive use of the processor may quickly drain the battery and render the device useless. In that sense, the approach used consists in minimizing the processing needed in the device. Given that we want to implement a real-time solution, the approach thus consists in sending the data about the acceleration to the server, in real-time, as it is generated. The server is then responsible for implementing the computationally harder machine learning algorithms for classifying activities and detecting falls.

Being Android Java-based, it is easy to develop communication mechanisms. At the outset of the project, the approach planned was to use agent-based technologies, given that it would simplify communication by using the tools that agent platforms provide. This idea was then abandoned since it would require extra resources from the mobile device and it was concluded that the not so significant increase in functionalities would not be worth it. Given that we implemented the communication mechanism without the support of an agent platform, the solution adopted consisted on the use of TCP/IP sockets. Sockets are an end-point of an inter-process communication flow, across a computer network. The solution adopted is in line with the ubiquitous computing vision as it is independent of technologies and does not require significant additional computational power.

3.7 Server

Let us describe in this section the role that server will have in the architecture. Its main aim is to process the data from the mobile device, increasing its battery life, using machine learning algorithms. Since the approach to classify activities consists in comparing past movement patterns with the current ones, there is also the need for space to store all the past data. Moreover, this database must be able to grow and store data about several users.

Furthermore, the server will also act as a gateway to enable the incorporation with other healthcare applications/projects, namely the ones being developed in the Intelligent Systems Lab of the University of Minho: iGenda and VirtualECare. iGenda is a mobile application that helps people organize their agenda, by providing support to cognitive tasks such as finding valid empty spaces, rearranging events, determining the necessary times between events, among others. Moreover, this project addresses this problem from the healthcare point of view, providing specific services for synchronizing agendas with formal and informal caregivers. VirtualECare is an indoors monitoring system whose central component is a Decision Support System that looks after the inhabitants comfort and well-being, also providing a connection to the healthcare facility or personnel. Given the scope of this work and of these projects, we believe that their integration results in mutual advantages.

The server will thus consist in an application containing a socket endpoint that will receive the raw data from the accelerometer. Based on this data and on patterns recorded from the user in the past, this application will be able to classify the activities being performed in real time using mathematic algorithms and machine learning techniques. This server-side application was also developed in Java, mostly to stick to a single language (given that the client had to be forcibly developed in Java).

3.8 Summary

Mobile Intelligent Sensing Systems can be seen as a subfield of application of Ambient Assisted Living, i.e., intelligent monitorization systems implemented with the objective of assisting users in their daily tasks, making their day-to-day easier, independently of their location. These monitorization systems are based on technologies that allow them to be portable, pervasive and integrated in common devices. This means that they can be used in any location, without functionality loss. This has numerous advantages for the user. In fact, monitoring the users with the objective of assisting them, means that they are able to maintain their autonomy and independence, increasing their well-being and confidence. We therefore believe that `MISS` are a strong answer to the challenges depicted in the first section, namely on how to develop accurate and usable fall detection mechanisms to the current ageing population while maintaining them with their normal day-to-day live. Defining a complete architecture for a `MISS` is an extensive work. There is a range of possible technologies that can be used as well as paradigms and methodologies. All these issues have to be analysed and responded to if we want to specify an architecture that can provide support to the such an application.

Chapter 4

Practical experiments

A good decision is based on knowledge and not on numbers.

Plato

4.1 Data analysis

Tim Berners-Lee [6] once said, *"Data is a precious thing and will last longer than the systems themselves"*. This project follows this same principle. In fact, more time was invested in analysing, studding and processing it than in developing a software solution. The information extracted from this analysis and study will be used for developing an algorithm able to address our main objective.

In this case, the data is composed by values of acceleration on the three axes and a timestamp. This data is transmitted via a TCP/IP socket in the form of a String object to the server, which is responsible for parsing it. This parsing results in three objects of type Double (one for each axis of the acceleration) and one object of type Date containing the time instant in which the acceleration values were read.

As said, data is very important. However, without any analysis or processing, it is just a bunch of numbers and text with no meaning at all. Our first approach was to represent this data graphically for an easy preliminary interpretation. As we can see in Figure: 4.1, the resulting graphic allows to easily identify different patterns in the data in a visual way, which would be a hard task if we were to look at the raw data.

The data generated has been analysed with several approaches in order to determine the most suitable one. In this section we depict the several approaches used as well as their strengths and weaknesses To proceed to the analysis of the data, several datasets containing data about user's movement were create, each one depicting data about one activity: running, walking, falling or standing/no motion. Each dataset contains around 2 minutes each of data of the activity and is stored into *Comma Separated Values* (`CSV`) files. The values were recorded with the smartphone placed in the pocket of the pants. To classify the real-time data we focused

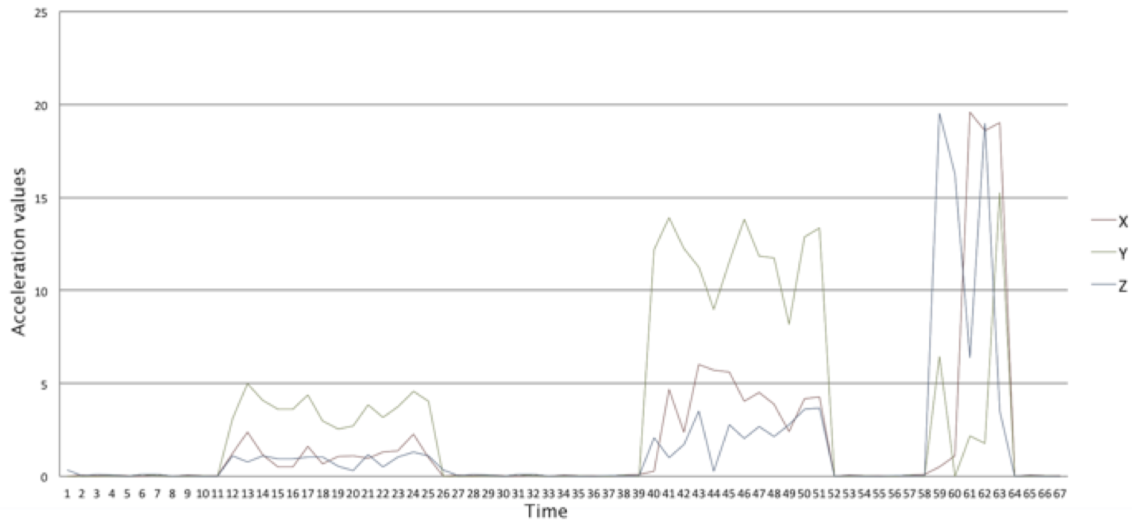

Figure 4.1: Preliminary visualization of the data generated with the device on the chest. It is possible to see that different activities generate different acceleration patterns.

on approaches to compare it with the known datasets and computing a measure of similarity. The results of this are detailed in this section-

Statistical approach

Statistics is the study of collection, organization, analysis, and interpretation of data. It deals with all these aspects, including the planning of data collection in terms of the design of surveys and experiments. The experiments described in this section were performed using the Wolfram Mathematica 8.0 statistical tool. In order to search for unique characteristics in the activities recorded in the files, several statistical concepts were computed, namely the mean, minimum, maximum, standard deviation and median.

Table 4.1: Statistical concepts computed for the activity "running".

Axis	Max	Min	Mean	Standard deviation	Median
X	20.5262	0.027611	4.85978	4.10966	3.88212
Y	30.0584	0.000897	7.18099	5.86044	6.12952
Z	18.3461	0.00465581	6.62817	4.47042	6.03861

At this point we have seen that there are indeed differences in the data between different activities: this has been seen graphically and through statistical concepts. However, in order to know the significance of these differences, we used techniques for statistical hypothesis testing.

Specifically, we used the Mann-Whitney test. This test is a non-parametric statistical hypothesis test for assessing whether one of two samples of independent observations tends to have larger values than the other. The null hypothesis is thus:

Table 4.2: Statistical concepts computed for the activity "falling".

Axis	Max	Min	Mean	Standard deviation	Median
X	20.3409	0.00253403	3.03877	4.33125	1.03487
Y	21.4759	0.00159168	2.97288	4.06194	1.2357
Z	22.7205	0.0029068	2.80911	3.9077	1.21806

H_0 = *The medians of the two distributions are equal* . For each two distributions compared, the test returns a p-value, with a small p-value suggesting that it is unlikely that H_0 is true. We thus compare each axys of each activity with all the others. In all the tests, a value of $\alpha = 0.05$ is used. Thus, for every Mann-Whitney test whose $p\text{-value} < \alpha$, the difference is considered to be statistically significant, i.e., H_0 is rejected. In table: 4.3 we depict the results of comparing the data of falling and running which show some degree of similarity when observed graphically. Nevertheless, the Mann-Whitney test indicates that they are indeed significantly different.

Table 4.3: Results of the Mann-Whitney Test comparing data of the activities "running" and "falling".

Axis	Value	p-value < 0.05
X	2.05435×10^{-14}	True
Y	2.42095×10^{-24}	True
Z	1.77022×10^{-28}	True

Having determined the significance of the differences between the several activities, work continued with the objective of developing a classification method suitable to be used in real-time. The approach consisted in trying to find a way of comparing the known distributions of data with the distribution being created in real-time and compute a value of similarity between them. If we had a good value of similarity between the real-time data and some data classified as a given activity we could thus classify the real-time data as belonging to that same activity.

We thus started by plotting histograms of the data in order to visualize the distribution of the data for each activity. The approach devised to classify the data consisted in computing the Confidence Intervals 4.2 of each distribution and then comparing these intervals. When two intervals are similar enough (their boundary values are close) we consider that the distribution of the data is similar and this way conclude that the data belongs to the same distribution. Thus, if we are constructing a real-time distribution whose Confidence Interval is similar to the one of the activity "running" we conclude that the user is currently running.

However, this approach did not prove to be as accurate as desired, due to the characteristics of the data. In fact, if we look at the histograms 4.3 and in Box-and-Whisker plot 4.4 the data from the activities "running" and "falling" is relatively

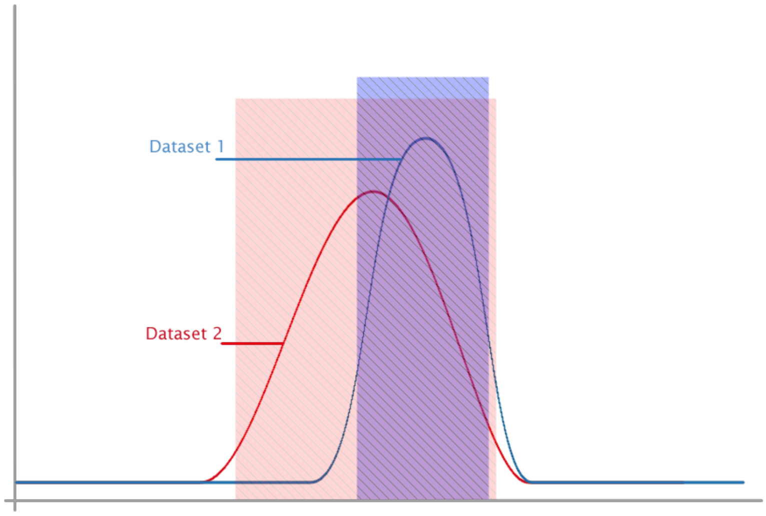

Figure 4.2: Interval of Confidence.

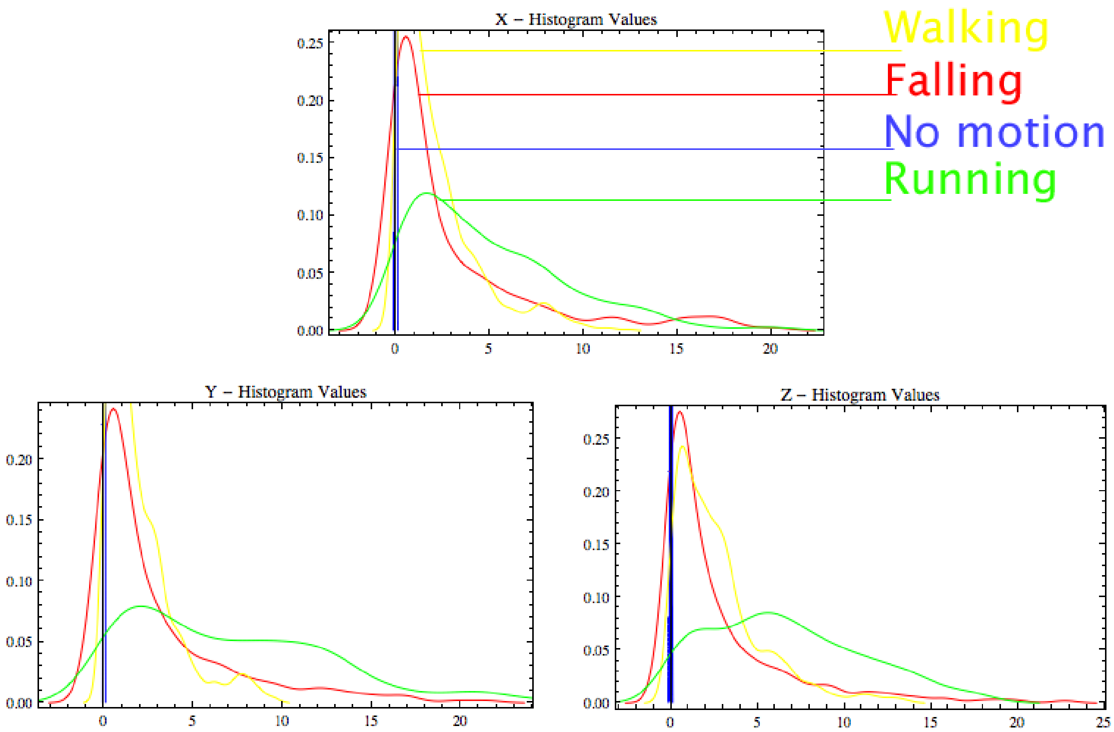

Figure 4.3: Histograms of all movement in the three axis.

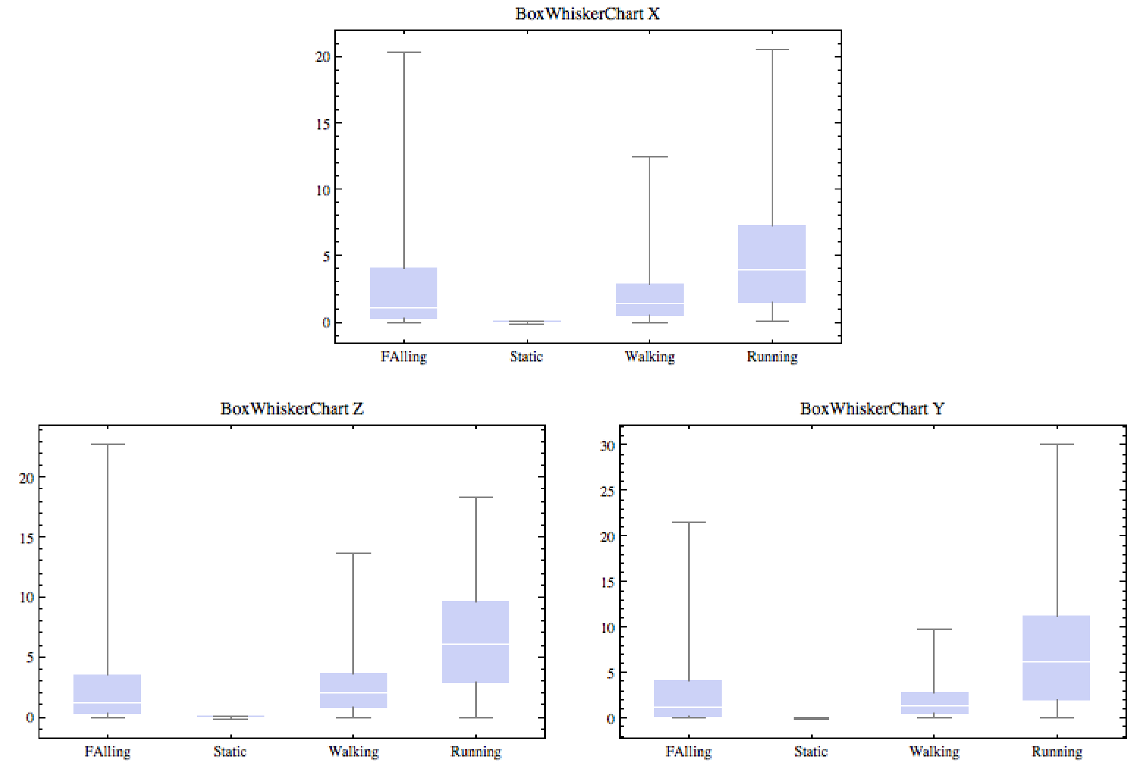

Figure 4.4: Box-and-Whisker plot of all movement in the three axis.

similar. This means that the Confidence Intervals are also very similar, making this approach prone to errors. We could additionally consider the fact that when someone is running it usually runs for a long period of time and a fall is a short event in order to implement a better classification algorithm. However this is also not a correct approach as we often increase our speed just to reach a closing door for example. Although this would be considered running, this approach would most likely classify it as a fall. Figure: 4.5 depicts a dataset in which falling and running have very similar values of acceleration.

Table: 4.4 shows the confusion matrix for this dataset when using this approach to classify the real-time data. As we can see, these results have too many false positives, which is undesirable for a critical objective as the one of this work. Therefore, this solution does not meet the required level of reliability.

Table 4.4: Confusion Matrix of the real-time data classification.

	Walking	Running	Falling	No motion
Walking	83	7	7	5
Running	11	70	8	1
Falling	73	8	6	3
No Motion	5	1	3	81

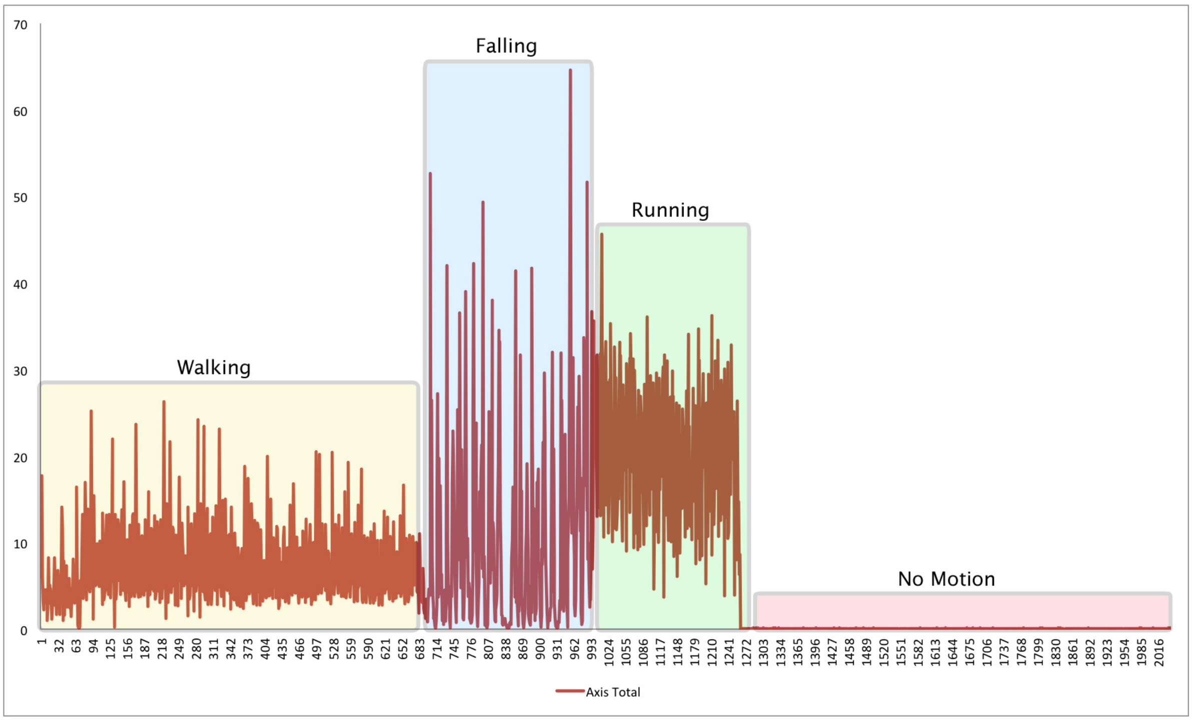

Figure 4.5: Plot of a dataset containing the module of the acceleration in all axes, with the respective activities shown.

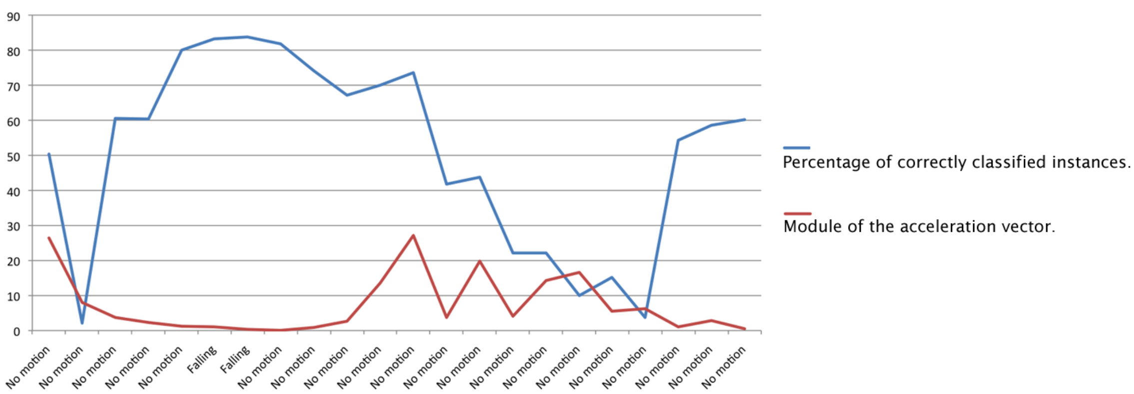

Figure 4.6: Analysis of the performance of this approach: the percentage of correctly classified instances is relatively low, mainly when we need the user is running/falling.

Data mining approach

Data mining, also called data or knowledge discovery, is a process of analysing data and summarizing it into useful information. Data mining tools allow users to analyse data from many different dimensions or angles, categorize it, and summarize the relationships identified. In other words, data mining is the process of finding correlations or patterns in data.

Data mining has been widely used in numerous projects, namely for classifying movement [9]. In these projects, one of the most popular data mining algorithms is the *K-Nearest Neighbour* (KNN), which is also one of the simplest classifiers [37] when compared with others. It is a method for classifying objects based on closest training examples in the feature space: an object is classified by a majority vote of its neighbours, with the object being assigned to the class most common amongst its k nearest neighbours (k is a positive integer, typically small). If k = 1, then the object is simply assigned to the class of its nearest neighbour.

This algorithm can be detailed graphically as depicted in Figure: 4.7. In this figure, several instances of the module of the acceleration vector for the activities "running" and "no motion" over time are shown. The differences are visually identifiable. The instance to be classified (red square) will be assigned to its closes neighbour (k=1). Thus, this instance is classified as "running".

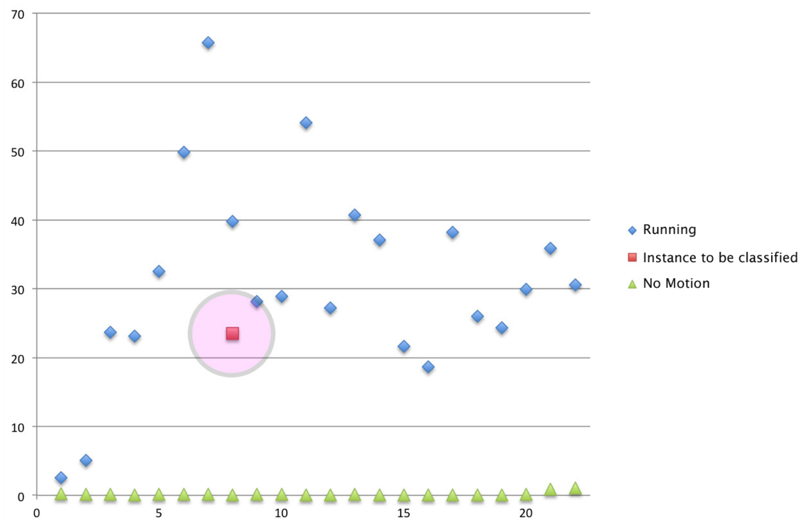

Figure 4.7: Representation of the nearest neighbours classification algorithm: the instance to be classified (red square) would be classified as "running" since we are using k=1.

The results of training a KNN algorithm with a mixed dataset were very positive. In fact, the algorithm correctly classified the 2038 instances as we can see in Figure 4.8 . This means that the values from every movement were classified.

With very positive results from the training of the algorithm we expected similar results for a real-time use of the model created but, in fact, results were somehow disappointing.

```
=== Run information ===

Scheme:weka.classifiers.lazy.IBk -K 1 -W 0 -A "weka.core.neighboursearch.LinearNNSearch -A \"weka.core.EuclideanDi
Relation:     Dataset_No_axis
Instances:    2038
Attributes:   2
              Total
              Movimento
Test mode:evaluate on training data

=== Classifier model (full training set) ===

IB1 instance-based classifier
using 1 nearest neighbour(s) for classification


Time taken to build model: 0 seconds

=== Evaluation on training set ===
=== Summary ===

Correctly Classified Instances        2038              100      %
Incorrectly Classified Instances         0                0      %
Kappa statistic                          1
Mean absolute error                      0.0007
Root mean squared error                  0.0008
Relative absolute error                  0.2096 %
Root relative squared error              0.2026 %
Total Number of Instances             2038

=== Detailed Accuracy By Class ===

               TP Rate   FP Rate   Precision   Recall  F-Measure   ROC Area  Class
                 1         0          1          1         1          1       Walking
                 1         0          1          1         1          1       Falling
                 1         0          1          1         1          1       Running
                 1         0          1          1         1          1       No Motion
Weighted Avg.    1         0          1          1         1          1

=== Confusion Matrix ===

   a   b   c   d   <-- classified as
 693   0   0   0 |   a = Walking
   0 258   0   0 |   b = Falling
   0   0 311   0 |   c = Running
   0   0   0 776 |   d = No Motion
```

Figure 4.8: Summary of Weka classification.

In that sense, we started searching for optimized values for K. We started by testing several values of K for classifying a dataset containing only data from a non-moving person. As Figure: 4.9 shows, with a K=1 there is a relatively high amount of incorrectly classified instances. This number tends to decrease as the number of K increases.

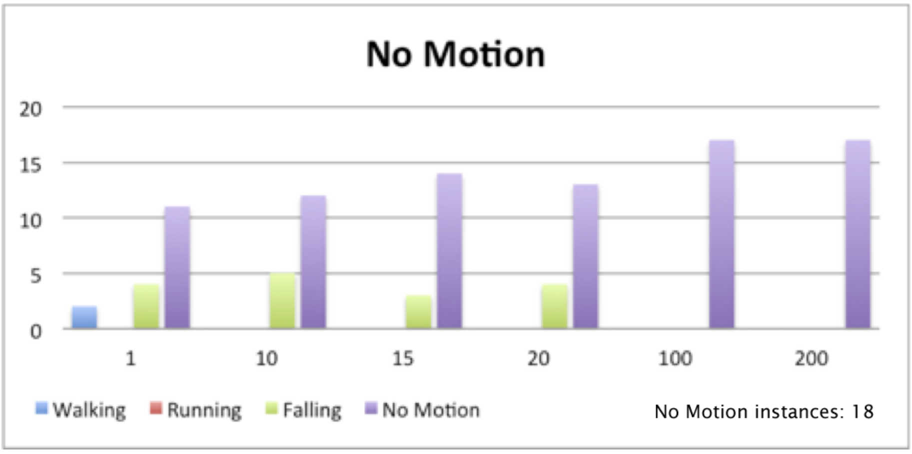

Figure 4.9: Results of the classification with the KNN algorithm with different values of K for the activity "standing".

In the second test performed with the algorithm, we used a dataset combining the activities "walking" and "running". Figure: 4.10 shows that the results differ from the previous test. In fact, in this second case, the algorithm shows better results for smaller values of K.

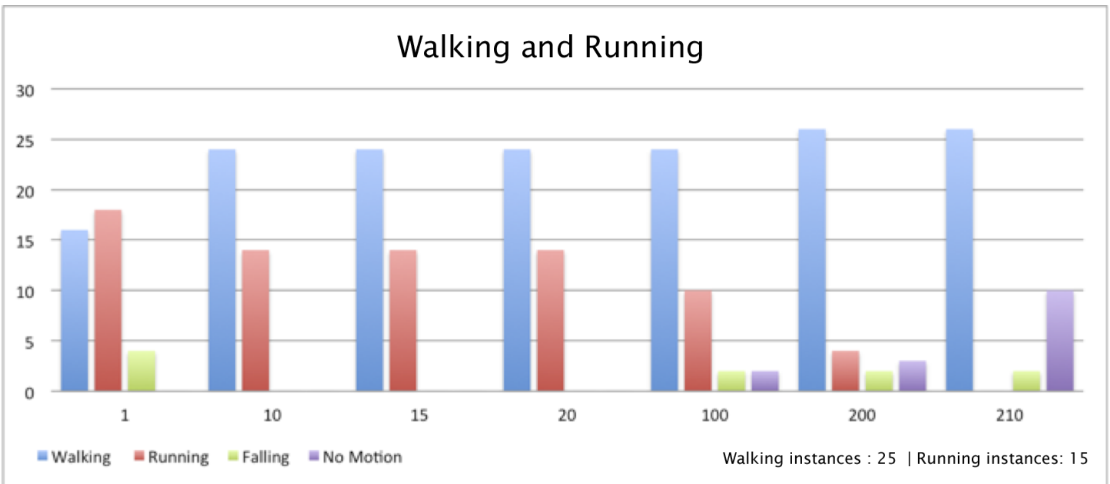

Figure 4.10: Results of the classification with the KNN algorithm with different values of K for a dataset with the activities "walking" and "running".

Given that this discrepancy in the results could be due to the type of activities being compared, we decided to classify only the activity "walking" in order to see if it had false positives as well. As shown in Figure: 4.11, there are several false positives even with higher K values.

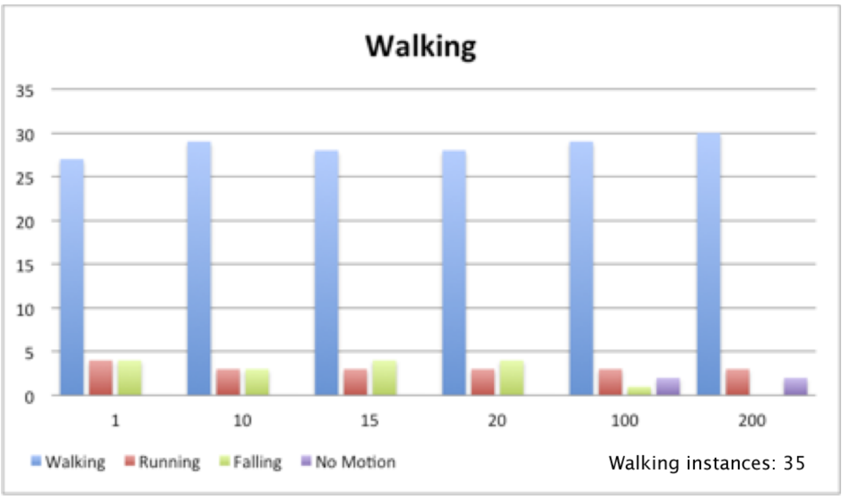

Figure 4.11: Results of the classification with the KNN algorithm with different values of K for the activity "walking"

Given that the results were not as consistent as expected and in order to improve the quality of the data we added a second device to the experiment. Now, instead of being based on one device in the pocket we started to perform the same experiments with a device attached to the wrist as well. The process described so far was repeated with the two devices. Similarly, the `KNN` algorithm revealed good results in the training phase of the model with a similarly high number of correctly classified instances. However, also similarly, the results of a live use of the model were not as satisfactory, as Figure 4.12 shows,

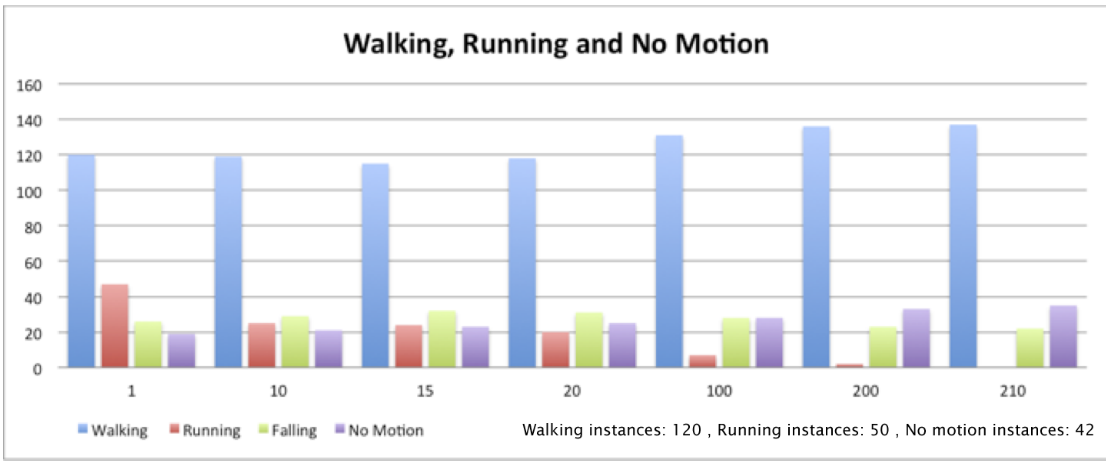

Figure 4.12: Results of the classification with the algorithm with different values of K for a dataset with the activities "walking", "running" and "standing". The data was recorded in the wrist.

Given the relatively unsatisfactory results, there was the need for a change in the approach. The decision was then to use a single device but fixed in a central position. We thus attached the device with duct tape to a sweatshirt, in the region of the chest Figure: 4.13.

Figure 4.13: Device fixed in a central position.

This way we expected to reduce the variability observed in the data collected in the pocket (e.g. a loose pocket would provide very different values from a pocket in some tight jeans in which the device would not move much). Moreover, given that the device was fixed, we started using the actual values of the acceleration in the three axes separately instead of using the module of the acceleration vector, as done until now. This resulted in an improvement in the quality of the data acquired, as depicted in Figure: 4.14 .

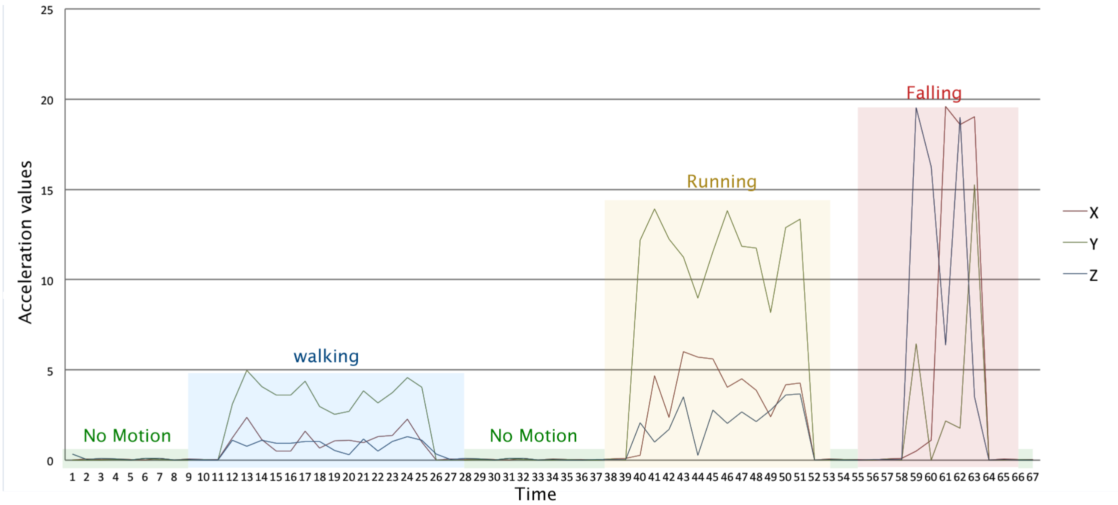

Figure 4.14: Plot of the data captured with the device fixed in the chest of the user.

Analysing each axis separately represents an added value as we know in which direction we are moving/turning (Figure: 4.15). When there is acceleration on the

Y axis, it means that we are moving up and down; on the X axis when we move sideways; and on the Z axis when we move forward and backward.

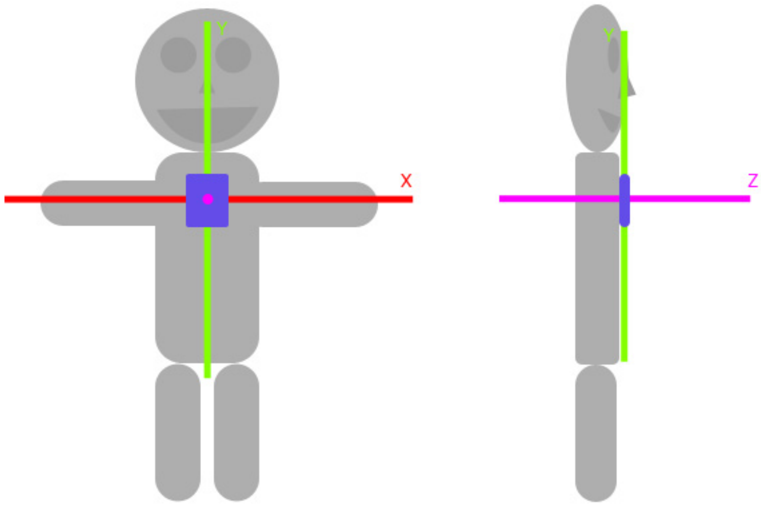

Figure 4.15: Axes orientation with the mobile device fixed in the chest.

This increased quality of the data acquired increases the possibilities of developing a better application. In fact, when we analyse the movement graphic depicted in Figure 4.14, we can see that each activity is more or less inside given ranges of values. With this thought in mind we analysed once again the module of the acceleration and computed the average value of each activity. As expected, the average value of the acceleration of each activity is different.

Table 4.5: Average values of the module of the acceleration vector for each activity studied.

Movement	Walking	Running	Falling	No Motion
Average	5,695392428	18,43042057	27,65319258	0,129717703

Supported by this, we used the c.45 data-mining algorithm, which is used to generate decision trees, in an attempt to classify the instances. Using the java implementation of the c.45 algorithm, (known as j48) we could generated the decision tree depicted in 4.16, using the Weka tool. Using this decision tree, we were able to create segments of values according to which one instance is classified. The result is visually depicted in Figure: 4.17.

Nevertheless, this solution was still returning some false positives. In order to improve the data further, we changed the use of linear acceleration (which we were using so far) for the actual value of acceleration (which includes the influence of

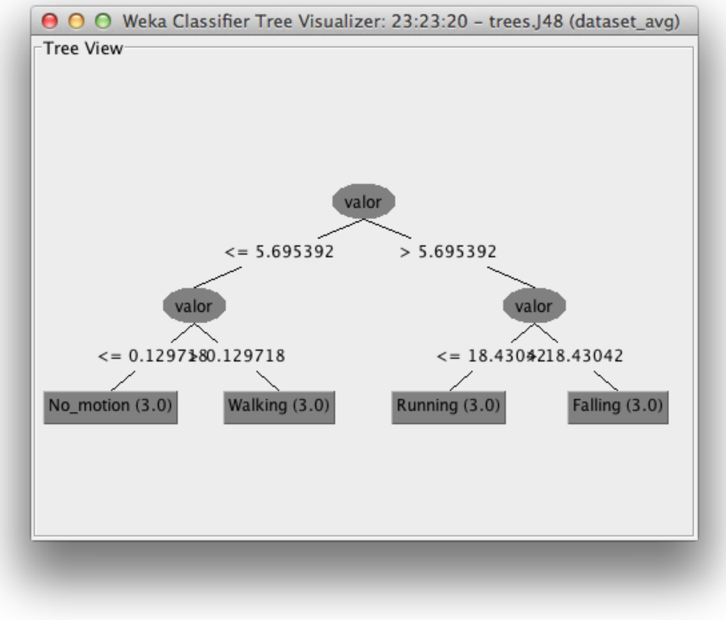

Figure 4.16: A tree resulting from the j48 algorithm, used to classify the instances according to the module of the acceleration.

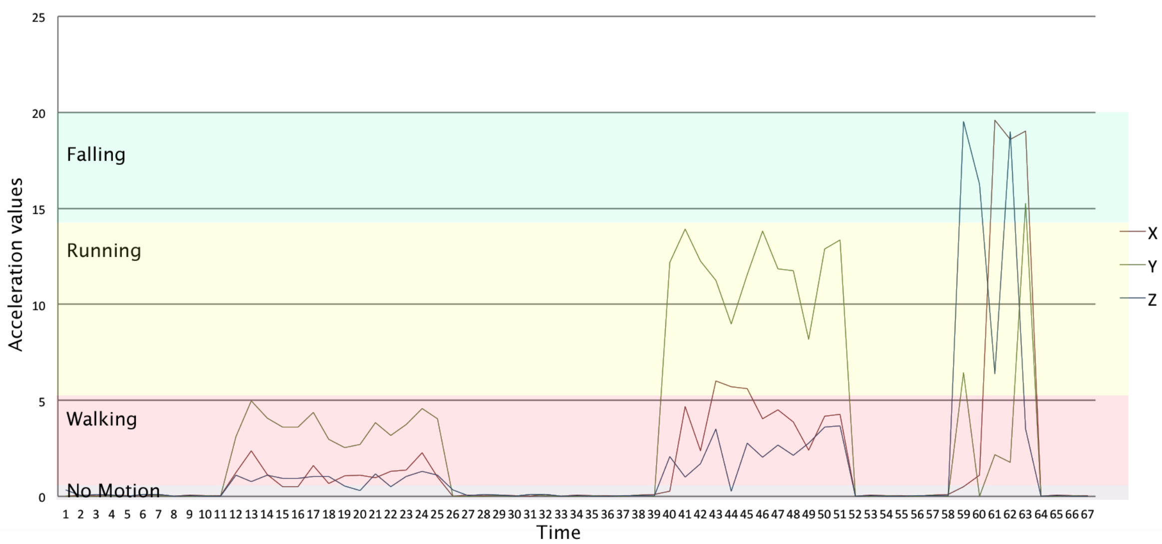

Figure 4.17: Segmentation resulting from the j48 algorithm for this specific dataset.

gravity). For instance, if we consider Figure 4.18 that depicts data from a user in a standing position, the Y axis will suffer a constant acceleration of $9.8\frac{m}{s^2}$ plus whatever acceleration is measured due to the movements of the user.

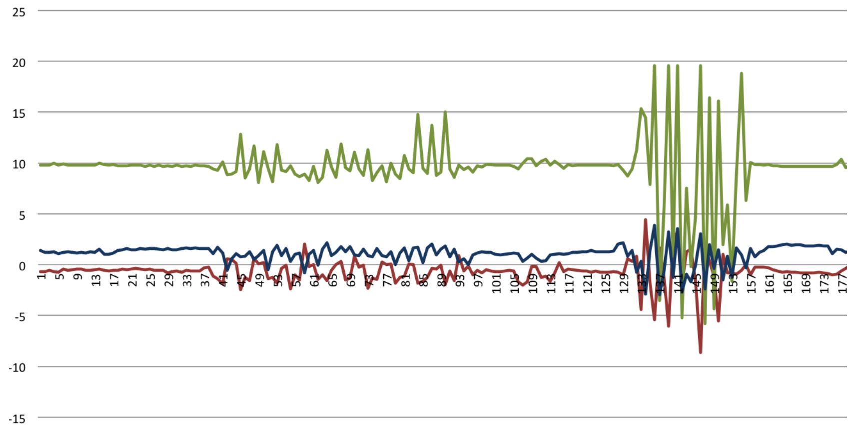

Figure 4.18: Detail of the data from the acceleration considering the influence of gravity, for a user performing different activities.

In Figure: 4.18 we can see the effect of the acceleration due to gravity in the Y axis, and we can also distinguish different activities being performed, namely a fall happening in instance 197. This last approach proved to be the best one, with no false positives as we can see in Table: 4.6.

Table 4.6: Result of classifying data of figure: 4.18.

Movement	Events
Walking	65
Running	54
Falling	1
No Motion	104
Total instances	224

4.2 Monitoring

In this section we will describe the monitoring module developed after the results achieved in the experiments performed. The solution developed is based on the conclusions achieved in the previous phase but works with the data provided in real time rather than stored datasets. The monitoring component is composed of the following modules: database, sensor monitor and decision making. All these modules make up the fall detection application. Additionally, a simple and intuitive graphical user interface was developed with two main objectives: to facilitate the test and assessment of the application and to act as the final interface for real use. Figure: 4.19 depicts the high level organization of the Monitoring component. The component acquires the data from the mobile device's accelerometer and uses the process described in the previous section to interpret the data and generate useful knowledge from it. With this knowledge, the decision making mechanism, based on the J48 algorithm, is able to characterize the user's movement patterns and detect eventual falls. The work depicted in this dissertation was developed with the objective of being integrated in other Ambient Assisted Living projects. This component will be made interoperable by means of a service endpoint in order to connect it with the afore mentioned projects iGenda and VirtualECare.

The hardware used in the project was a smartphone, acting as client, and a desktop computer, acting as server. The mobile device used was a HTC Wildfire with a 528 MHz processor, 384 Mb RAM, running Android 2.3. The specifications of the desktop computer are 2.2 GHz quad-core processor and 8 Gb RAM.

A database is also used that stores all the users sensory information, namely the users movement, the result of the classification and the timestamp. This data will be useful for later developing a module to analyse the evolution of the movement patterns of the user over longer periods of time. The database is accessible through the application only, in order to ensure the consistency and security of the data

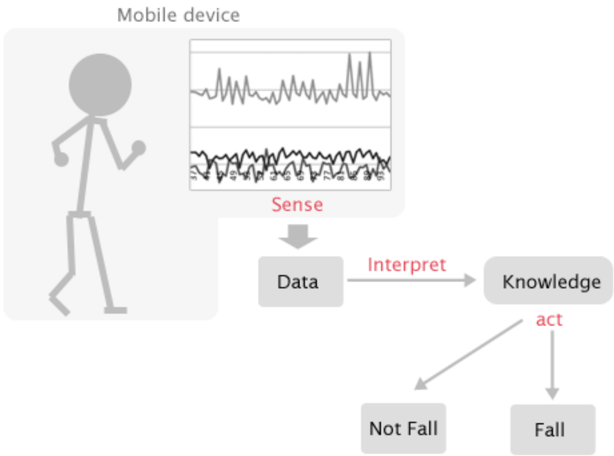

Figure 4.19: The data flow in monitoring module.

stored, which is sensitive. The structure of the database is depicted in Figure 4.20.

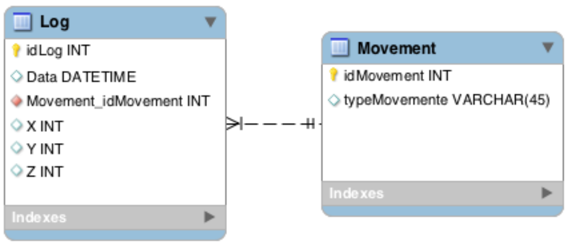

Figure 4.20: Entity-Relationship of the database.

The table "log" contains the information about the movement of the user, the time at which the event occurred and the values obtained from the sensors.

The motion monitor is responsible for reading the values of the acceleration in the different axes and to classify the movement according to those values, using the described data-mining algorithm. At the same time, the motion monitor writes, in real-time, the values and classification of the movement to the database.

To make some tests and improve the usability of the final solution a GUI was created. This GUI shows what movement the person is doing, the values sent by the mobile device and the counting of movement by day.

4.3 Summary

In this section we described the approaches pursued until a satisfactory result was achieved in order to achieve our main goal: detecting falls. Different approaches have been tested, analysed and studied. This included the analysis of factors such as mobile device's position or the different use of the information from the three axes. Different approaches to deal with the data collected were also tested, ranging from

Figure 4.21: Desktop application, showing what movement the person is doing. On the bottom are the rest three icons of movement.

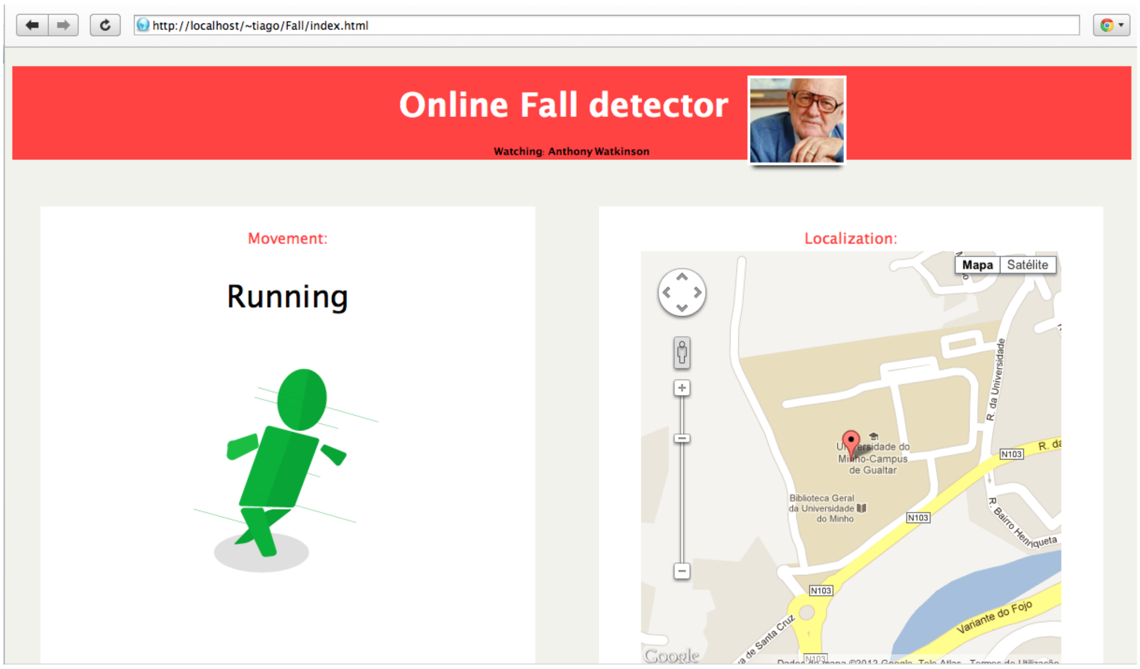

Figure 4.22: Web application, showing what movement the person is doing and where the movement is being done.

the use of statistical concepts such as maximum, minimum or mean values, to more complex approaches such as the analysis of the intervals of confidence of the distributions. We also analysed the use of data mining algorithms such as the K-nearest neighbours and the J48 Decision tree. Each different technic or approach was evaluated on its performance, based on the number of correctly and incorrectly classified instances. The best solution was achieved when using acceleration considering the effect of gravity in the vertical axis, in order to detect the movement direction, and using the three axes and the k-nearest neighbour data mining algorithm.

The monitoring of a person's movements in order to detect falls is the main objective of this MISS. Monitoring, in this case, consists on the continuous providing of data about the person while on the move, in order to detect falls, in a non-intrusive way. In this work both these objectives were kept in mind. On the one hand, the person is continuously monitored and the values are logged so that later, if needed, they can be studied. The data obtained is also analysed on real time so that if any fall is detected actions can be triggered, improving the sense of security. Moreover, these objectives are achieved in a way that minimizes the intrusion in the life of the user so that they are able to continue to develop their daily tasks. In the whole, the solution developed has shown itself fit for monitorization based on mobile devices and suitable for being integrated with other e-health applications.

Chapter 5

Conclusion and Future Work

It's fine to celebrate success but it is more important to heed the lessons of failure.

Bill Gates

The generalized problem of the ageing population is maybe one of the most important challenges that we face in this century. We know nowadays that, if changes are not made, social security systems and healthcare institutions are likely to collapse due to the growing costs that the elderly population entails. There is, for sure, a need for a change, and the time for this change must be now. The change, we believe, can be accomplished with the new ITs and, in line with this belief, we hope to have contributed to the advance of this vision.

There is a wide range of technologies that are nowadays cheaper and more available, allowing things that a few years ago seemed impossible. Tools such as Video Conference, Digital Signature, and many other are nowadays common and are an example of how people can be virtually in more than a place at the same time, thus reducing transportation costs and others. This kind of technologies can be used by doctors to provide care and advice without leaving their offices and with the patient being comfortably kept on their environment. This is just a mere example of the possibilities raised by these technologies. During the execution of this project we concluded that it is possible to build a mobile and non-intrusive movement monitoring solution that is able to detect falls, following an inexpensive approach. The solution presented will provide its users with a sense of security and support additional features such as a direct line of communication with a medical team or informal caregivers. This type of monitoring is in fact what we believe to be the future of healthcare, following a vision in which people continue to live in their environments, consequently reducing costs and maintaining their comfort and routines. Moreover, these systems can be made interoperable and integrated with others with similar or complementary objectives, resulting in more complete solutions.

Synthesis of the Work Done

The main contributions of this work revolve around the study of the acceleration measured on a mobile device in order to correctly detect falls.

They can be summarizes as follows:

- Development of a mobile device application that can send acceleration values from an Android device to a remote server;
- Development of a server application able to acquire sensorial information form an Android mobile device and to process it in order to be analysed further;
- Development of a web application allowing easy access to movement monitorization anywhere.
- Determining the most suited process to analyse and study the information gathered using different statistical and data mining methods in order to detect falls;
- Development of a prototype for detecting falls, in real time;
- Submission of a paper entitled "Two approaches to classify movement patterns of a user on the move in real time" to the International Joint Conference on Ambient Intelligence (AmI 2012).

The work described contributes to advance the field of Ambient Assisted Living by providing means for the integration of common technologies with the objective of assisting people in their daily living.

Future Work

Although the objectives of the work have been accomplished, some work has yet to be done to transform this into the desired reality, being the most significant to implement this project in a real environment, with people in need of care and study the feedback from such implementation. In order to do accomplish this, a list of further tasks was identified:

- Developing more exhaustive tests and fix minor issues;
- Integration with already implemented monitoring systems, in order to share advantages;
- Keep studying new potentially interesting technologies as they appear in the market in terms of their viability to integrate the system and of their potential advantages.
- Development of an OSGi gateway to make the system compatible with existing healthcare service-oriented architectures such as the iGenda and VirtualECare.
- Using the information from the database from several users to enrich the training dataset, improving the system.

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