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SmartGuia: Shopping Assistant for Blind People

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Abstract

Regarding the limitations of disabled people, the present work acts in a specific scenario, improving the quality-of-life of the people involved. As part of a research group on Internet of Things, we collaborated with three institutions, raising the requirements concerning how the Internet of Things could help people with special needs. After that, we chose and focused on the adopted workplan, as one of the scenarios where we could help.

We propose a system for indoor assisted shopping and navigation for blind people. The proposed system helps the user navigate and find desired or available services and products in buildings. It aims to increase the autonomy of blind people in day-to-day indoor activities. A blind person does not have access to the common visual information. The proposed system consists of a smartphone application which offers guided navigation inside public buildings, answering questions, and providing objective information about places, products and services that are available.

The proposed system also includes an information system. This information system identifies the intended destination and offers concise or detailed information on local products or services. The system continuously determines the user's location, calculates routes, guides inside the building, and identifies areas in the vicinity of the user. The system also requires locating beacon technology, which may be for instance Bluetooth or Wi-Fi based. Comparing to the state-of-the-art, our solution offers some important advantages: it minimizes the amount of interaction that would be necessary in other systems in order to specify desired destinations, products or services; it handles a dynamic and walking environment where the number and positions of beacons in range is changing; it takes advantage of devices that the blind person already has, and also any beacons that may be available or cheaply

installed. Besides these advantages, we designed the system to be as easy to use and user-friendly as possible, applying blind-friendly mechanisms.

We developed a prototype in Java for an Android environment. In order to do this, we have also studied and used the technologies and programming language for the Android device and used several existing API's.

Resumo

Tendo em conta as limitações das pessoas com deficiência, o presente trabalho pretende agir num cenário específico melhorando a qualidade da vidas destas pessoas. Integrados num grupo de investigação em Internet das Coisas, colaborámos com três instituições, levantando requisitos no que concerne a aplicabilidade da Internet das Coisas para ajudar pessoas com deficiência. Depois disso, escolhemos e focámo-nos no plano de trabalho adotado, sendo um dos cenários identificados onde poderíamos ajudar.

Com este trabalho é proposto um sistema para apoiar pessoas cegas na ida às compras e navegação dentro de edifícios. O sistema proposto ajuda o utilizador a circular pelo edifício e encontrar serviços e produtos desejados ou disponíveis. Tem como objetivo aumentar a autonomia das pessoas cegas nas atividades do dia-a-dia dentro de edifícios. A pessoa cega não tem acesso à informação disponível por meios visuais. O sistema consiste numa aplicação para *smartphone* que oferece navegação assistida em edifícios públicos, respondendo a questões, guiando a pessoa, e disponibilizando informação objetiva sobre os espaços, serviços e produtos disponíveis.

O sistema proposto inclui também um sistema de informação. Este sistema de informação identifica o destino pretendido e oferece informação concisa ou detalhada sobre os produtos ou seviços disponíveis. O sistema determina constantemente a localização do utilizador, calcula rotas, guia a pessoa dentro do edifício, e identifica pontos de interesse na vizinhança da pessoa. O sistema requer tecnologia de localização por *beacons*, que poderão por sua ver ser baseados nas tecnologias *Bluetooth* ou Wi-Fi. Relativamente ao estado da arte, a nossa solução oferece vantagens importantes: minimiza a interação com o utilizador, que seria necessária para escolher destinos, produtos ou servios desejados em outros sistemas; lida com o ambiente dinâmico result-

ante da caminhada do utilizador, como a variação do número e posição de *beacons* ao alcance do utilizador; utiliza dispositivos que a pessoa cega já possui, e eventualmente *beacons* que possam já existir ou tenham uma custo de implantação baixo. Além destas vantagens, desenhámos o sistema de forma a ser o mais fácil e intuitivo de utilizar possível, aplicando mecanismos acessíveis a pessoas cegas. Para além disso, o sistema está desenhado para lidar com o dinamismo do caminhar, sendo que o número e posição dos *beacons* varia.

List of Acronyms

ACAPO	Associação de Cegos e Amblíopes de Portugal
APCC	Associação de Paralesia Cerebral de Coimbra
API	Application Programming Interface
Beacon	Emitter deployed on the environment.
CHUC	Centro Hospitalar de Coimbra
dBm	Decibel-Milliwatts
DEI	Department of Informatics Engineering of University of Coimbra
EPC	Electronic Product Code
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ICIS	Intelligent Computing in the Internet of Services
IoP	Internet of People
IoT	Internet-of-Things
PDA	Personal Digital Assistant
QR	Quick Response
RG	Robotic Guide
RSSI	Received Signal Strength Indicator, in dBM
RFID	Radio frequency identification
SAXParser	Simple API for XML
SRS	Software Requirements Specification
TCP	Transmission Control Protocol
TOA	Time Of Arrival
TDOA	Time Difference Of Arrival
TTS	Text-To-Speech
UPC	Universal Product Code
XML	eXtensible Markup Language
WLAN	Wireless Local Area Network

Contents

Chapter 1

Introduction

1.1 Context

The Internet-of-things, IoT, embeds everyday objects with network connectivity, allowing them to send and receive data. In IoT, objects are ubiquitous and the center entities in the network. The Internet of People, IoP, is envisaged as a world where people also become part of the ubiquitous network of networks. By contrast, in IoP the individual person becomes the center entity but, more generically, objects and people collaborate to fulfill useful tasks in the daily lives of people.

One field where we believe IoP can make a significant difference is for helping people with disabilities. This thesis was done in the context of the task "Internet of Things", IoT, within the project "Intelligent Computing in the Internet of Services", ICIS. Regarding the amount of people with special needs around the world, the IoT task within the ICIS project focuses on studying the usability of new technologies to enhance the daily lives of such people. The main objective is to support them in common tasks, decreasing or suppressing their dependencies. We intend to take a different view of the possible applications of technology, using it to provide self-confidence and self-esteem to those who currently have limitations constraining their lives. As a primary requirement, the result of this work should endorse the utility of technology in a specific daily need of people with some disability.

We have put together a team and a workplan to collaborate with institutions serving people with disabilities or other forms of special needs. The team is composed of professors and researchers of the Department of Informatics Engineering (DEI) and students of different areas. Specifically, the team consists of Prof. Jorge Sá Silva (professor at DEI), Prof. Pedro Furtado (professor at DEI), Dr. José Cecílio (researcher at DEI), Elis Regina (informatics engineering master student at DEI), Joana Alves (doctoral student of sociology at CES), José Alves (informatics engineering master student at DEI), Karen Duarte (biomedical engineering master student at DEI) and Rita Capelo (design and multimedia master student at DEI). The workplan involved first raising the requirements for helping the people being served by those institutions, then focusing on specific scenarios considered important by the stakeholders, and developing working prototypes for those scenarios.

The IoT team was able to start collaborations with three institutions representing people with special needs - Associação de Paralesia Cerebral de Coimbra (APCC), Associação de Cegos e Amblíopes de Portugal (ACAPO), and Centro Hospitalar de Coimbra (CHUC). During the first semester - September to January - three MSc thesis that were being done within the scope of the IoT task of project ICIS were raising requirements for helping people with special needs in those institutions. In a first stage, the three students and advisors met with people from the institutions and raised their most pressing needs that could be supported by IoP technology. From September to November, all team members went to meetings in all institutions. The output from those efforts is present in the report "Relatório de Levantamento de Requisitos nas Instituiçõe ACAPO, APCC e SEDM/CHUC" in appendix J.

A second phase started in late November and December. According to student preferences and institutional needs, the students were assigned a specific institution, prepared an IoP system proposal for helping people with special needs, and met with the staff from the corresponding institution to raise feedback on the proposal. After the proposal was set with the institutions, each MSc student started planning the approach for each scenario. The first semester ended with the writing of a report on the approach. The output from this effort is present in a report "Relatório de Levantamento de Requisitos - ACAPO" in appendix K.

The second semester was entirely devoted to phase three of the workplan. During this phase, each team developed the prototype for the specific scenario that was raised within each institution. This thesis first reports on the two initial phases, then most of the work presented concerns the scenario of "Assisted Shopping for People with Blindness or Partial loss of Sight".

More generically, a smart utilization of Internet of Things has the capability to predict behaviors and consequences and to act in order to lead the person to outcomes that benefit the intentions of the person. Being aware of the potential utility of Internet of People, the fundamental purpose of this thesis is to evaluate and structure a specific application of this concept to benefit the life of disabled people.

1.2 Assisted Shopping Objective

The IoP scenario chosen for this thesis concerned "Assisted Shopping for People with Blindness of Partial Loss of Sight". It aims to increase the autonomy of blind and partially sighted people in their day-to-day lives. The proposed system, that we call *SmartGuia*, provides a mechanism for navigation within public buildings. A blind person does not have access to the information common in visual cues. The new system adds an application to the smartphone to allow guided and assisted navigation inside public buildings. The system guides the person, answering questions and providing objective information about places, products and services that are available, or promotions and events taking place. The smartphone interacts with the person by voice, and guides the person. The information system identifies the intended destination, and offers concise or detailed information on products or services. The system continuously determines the user location, calculates routes, guides inside the building, and identifies areas in the vicinity of the user. Determination of user location is based on calculations from beacon signals.

In order to develop the system to handle this scenario, we created a set of software modules that comprises a Beacon Module, a Location Module, an Information Module, a Routing Module and a Voice Module, and we developed the application prototype for Android[1].

In this thesis we report our work on both the requirements raising with the institutions, and on the assisted shopping prototype.

Although the work that was planned for this thesis was all successfully done and tested within the scope of the thesis, further work is still required for the system to be working in real environments. In particular, work is

[1]Operating system based on Linux for mobile devices.

needed regarding deploying and testing a large number of beacons, and usability testing within the context of the intended users and in a real shopping center environment. Very interesting research issues were also raised within the scope of this thesis, such as indoor localization with uncertainty and wall conditions, indoor navigation, middleware for IoP systems and shared ontologies for generalizing the use of the information system module. These are future work issues that we intend to address.

1.3 Scheduling and Publications Resulting from the Thesis

Figure 1.1 shows the schedule of the thesis project. Along the first month and a half we raised requirements of institutions, comprising real understanding of needs and limitations of disabled people (in the scope of the institutions) (Sept-Oct 2013). A report of identified possible actions was built in this phase, as presented on appendix J. From then on, the scope of this thesis was focused to raising the needs of blind people and then on developing for a specific scenario. A first project proposal was elaborated and discussed with the institution, and then a report describing the fundamental needs identified with them was elaborated, as shown in appendix K (Nov 2013). Finally, a project proposal was built in collaboration with the institution, we involved them in the project process in order to prepare and build a system that is actually needed (Dec-Jan 2014).

Given the idea of what the system would be, the system requirements were defined, then we defined its architecture and test cases to evaluate each individual module and the final integrated system (Jan-Feb 2014). Once the architecture was fully defined, the development of the modules evolved as

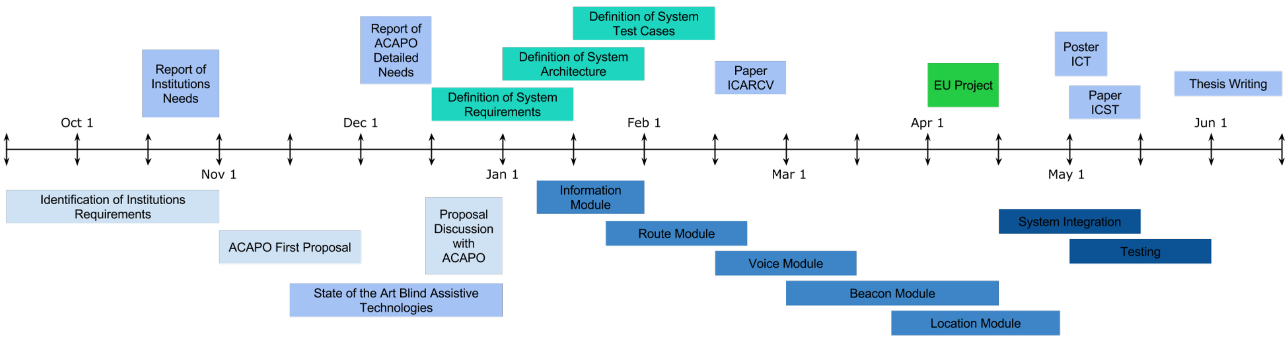

Figure 1.1: Project schedule.

described in the figure (Jan-April 2014). Once the development of all modules was finished, they were all put together for building the final application, and tests were performed to evaluate the functionality of the integrated software as well (April-May 2014).

The thesis was written in June 2014.

In parallel, some papers were written, submitted and accepted (Feb 2014, May 2014), and the student also helped preparing an application process for an European project proposal (April 2014). As part of the collaboration done within the IoT research group, a poster was presented in the ICT 2013 European Commission conference (Vilnius, Lithuania), reporting the acting scenarios identified on the initial phase of definition of the thesis project (Nov 2013). With the same group, a paper was submitted to a journal with a proposed middleware architecture to build applications to support disabled people, referencing the scenario cases identified in the requirements identification phase (Jan 2014).

Three papers were submitted: two full papers and an extended abstract. The extended abstract and one of the full papers were already given a positive acceptance answer, and may be found on appendix I. The extended abstract, with the title “Assistive System for Blind People on Shopping” was accepted in the ICT Innovations 2014 conference (Ohrid, Macedonia), it presents an initial concept of the system presented in this thesis, and will be presented in the conference. The full paper was accepted in the ICST2014 conference (Liverpool, United Kingdom), whose title is "Information and Assisted Navigation System for Blind People". In this paper the architecture of the system built with this thesis project is presented. Another paper was submitted to ICARCV 2014 conference (Marina Bay Sands, Singapore) with the title "Overview of Assistive Technologies for Blind and Partially Sighted People", and presents a summary of the state-of-the-art of technologies designed to assist blind people, in particular in navigation and shopping. This paper is not annexed to this thesis, since the decision was not yet communicated. Its content is still partially present in the state-of-the-art of this thesis. Also, we have an extended paper in this subject for submission to a journal that was not submitted yet because we are still working on improvements.

Within the thesis work time span, three European Program Horizon 2020 project proposals were submitted that are related to the scope of our IoT group. The proposals resulted from the requirements raised with the institutions with whom we collaborate in the IoT task of the ICIS project. I collaborated together with the team, and in particular with my advisor, Prof. Pedro Furtado, and team member Dr. Jose Cecílio, in the writing, organizing and preparation of the proposal. The main tasks I did were to communicate with the consortium partners and to organize their contributions. The project proposal is to assist diabetic patients on the estimation of macro-nutrients in food using a smartphone, by means of image recognition.

1.4 Other Contributions and Important Collaborations of this Thesis

Besides the publications described in the previous section, we plan to take the following actions now that we have a working prototype (some of these actions are already in place). We have recently submitted applications for funding to Vodafone and PT foundations for social interventions. We also plan to submit the thesis to scientific and practical prizes, including *Fraunhofer Portugal Challenge 2014* (deadline 31 July 2014).

We had a meeting at Architecture and Planning Department of *Metro do Porto* with the director and aide concerning the approach followed by NAVMETRO, a very interesting navigation system for blind people deployed in the network of metro of Porto. The navigation system uses the sound of birds singing along the way that the blind person should follow. This guides the blind person all the way from the entrance of the metro station to the train, and from the train to the exit. This system is already in Trindade station and is going to be expanded to all the metro. The NAVMETRO staff was very pleased to know about our effort and are willing to collaborate in the future.

As the prototype was planned for shopping centers, we requested meetings with *CoimbraShopping* and *Dolce Vita* board to present the planning system and to evaluate how we could design it to best fit their interests. These contacts are on hold, since the prototype was being developed. We plan to reenact them as soon as we have the beacons.

All along the design and development phases, we kept in contact with ACAPO, had some training with blind people orientation experts, that is, instructors who teach blind people how to orient and navigate in different spaces. This was very important for us, since it provided us with clues for our system. Peter Colwell, an accessibility technician from ACAPO - Lisbon, was particularly useful, since he provided us with relevant information concerning NAVMETRO, Colombo and other efforts in the area that we were seeking. Also contacts with a group from Politecnico of Viana do Castelo and a group from University of Minho working on assisted shopping and indoor localization were very useful.

The work in this thesis was presented to visiting Professor Stephane Jean, from Institut Supérieur de l'Aéronautique et de l'Espace, Poitiers - Futuroscope. He contributed with an interesting idea related to generalizing the use of this system all over the world and to make it really global. The system could have a centralized server where building owners would add information concerning their scenario, and it could include a more complete treatment of semantic information. A future collaboration was planned, taking advantage of the knowledge of Professor Stephane in data integration and semantic ontologies.

CES (Centro de Estudos Sociais da Universidade de Coimbra) was also a partner of the working group. Their role in the workgroup was to deal with social and psychological issues related to deficiency and caregivers. This provided a multidisciplinary perspective to our work.

1.5 Methodology

The collection of possible applications and scenarios of use of the IoT was developed in meetings with professionals that work close to disabled people. Those meetings had the objective of the identifying, clarifying and specifying possible scenarios and mechanisms. At the same time, and along the project duration, weekly meetings with the whole IoT project team and meetings with advisors enabled support, project planning, organization and adjustment of objectives.

When the concrete scenario of application of this work was defined, the requirements specification was elaborated, a system architecture and application was designed and the full list of test cases was defined. Afterwards, the system was developed and tested, testing if it fulfilled the requirements and functionality defined for the system.

1.5.1 Requirements

In software development, the software requirements specification, SRS, is a description of the behavior of the system to be developed[94]. SRS is written to understand the features and accurate details that each module, and the final system, must comprise. The requirements describe every external functionality of each module of the system.

Each requirement defined should be correct, traceable, unambiguous, verifiable, prioritized, complete, consistent and uniquely identifiable. Verifiability is the characteristic that enables the testing phase to evaluate the requirements accomplishment. Each requirement has an unique identifier, a brief description and a priority associated. A second classification, related to the purpose of the requirement, is also associated with each one. There are three classifications: Structure Requirements, Functional Requirements and Non-Functional Requirements. Structure requirements are related to specifications that the software must have, not related to interaction with users, people or other systems. Functional Requirements are those describing the forehand behavior of the software, such as user interactions and deliverables. Non-Functional Requirements are always associated with a functional requirement, its function is to evaluate performance and reliability of the function performed by the father requirement. Therefore, another column is included for those requirements with the unique identifier of the primary requirement, called father requirement. Table 1.1 presents an example of the requirements defined for each module and for the software integration. The extensive list of requirements defined is presented in appendix D.

Identifier	Description	Father's ID	Priority
Structure Requirements			
VM_S1.0	Prepare voice outputs.		High
VM_S1.2	Create TextToSpeech object.		High
VM_S2.0	Prepare voice inputs.		High
VM_S2.2	Create RecognizerIntent.		High
Functional Requirements			
VM_F1.0	Receive user input.		High
VM_F1.1	Convert speech to text.		High
VM_F3.0	Deliver voice output.		High
Non-Functional Requirements			
VM_NF1.1	Receive user input without Internet connection.	VM_F1.0	Low
VM_NF1.2	Receive user input with Internet connection.	VM_F1.0	High
VM_NF2.0	Conversion from speech to text is correct.	VM_F1.1	High
VM_NF5.1	Deliver voice output without Internet connection.	VM_F3.0	Low
VM_NF5.2	Deliver voice output with Internet connection.	VM_F3.0	High

Table 1.1: Example of requirements defined for each module.

1.5.2 Design and Development

The design of the system architecture intends to provide a blueprint for the system that is going to be developed. A modular approach was used, so that it could be developed and tested adequately, and would be easy to extend and/or modify. The system was divided into five different modules, dividing required functions of the system by modules. This approach of modularizing the system, designing each separate module and software integration between those, specifying and doing test cases per module and over the integrated system as well separates complexity and eventual failures, eases development and results in a more coherent and adequate final application.

All the modules that are necessary for the system to work were developed for a specific target prototype. They were coded in Java for an Android environment. This entailed learning the technologies and programming frameworks and languages for the Android device, as well as studying and applying a significant number of libraries and API's from that framework.

1.5.3 Software Testing

The tests were identified with unique identifiers, and each one was rated as Pass or Fail, for approval or not in the test. The severity of defect, associated to those that not fully accomplish the test case, is rated as Low, Medium, High, each one respecting to a different level of nonconformity with requirements. Some tests were considered passed even with small disagreements with the requirements. Every case was individually evaluated, and in some situations a small fault was considered not to be enough for the functionality to fail. Furthermore, a summary of defect and a commentary to each test was added when necessary. Test cases and developed tests are explained later, and a full list of tests and results is found in appendix H. When important, we identified limitations of the module, most of the times related to third party technologies and software that were used.

1.6 Document Structure

The master thesis document is structured into seven chapters. The first exposes the Requirement Analysis phase. The second presents the State of the Art of Technologies to Assist Blind People and of Indoor Positioning Techniques. The next three chapters are related to the system developed: Architecture (which includes an user's guide for the *SmartGuia* prototype), Modules Testing and Software Integration Testing. The sixth presents the User's Guide of the developed application. In the last one are discussed conclusions and future work. In order to complement the material exposed in this thesis, we added several appendices. These appendices are related to: the simulated building, some calculations made, requirements defined, test cases and test results, accepted papers and reports made along the thesis.

Chapter 2

Requirements Analysis

As explained in the chapter 1, the requirement gathering was performed by several meetings with professionals that work with disabled people. Three main areas of disabilities were analyzed: cerebral palsy, diabetes mellitus and blindness. The needs of people with cerebral palsy were studied with an association for integration of people with that deficiency (APCC). We also studied the needs of people with diabetes, by collaborating with the unit of the Hospital of Coimbra (SEDM/CHUC). Finally, we studied the need of blind people together with an association for inclusion of blind and partially sighted people in society (ACAPO).

In this chapter we summarize some of the requirements that we raised in the three institutions. A detailed document of this work is presented in appendix J.

2.1 Cerebral Palsy

Cerebral palsy is characterized by a sort of disturbances that compromise the motor system and posture control. Generally, people with cerebral palsy have limitation in controlling movements, speech and legs, which usually implies their constant dependence on third people.

Although the range of cerebral palsy can be limited to a few standardized groups, capabilities and dependences vary from person to person, which compromises the development of assistive technologies. Sometimes, other deficiencies, such as blindness, deafness, speech impairment and epilepsy, are also associated to cerebral palsy.

2.1.1 Requirements Identified

Among the needs and lacks of the association to assist and develop capabilities of people with cerebral palsy, the major identified requirements are related to mobility, speech therapy and alternative communication.

Since most people with this deficiency also have mobility limitations, wheelchairs are relevant in this field. A limitation compromising the allocation of wheelchairs to people is that the process of defining the adequate wheelchair is not standardized, therefore a therapist has to individually evaluate the person capabilities to use the chair and then to test different chair types to fully evaluate his/her capabilities. In order to enhance autonomy of the disabled person with motor and mental capability, it is important to assess whether he/she can control the wheelchair. This increases the tests and experiments required before assigning a chair to a disabled person. The APCC defines this as a major limitation.

In the field of speech therapy, there are a few technologies that can be used, since the target people usually have motor and mental limitations. The lack of software and technologies designed for people with disabilities limits the choices in what concerns development and stimulation of speech.

Alternative communication is used whenever a person cannot use the standard communicating protocols, but the available alternative communication technologies are often not adequate to people with cerebral palsy, due to their motor control limitations. The APCC points this as an important lack in available resources, since professionals often end up developing amateur techniques for this purpose.

2.2 Diabetes Mellitus

Diabetes Mellitus is a pathology that affects the glucose blood level as a result of a deficient insulin secretion by pancreas, or correct secretion but the organism cannot recognize the produced insulin. A high level of glucose in the blood may deteriorate tissues and organs. Long term consequences of uncontrolled diabetes are retinopathy with potential loss of vision, peripheral neuropathy that may originate ulcers and required amputations, and autonomic neurophaty which is generally related to several dysfunctions, such as gastrointestinal, cardiovascular and sexual.

As a consequence of the inability of the system to produce efficient insulin, diabetes patients have to regularly rebalance insulin amounts, by invasive techniques. There are two main used techniques: insulin pumps, that remain in the patient organism and regularly release insulin amounts on the blood, and insulin pens, which are used directly by patients to inject insulin to bloodstream in arbitrary moments.

2.2.1 Requirements Identified

The two fundamental needs identified with professionals that work closely with this pathology are the remote traceability of patients with insulin pumps, and a method to correctly count macro-nutrients present in the food, since insulin injections have to be coordinated with eaten food.

Patients with insulin pumps usually carry a device constantly measuring blood sugar level, enabling them to supervise this level and to take action whenever it is irregular. The inconvenience here is that, when patients are children or elderly people, that control may not be properly performed, and so a caregiver has to control the evolution of blood sugar level. An extremely low level of sugar in the blood may lead to a deficient income of glucose in the brain, compromising the well functioning of the system, which may occur if the person does not eat properly, or the dose of insulin injected is not correct.

Another necessity identified by professionals that work with diabetes mellitus in CHUC is the automated estimation of macro-nutrients amount in the food. Currently, patients have to estimate this quantity to inject the correct insulin dose in the organism, this estimation is however dependent on person abilities to estimate correctly, and thus considerable error may be taken. Automated estimation can be done by means of a smartphone-camera and computer-vision algorithms.

2.3 Blindness

Blindness is the condition of limited vision capacity that may have various origins, among the most relevant are trauma, disease, malformation and poor nutrition. People that grow up with blindness usually adapt easily to that condition. Otherwise, people that acquire blindness as adults have severe difficulties. The ACAPO association intends to provide assistance to both types of blind people, and specially to enable them to have a job and to integrate actively into society.

2.3.1 Requirements Identified

Several limitations on the resources available to blind people were identified by professionals that work with the blind people, ranging from domestic environments to huge public spaces. Specifically, and taking into account the available resources of this project (time and people), four scenarios of possible intervention were defined.

1. **Domestic appliances**: The emergence of touch devices deprives blind users to have full and comfortable access to home appliances and devices. There must be a way to enable blind people to have modern appliances and still be able to fully access its functionalities.

2. **Computer access**: Usually, blind people use screen readers and voice synthesizers to access computers. In the particular case of web pages, the screen reader cannot identify and read images and buttons as images, limiting access of blind people to the available information there. Another important feature is the structure of web pages, as the screen reader is not enabled to identify major structures on the page, the user may have to listen a lot of useless information before reaching the target.

3. **Mobility**: A strong limitation of blind people is the autonomous navigation, as they cannot identify obstacles, danger or signaling along the path. Currently, blind people use white canes and guide dogs to assist navigation, however they are not enabled to navigate through unknown routes.

4. **Accessing public spaces**: On the road, blind people have to be aware of the traffic, semaphore signals, crosswalks positions and other import-

ant information by alternative methods. There are already some semaphores with sounds signals and some crosswalks with signaled with ledges on the ground. Concerning public buildings, there is a lack of signaling adapted to blind people, therefore blind people cannot go to those places without third party help.

2.4 Definition of Thesis Project Scope

Within the available areas of action, for this project it was chosen the blind people issue of going to a supermarket. An initial project proposal intended to build a system that provided assistance to blind users on going to the supermarket, finding specific products and traveling autonomously through the store. This proposal was presented to the ACAPO association and in discussion it was changed to the final and developed project presented with this thesis: assistance on accessing shopping centers.

Although necessary and an important lack in blind people's life, going to a supermarket concerns a public issue, since some changes would be required to stores structure and maybe to each product fabrication. However blind people are not totally deprived from independent shopping since they can shop on the Internet.

Chapter 3

State of the Art

In this chapter we investigate two main issues: assistive navigation and shopping technologies to support blind people and indoor positioning techniques. The first section is a review of technologies designed to support blind and partially sighted people for navigation, shopping, and navigation and shopping together. The second section reviews indoor positioning. In this thesis we use existing technologies and mechanisms, instead of creating entirely new solutions. However, the issue deserves future work, not only concerning improving existing approaches, but also to embed them into the requirements of our system, and eventually improving the mechanisms so that they would be able to deal effectively with our scenario.

3.1 Assisted Navigation and Shopping for Blind People

On the spectrum of tasks and needs of visually impaired people, navigation plays a fundamental role, since it enables, or disables, the person to independently move or safely walk. The dynamic environment easily perceived by visually enabled people is an everyday challenge for blind people, relying only on the hearing and touch. For help on walking trips, visually impaired people often use white canes and dogs, intending to detect obstacles and danger.

Another challenging task for these people is independent shopping. In most supermarkets information about products is only presented for visually enabled people, making blind people dependent on others.

This section provides an overview over a few technologies specially designed to support blind and partially sighted people tasks, in particular navigation and going to the supermarket. Assistive technologies, as we call them, were divided into three categories: Navigation Systems, Shopping Systems and Navigation and Shopping Systems. The third one concerns technologies intended to help users in both tasks, navigation and finding wanted products.

3.1.1 Used Technologies

This section is composed by an overview of a few technologies used to help visually impaired people.

EPC and RFID

Radio Frequency Identification, RFID, is a method of automatic identification by radio signal. A tag identifies and object and is able to respond to radio signals from a radio waves transceiver[1]. Tags can be active or passive: active tags have external power supply and therefore a greater range. The Electronic Product Code, EPC, is a universal identifier designed to be stored on an RFID tag.

[1]A device that can transmit and receive communications.

UPC, Barcode and QR Code

The Universal Product Code, UPC, is the foundation of EPC. UPC is a barcode symbology that stores information within black bars and white spaces. There are a lot of UPC types that can be used for many different applications. An innovation to those codes are the Quick Response codes, QR, that can easily be deciphered by a mobile phone with camera. Those codes usually store text information, numbers, geographic coordinates or other information.

Bluetooth, ZigBee and Wi-Fi

Bluetooth is a wireless transfer technology of a small range widely used on mobile phones, computers and accessories. ZigBee is another wireless communication technology used between devices, known by its low powered operation and long distance range.

Unlike Bluetooth and ZigBee, that are personal area networks, Wi-Fi is a local area network with wider range and enables devices to exchange data or connect to the Internet using radio waves.

GPS

The famous GPS standing for Global Positioning System, is a satellite based positioning system, enabling to specify the position of any point on the earth's surface with an unobstructed line of sight to four or more GPS satellites.

GSM

The Global System for Mobile Communications, GSM, is the standard used by mobile phones. GSM operates in the 900MHz or 1800MHz for the second generation networks, 2G.

Infrared and Ultrasounds

Infrared radiation is part of the electromagnetic radiation with longer wavelengths than visible light, 700 nanometers. Infrared radiation is widely used on remote controls of televisions and other devices.

Ultrasounds are sound waves with a frequency greater than the human hearing range, approximately 20kHz. Ultrasounds are often used in medical imaging and on boats to calculate distances.

Voice Recognition and Speech Synthesizer

Voice recognition software is used to convert speech to words. Several software can be used for this purpose, the choice of the best to use depends on the application features.

Speech synthesizers execute the opposite operation, converting from words and sentences to speech.

3.1.2 System Requirements

Several features must be taken into account when considering to design an application, device or system for visually impaired people. The requirements here presented were defined with basis on the support literature. We concluded that a system intended to provide autonomy to blind and partially sighted people has to accomplish the requirements presented in table 3.1.

Providing assistance to reach the entrance of the building, R1, is a commonly neglected issue when developing a system for this audience. If the user needs third party help to reach the public building entrance, he will more likely use that help indoors as well. For example, integrating a GPS guidance

Access to the Building	R1
User Positioning	R2
User Guidance	R3
Obstacle Detection	R4
Existing Technologies	R5
Minimal Env. Adjustments	R6
Easy Portable Device	R7
Desired Products List	R8
Product Finding	R9

Table 3.1: Requirements used to evaluate the proposed systems.

system on the application enables the user to reach the building if he does not know well the surrounding environment, in this case R1 is almost filled, since GPS does not provide an acute localization, but if the system requires identification of the door, it is perfectly accomplished. For systems that only focus on indoor navigation, R1 is considered null.

User positioning, R2, is an important aspect when the user gets lost or exits the predominant system acting zone, that may be the area where the embossed orientation system on the floor is implanted. For a system permanently aware of user's position, R2 is perfectly accomplished, and for a system dependent on the user guidance skills this requirement is barely or not even accomplished.

Although blind and partially sighted people already own several orientation and guidance abilities, we considered that a system providing guidance help must be better rated. Therefore, the requirement R3, User Guidance, is fulfilled when guidance instructions are given the user. Otherwise, a system that simply identifies if the user is in the desired point has R3 null.

Once again, like navigation skills, obstacle detection is a second feature, regarding that blind people already have several obstacle detection skills. A system provided with obstacle detection, R4, is presented as a more pleasant system once user will have support to this common task. A system without any support on detecting obstacles or danger on path has R4 null.

R5, existing technologies, is related to use of devices and technologies that people already own and know how to operate, either blind or not. A system using new technologies, like robots and devices that need to be produced will have this requirement null or slightly filled. On the other hand, a system using, for example, barcodes that the store already uses to identify each product and a personal cell phone that the blind user already uses will have R5 fully accomplished.

Minimal environment adjustments requirement, R6, is related to technologies, devices or structures the building has to install to enable users to use the application or system. For instance, a system based on vision will maximum grade to R6, and a system that requires RFID implantation on every product of a supermarket will have low grade because there are a lot of work and investment to do.

The size of the device user has to carry, R7, is another considered requirement, a smaller and weightless device will be a more agreeable device. Otherwise, if the system may be used from the cell phone that user already uses, we considered this requirement is filled, since he does not have to carry another device, the application/system will run upon a device the user is accustomed to carry. If, on the other hand, the system relies in a computer the user has to carry, R7 is null or barely achieved. So we named this requirement as easy portable device, allowing to include the device size and if it is new, or not, to the user.

The last two requirements refer specifically to shopping environment: it is important that the user can easily find the desired product by receiving instructions that lead to it, R8, and that the product found is exactly the one user intends to acquire, R9. The desired products requirement is filled when the application enables the user to specify a product, or list of products, and then receives instructions to reach the product. Another situation is really finding the specified product, the system may guide the user to the vicinity of the product but does not provide him instructions to find the product the indicated, in this case R9 is null and R8 is achieved. And if the system enables the user to identify doubtless the product he grabbed, but does not allow the user to skip grabbing all products to find the desired one, R9 is achieved and R9 is null.

3.1.3 Proposed Navigation Systems

RFID Based System 1

The environment must be covered with RFID tags and the objects intended to be found too, allowing the user to travel through the space and to find those objects[70]. Each tag is documented on a database and has a corresponding voice recording or text data that will guide the user. The user has to carry an RFID reader device and a earphone, and the information travels via middleware: the RFID reader collects the tags on the vicinity and sends their identity code to the remote computer which will process the information and send the movement instructions to the user via earphone. The database is implemented on the server and can easily be modified, making each update available to all users. The remote computer, earphone and RFID reader must be in permanent wireless communication.

This proposal ensures user positioning and guidance, but relies on user abilities to detect obstacles and avoid them, so only R2 and R3 are perfectly accomplished and R4 is null. Since the building and products have to be covered with RFID tags, R6 is null and R5 is minimally achieved because the technology used is already commonly known, and so the system does not provide assitance to reach the building, R1 is null. We considered R8 and R9 as accomplished since the user is enabled to indicate a desired destination or product, among the documented by RFID tags, and be lead to it. R7 is almost achieved considering an earphone and a RFID reader are not very uncomfortable to carry.

RFID Based System 2

S. Chumkamon proposes a system with three subsystems: the track infrastructure, the navigation device and the navigation server[22]. The first one is related to the RFID tags network, it intends to place tags on a tactile orientation system on the footpath, which is used by visually impaired people for orientation. The navigation device is composed of an RFID reader, a microprocessor, a communication module, a user interface and a memory module.

When the user wants to start the navigation, the communication module of the navigation device asks the navigation server, via GPRS network, for a route and stores the information received. This way, communication with the server is only required on the route start or when the user wants to start a new one, or gets lost.

Since this system relies on the tactile orientation system with implanted RFID tags, it barely accomplishes R1, assuming the tactile orientation is user to reach the door, R5 and R6, assuming the tactile orientation is not a common method used and is not already installed on the building or space, and R7, because the user's device is completely new and has considerable dimensions. The system intends user guidance at least in the decision points, so R3 is achieved. Obstacle detection relies on user's abilities, so R4 is null. And being this system designed to navigate assistance R8 and R9 are both null.

RG

Robotic Guide, RG, is a robot that guides the user through a route, it is intended to assist users in navigating unknown environments[43]. Indoors navigation is performed by potential fields and by finding empty spaces around the robot. Potential fields is an algorithm that calculates robot motion by attracting it to the desired end and repulsing it from obstacles. This technique enables the robot to follow corridors without orientation sensors. RFID tags are used for navigation and for robot location.

This system has the advantage of not requiring a global map of the environment to navigate, the last position is always stored on the connectivity graph and precise locations are known when the robot receives an RFID tag.

Although the RG is enabled to navigate in unknown environments, R5 and R6 are not fully achieved because the robot is a completely new device and it is not enable to localize itself without RFID tags, and so R2 is almost accomplished. Obstacle detection, R4, and user guidance, R3, are achieved since the robot is enabled to perform that. Access to the building requirement, R1, is barely achieved considering the robot is capable of detection of entrance structures. As the previous system, R7, R8 and R9 are null.

BlindAid

RFID based system composed of a portable RFID reader in communication with an as well portable computing device, such as smartphone[52]. Users location and route to a destination are calculated based on prepared map data. An effective tags placement enables user localization everywhere and direction of travel calculation in order to plan route and deliver the right instructions to the user. Path calculation is performed by Dijkstra's shortest path algorithm.

User inputs may be received through voice instructions or using buttons on the device.

Since the system enables user positioning and guidance, R2 and R3 are accomplished. R1 is not filled since the system works only where RFID tags were placed, and R6 is also not because it is necessary to install a lot of RFID tags. R5 is almost achieved, since RFID technology is somewhat common. Once this system relies on user skills to detect and avoid obstacles, R4 is null. R7 is almost achieved since the system enables the user to use is own smartphone more an RFID reader device. R8 and R9, as said before, are related to finding a specified product, so are null for this system.

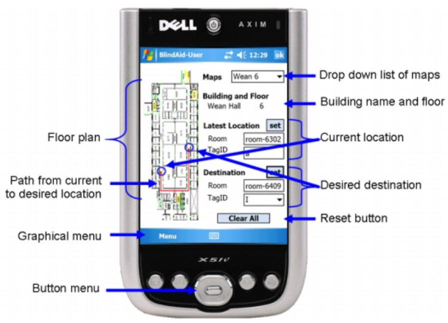

Figure 3.1: BlindAid, assisted indoor navigation system for blind people.[52].

Smart-Robot

Smart-Robot is a robot proposed for indoor and outdoor navigation[72]. Indoor navigation is performed using RFID technology and outdoor by GPS. The robot is equipped with an analog compass for orientation, ultrasonic and infrared sensors for obstacle avoidance, a speaker and a vibrating glove for instructions delivery, and a keypad for user inputs.

Destination is recorded by the keypad and the robot performs navigation always checking for obstacles on the way. Indoors the Smart-Robot travels close to the wall where it finds best RFID signal intensity.

Assuming an environment equipped with sufficient RFID tags, and assuming the precision of GPS, this proposal was rated with maximum for the requirements 1 to 4, since the robot performs indoor and outdoor navigation assistance detecting and avoiding obstacles. Once it is a whole new device the user has to carry and that the building has to be equipped with RFID tags, R5, R6 and R7 are partially or non accomplished. As the Smart-Robot is intended only to help on navigation, R8 and R9 are null over again.

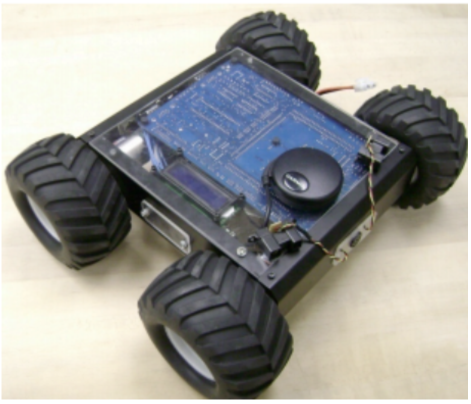

Figure 3.2: Smart-Robot, assisted indoor and outdoor navigation system for blind people.[72].

GPS Based System 1

This system integrates a mobile phone with camera and GPS technology, and motion and magnetic induction equipment[91]. The aim is to provide information to travel a specific route calculated for the system regarding user desired destination, this will comprise traffic and obstacle information.

Localization and route calculation are based on GPS, the mobile phone enables permanent user positioning and orientation and motion are received by the motion and magnetic induction equipment. Obstacle information will be detected through mobile phone camera.

Although it is known that GPS technology does not deliver precise positioning information, in theory the proposed system performs perfectly R2, R3, R4 and R6. As this system is intended for outdoor navigation, it can not really be compared to others, therefore it will not appear on the final comparison table. Other navigation requirements, R1, R5 and R7 are almost accomplished, as the user will have to carry a device in addiction to the mobile phone, the motion and magnetic induction equipment.

GPS Based System 2

A similar system has a built in navigation map used for route calculations, using a weighted graph. The GPS system is used for user positioning and frequent actualization of the route and instructions to deliver to the user. The navigation device is composed of a power supply module, a mobile communication and positioning module, a voice module, a processor module and a blind people input keyboard[78].

Once again, due to the GPS limitations this system was evaluated on theoretical terms and will not be presented on the final classification. However it can be said that the system accomplishes R2 and R3, since GPS system enables positioning and guidance. R1 and R4 are not filled because the system relies on user skills to detect obstacles and buildings entrance. As the user device is not one that he already owns, R7 is merely filled. Due to GPS characteristics, R5 and R6 are perfectly accomplished.

Ultrasounds Based System

The present system uses ultrasonic technology to detect whether are obstacles in front of user and if they are moving or may be dangerous. The user devices embodies the information processing equipment, a micro-controller, an ultrasonic transmitter and receiver and the alarm apparatus, sound and vibration. The micro-controller is simultaneously in connection with the information equipment and the alarm apparatus, thus the information equipment is connected to the ultrasonic device[98].

The ultrasonic transmitter emits ultrasonic waves that are reflected by the environment, and thus obstacles, and the ultrasonic receiver receives the reflected waves. Then the information processing equipment processes the signal and calculates obstacle distances and motion information (moving or stationary, and moving slow or fast). Micro-controller has to deliver right alarms: fast and slow moving obstacles through sound and vibrations for different levels of warning.

The presented system only helps the user on his/her arbitrary path, thus requirement R2 is rated null, and R1 and R3 are slightly accomplished once the user is informed on obstacles and dangerous areas on the environment. The user is enabled to use the system on any environment, thus the R6 is perfectly accomplished. As the device is new to the user, R5 and R7 are merely filled. The two last requirements are not accomplished since the system does not performs product findings.

Mobile Phone Based System

The system presented here intends to provide information about public transportation normally only available visually through posters or informative signs, and to provide users orientation inside a building or public space[83].

The proposal is available anywhere through a simple voice call from any mobile device.

Orientation and navigation is performed by a discrete and non-obstructive system of acoustic emitters that with user interaction is able to know users position and to calculate a route to the desired point of interest.

This system fills R3, R5 and R7, once the only device user needs is his own mobile phone and the used technology is the sound emission. R2 is almost accomplished since the system relies on user abilities to indicate is actual position. Access to the building and obstacle detection relies on user abilities, so R1 and R4 are null. The environment must be provided with sound emitters, R6 is almost zero.

Vision Based System

User device are acrylate protective glasses holding two cameras that transmit video streaming to the operator via Wi-Fi[71]. Operator sees the context of environment 3D so can estimate distance of obstacles. With a joystick the operator handles the choice of the audio sample heard by the user in the memory of a portable computer he is carrying. Instructions to user's guidance are artificially generated simulating virtual source of an audio signal. A drawback of the presented system is the frame rate and size of images, the achieved was 15 frames per second and 640x480 pixels.

Since the system is based on stereoscopic vision, there are no environment adjustments and the requirements R1, R3, R4 and R6 are perfectly provided. R2 is partially accomplished since position can ambiguously be known from users vicinity images. R5 is considered null once the user as to use a new device and there must always be an operator available. R7 is merely accomplished considering the dimensions of the glasses.

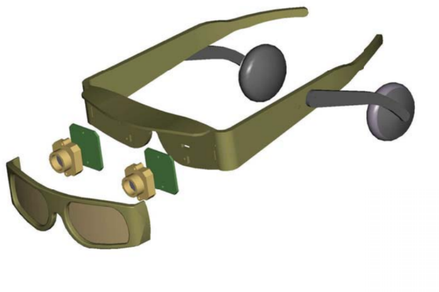

Figure 3.3: Prototype proposed to assist navigation of blind people by remote access.[71].

3.1.4 Proposed Shopping Systems

This systems are intended to perform help on supermarkets by finding products, therefore all system presented in this subsection have R1, R2, R3 and R4 null. Positioning and guidance are approached in other subsections.

Voice Shopping Guide

This system places voice emitters near the products on the shelves that displays information when the blind user approaches them[89]. Infrared sensors are used to detect the proximity of blind users, that proximity distance ranges since 10cm to 50cm. Information displayed can introduce the section the user just entered, or identify product types in the user's vicinity, and can be easily changed anytime to adapt the environment changes.

R5 and R6 are somewhat accomplished since that the major technology used is sound informations and the required changes on the environment will depend on the level of specification intended to achieve. Requirement R7 is fully accomplished, once user does not need to carry any device to use the proposed system. Although the system can provide much information, the user will rely on his skills to have sure he has the specific wanted product, so R9 is almost filled.

GroZi

A different proposal is the presented by GroZi[54][69][81] project. This proposal is composed of a web site for wanted product's list creation, a computer vision software for products recognition in stores and a portable device that can execute computer vision algorithms and give the user haptic and verbal feedback. The user compiles a shopping list of products and uploads it on the portable device. In the store, the user wears a hand glove with a small camera and vibrating motors to point aisles, the application will return information about products there and instructions to find the desired product. When a product on the shopping list is detected in the video stream, the application will give the user either haptic or verbal instructions to reach it. GroZi uses *in vitro* and *in situ* images: the first are taken under ideal lighting and perspective conditions, the second are obtained from video streams in the store.

This proposal accomplishes the desired products list, R8, and the minimal environment adjustments requirement, R6, since it relies on images and allows the user to specify wanted products before go to the store. R9 is almost accomplished once the system does not indicate where the products are, only tells what is the product the user is pointing at. R5 is somewhat filled because it only is needed on the user's side, and because it is only a glove, R7 is almost filled.

Barcode Based System

The system is based on barcode recognition: barcodes on vision range of the user are detected, thus using code information and known location the user is informed about commodity regions, products arrangement, and name, trademark and price of a single product[93]. Barcode identification comprises a set of image processing steps, such as filtering to noise and texture detection.

Since supermarket products are already identified by a single barcode, R5 and R6 are perfectly accomplished, and assuming the system can be implemented on a simple device, or even on the smartphone, R7 is almost fulfilled. The user's device will encompass a camera, and can be the user's phone, so R7 is nearly accomplished.

QR Code Based System

This proposal is implemented on a smartphone equipped with QR code reader software[1]. The user uses the mobile phone to scan QR codes on products, the device will connect to internet and a verbal description of the product will be delivered. To enable blind people to find the QR code, its location is marked with a Braille seal.

As the previous systems, the presented here is designed only to products identification, and so R1 to R4 and R8 are null. The system relies on user's smartphone, so R7 is accomplished and R5 is approximately. Considering the products are not yet equipped with QR code and Braille seals, R6 is barely filled. R9 is perfectly accomplished once the user is enabled to receive information about the unique product he is holding.

RFID and EPC Based System

An EPC-RFID combined system was proposed by Sreekar Krishna[42]. A RFID reader collects the EPC code from the products on the shelves as user approaches them, and the product's information is accessed by user's PDA[2] or smartphone and delivered to the user via synthesized speech. The users device communicates with the central server in the supermarket through

[2]Personal Digital Assistant.

Internet. Central server is essentially a relational database with information of all the products which performs the task of associating EPC sent by the portable computing device to a unique product's information. The interface between the user's device and the database is implemented as a middleware layer. RFID reader is mounted on a bracelet and ensures Bluetooth communication with the user's device.

R5 and R6 are not merely accomplished, since the system requires EPC identification allocated to all products. Since the user's device is the personal smartphone or PDA, R7 is achieved. R9 is accomplished, since the product is identified by an unique EPC. R8 is merely filled considering the information received about products can lead the user to the wanted product.

Trinetra

Trinetra is a solution based on RFID and UPC identification[46]. One of the requirements while developing the solution was that the blind shopper should not need to ask for assistance from anyone. Trinetra is composed of an Internet and Bluetooth enabled cell phone, text-to-speech software and a portable barcode reader. The shopper's phone receives information from the barcode reader, RFID reader or keypad; the first two are via Bluetooth. When an identifier is received, phone application matches it with a most recently used identifiers looking for a match; when no match is found, phone communicates with the server via TCP[3], the server will match the identifier with all product identifiers available in the store. Once a product is identified, its description will be returned to the user. Information is delivered to the user via synthesized speech.

Although this solution identifies well each product, it does not allows the

[3] Transmission Control Protocol, protocol used in Internet.

user to navigate autonomously within the store, and so only R9 is fulfilled. R5 and R6 are almost accomplished regarding which when the environment does not is provided with RFID tags, the UPC identification prevails. User will have to carry an RFID reader, but the system also relies on user's smartphone, so R7 is almost filled.

3.1.5 Proposed Navigation and Shopping Systems

Virtual Walking Stick

This system intends to allow detection of obstacles, identification of colors, recognition of products/objects by barcode or RFID reading, orientation, reproduction of audio content, signaling the user on dark environment and recognition of letters, words or sentences through a digital camera. This device is aimed to provide as much information as the user may need, since date and hours information to points of interest in public spaces, replacing the traditional white cane by a stick with technology that collects information about the environment without having to physically touch objects and obstacles[99]. Ultrasonic sensors are used for obstacles and depressions detection (R4) and alarms or warnings are delivered by vibrations and sound alerts. A digital compass and a GPS system are installed for outdoor navigation and positioning information. Product recognition is enabled by digital camera or RFID reader and a wireless connection to an existing database on the establishment, which delivers information about the product/object.

As this presented virtual stick provides a lot of information about the surrounding environment, R1 is almost filled. Since GPS system is used for positioning and guidance, although GPS limitations, R2 and R3 are both almost achieved. R5 is null considering the user device comprises some different technologies and the environment must be changed, namely for integrate RFID tags, so R6 is not filled too. As this system intends to replace the white cane that blind users are used to use, R7 is not accomplished as well. Once it enables recognition of products through the camera or RFID identification, R9 achieved.

BlindShopping

BlindShopping is an RFID and QR-code based mobile solution[51], that demands inexpensive off-the-shelf technology. The products are grouped into different categories, and these are divided into product types which are separated into concrete brand products. The supermarket surface is mapped with cells containing shelves and passageway cells, and RFID tags are distributed throughout the floor creating an RFID map. BlindShopping maps the IDs of the RFID tags within a cell to navigation and product localization, instructions are given to the user through voice messages. Once in the target aisle, this solution offers support for product recognition by shelf section identification, by QR code, product own ID, or barcode scanning. The user will use personal smartphone and the supermarket must have a wireless network and server installed. RFID readers, attachable to the white cane, are lent to visually impaired clients by supermarket.

Once the floor is mapped with RFID tags, user's position is always known, R2 and R3 filled, R1 is null because the system only works where system is mounted. Obstacle detection relies on user abilities, so R4 is null. As the system implies the deployment of an RFID web to user's location and QR codes on the shelves for products identification, R5 and R6 are minimal. User's device is his own smartphone and an RFID reader, so R7 is almost accomplished. R8 and R9 are almost both filled once the user is enabled to specify a wanted product and be guided to it, but he can not specify a list of products in one time.

Figure 3.4: RoboCart, assistive technology to support blind people on supermarkets.[44].

RoboCart

Another solution uses a robot to help the visually impaired costumer to find wanted products. RoboCart[29] presents to the user a product selection interface, when confirmed the selection guides him to the vicinity of the product. Once there, RoboCart uses the user's egocentric frame of reference to find the product and a barcode reader ergonomically modified to help the alignment with the shelves, where the products barcodes are placed. The floor of the store is converted into an RFID-enabled surface, where each RFID tag had its 2D coordinates. This RFID tags are used as recalibration areas, when the robot reaches a recalibration area its localization is well known.

Two drawbacks of RoboCart are that the user has to scan all barcodes until reach the target one, R9, and he can completely miss the barcode he is looking for and never find the product. As the user's device is a robot that needs an RFID map, R5, R6 and R7 are not accomplished, and R2 and R3 are perfectly filled as the RFID identification enables constant and precise positioning. Obstacle detection is up to the user so R4 is not achieved.

ShopTalk

Nicholson proposed the ShopTalk[57], a system composed of a processor, a numeric keypad and a barcode scanner. ShopTalk guides the user to the vicinity of the target product with vocal instructions about route directions and descriptions of the store layout.

Figure 3.5: ShopTalk, assistive technology to support blind people on supermarkets.[57].

The topological map of the store, used for route calculations, is a directed graph whose nodes are decision points like aisle entrances or cashier lane entrances. Route directions are constructed from a database of parametrized route directions, and the keypad is used to set instructions as done, the system is unaware of the shopper's actual location and orientation. The barcode scanner was modified with stabilizers to align more easily with the shelves where the product barcodes are, beneath products. The key data structure that associates barcodes with aisles, aisle sides, shelf sections, specific shelves and relative positions on the shelves. This matrix is used to generate the store navigation and product search instructions. Users location can be known once he/she scans a barcode on an aisle, allowing the user to use the system even if he/she gets lost.

Due to the inability to know precise user's position, R2 is only half accomplished, since the system will know his position once he scans a barcode. R3 is filled as the user is guided to the vicinity of the wanted product, but relies on user's sensory ability for obstacles detection, so R4 is null. The system comprises a whole new user device, R5 is null and R7 is barely filled, and uses barcodes on the shelves that may already exist, so R6 is somewhat achieved. Once the user can specify the desired product and actually find it, R8 and R9 are almost accomplished.

ShopMobile

ShopMobile is an updated version of ShopTalk, that runs on a mobile phone. A vision-based barcode scanning method[41] is proposed. Once again are applied stabilizers to help the VI user align the camera with shelves, where product barcodes are placed. The system finds barcodes in images: when part of a barcode is detected, instructions are given to slide the phone along the shelf in one specific way. Once the target barcode is reached, the user takes a product from the shelf.

This system has better grade than ShopTalk, being improved on R7 and R9 that here are completely accomplished.

3.1.6 Technologies Comparison

Comparison of presented systems is divided into two categories: navigation systems and shopping assistive systems. Table 3.2 compares systems that perform navigation assistance, and table 3.3 systems for assistance on shopping.

Related to navigation assistance, the proposed systems with best grade are those intended for outdoor navigation, the Virtual Walking Stick and the

System Proposal	R1	R2	R3	R4	R5	R6	R7	R8	R9	Total
Indoor Navigation										
ShopMobile	0	3	5	0	0	3	5	3	5	24
RFID Based System 1	0	5	5	0	1	0	3	5	5	24
BlindShopping	0	5	5	0	1	0	4	3	5	23
ShopTalk	0	3	5	0	0	3	2	3	4	20
Mobile Phone Based System	0	4	5	0	4	1	5	0	0	19
RoboCart	0	5	5	0	0	0	0	3	4	17
RFID Based System 2	2	4	5	0	2	2	2	0	0	17
RG	2	3	5	5	0	2	0	0	0	17
BlindAid	0	5	5	0	3	0	4	0	0	17
Outdoor Navigation										
Virtual Walking Stick	4	5	5	5	4	5	3	0	0	31
GPS Based System 1	4	4	4	5	0	3	3	0	5	28
GPS Based System 2	0	5	5	0	5	5	2	0	0	22
Indoor and Outdoor Navigation										
Vision Based System	5	3	5	5	0	5	2	0	0	25
Smart-Robot	5	5	5	5	0	3	0	0	0	23
Ultrasounds Based System	4	0	2	5	2	5	2	0	0	20

Table 3.2: Proposed systems comparison table, considering navigation assistance.

GPS Based System 1. A reason for this classification is the considered GPS precision, it was assumed that GPS system provides accurate positioning information. However it is already known that GPS have an error of a few meters, for pedestrian navigation that is a wide error. And so, for indoor navigation, which means more accuracy, the list is spearheaded by ShopMobile and RFID based systems. More comprehensive systems that allow indoor and outdoor navigation, although few, were all good graded.

In relation to systems intended to provide assistance on the shopping activity, RFID based systems are also on the leading ones, Trinetra and BlindShopping, but the most graded, GroZi, is based on image processing. Virtual Walking Stick is very good graded but it is not intended to shopping, it can be used there if products are all labeled with RFID tags. Another relevant technology used on this systems is barcode and QR code identification, as it is already used for products unique identification it is highly advantageous to support systems on it.

System Proposal	R1	R2	R3	R4	R5	R6	R7	R8	R9	Total
Shopping Assistance										
GroZi	0	0	0	0	3	5	4	5	4	21
Trinetra	0	0	0	0	4	4	4	0	5	17
QR Code Based System	0	0	0	0	4	2	5	0	5	16
Barcode Based System	0	0	0	0	5	5	4	0	5	19
Voice Shopping Guide	0	0	0	0	4	2	5	0	4	15
RFID and EPC Based System	0	0	0	0	0	0	5	3	5	13
Shopping and Navigation Assistance										
Virtual Walking Stick	4	4	4	5	0	3	3	0	5	28
BlindShopping	0	5	5	0	1	0	4	3	5	23
ShopMobile	0	3	5	0	0	3	5	3	5	24
ShopTalk	0	3	5	0	0	3	2	3	4	20
RoboCart	0	5	5	0	0	0	0	3	4	17

Table 3.3: Proposed systems comparison table, considering assistance on shopping.

Virtual Walking Stick ranks high on all navigation-related items, while GPS Based System 1 has the limitation that it requires totally different technologies and also ranks badly in easy portability of the device and the need for environment adjustments. GPS Based System 2 also fails to detect entry and obstacles, and is also not very portable. In conclusion, successful navigation technologies should be light, use existing technologies instead of requiring new ones, and they should help finding the place and obstacles. All failed in terms of using existing technologies and being portable. This means that there is a need for approaches that succeed in these important requirements and are useful for both indoor and outdoor navigation.

It is interesting to note that the image-processing based system (Grozi) was the one that best fitted most requirements, in particular those related to using only existing technologies, being portable and exhibiting a good recognition capability. The RFID systems that were analyzed could recognize the product, but they did not allow the user to find the product that he wants, they only identify the product currently being scanned. Generically, image-based approaches are quite promising, since they do not require products and places to be instrumented. It is also possible to think of using both alternatives.

3.2 Indoor Positioning Techniques

Indoor positioning is a complex area whose main objective is to estimate or determine specific positions indoor. Outdoor positioning is already performed, although with the known error of a few meters, by GPS. GPS cannot be used indoors due to signal attenuation through walls and structures, and due to the required accuracy of indoor localization techniques. Indoor positioning systems are used in various applications, such as location-aware services, tourism or military infantry.

The main focus in this document is the assistive technologies and systems for the blind, indoor positioning is only used to enable navigation. As part of future work, we intend to explore approaches for improving indoor localization in the presence of uncertainty which is due to limitations of beacon technology when used for indoor positioning. In this section we briefly review works on the issue of indoor positioning.

3.2.1 Wireless Technologies

Several wireless technologies can be used for indoor positioning, such as Bluetooth, RFID, infrared and ultrasound. When building an indoor positioning system, these alternative technologies must be evaluated in terms of whether they already exist in the building, deployment implications and costs, accuracy and maintenance.

Received Signal Strength Indicator, RSSI, is a measure widely used of the strength of an incoming radio signal[12], since there is some relation between RSSI values and proximity to the signal source, because the signal is attenuated along the distance. However, indoors there is a significant feature that constantly affects accuracy and feasibility of the RSSI values, that is the inevitable reflection of waves by matter (e.g. walls, windows, structures with different matter and surface, people, moving objects). Those reflections cannot be controlled and the positioning system must be strong enough to deal with it. Multiple WLAN's[4] and beacon sources can be used simultaneously as indoor proximity solutions[84], since any RSSI value can be related to distances.

Works such as [38][50][2] describe algorithms/methods to determine the position of robots/people. We emphasize [50] which divides indoor positioning into three sections: fingerprinting, triangulation and proximity. The next three sections will explain this techniques.

Paper [30] presents an evaluation of various indoor positioning systems, including infrared, ultrasounds, radio frequency, magnetic, vision and audible sound based (those technologies are thoroughly exposed in [53]). That study evaluates systems in terms of accuracy, performance, robustness, deployment cost, security and privacy.

Several studies on indoor positioning are based on Bluetooth technology, [17][28][12][73]. Works presented on [23] and [8] present a different approach using Bluetooth technology, where Bluetooth beacons on the environment have the active function of detecting user's device (the device to be positioned). The advantage of this approach is that the user's device does not have to install any specific software to be positioned. Authors of [31] shows that the accuracy obtained with Bluetooth signal is not enough for use triangulation algorithms that are required for Bluetooth indoor positioning based systems, and therefore fingerprinting is more adequate.

Indoor positioning systems based on Wi-Fi have the great advantage of buildings already being provided with Wi-Fi networks. The paper [14]

[4] Wireless Local Area Network.

presents an indoor positioning system based on Wi-Fi that is capable of robot navigation. Other positioning systems based on Wi-Fi were presented in [66][58][67][76][20][34]. K. Arai presents a fingerprinting method for Wi-Fi environments that reduces calibration effort while creating the fingerprinted map, [10].

Some indoor positioning systems relying in RFID technology were already presented on section 3.1, here are reported some works that were not intended to assist blind people, as the others. Some systems based in RFID are presented in [75][19][74][21][32][33]. The particular case of [64] is an indoor positioning system that does not require the definition of maps, the system stores and matches radio and compass signatures to record paths traversed by people, thus self-creating a map of the environment.

[4][3][62][26] present indoor positioning systems based on ZigBee technology. A fingerprinting approach is presented in [5], and on the contrary, [59] presents a system based on triangulation. A study of ZigBee RSSI properties, [37], is presented to improve the usage of this technology in indoor positioning systems.

3.2.2 Fingerprinting

Fingerprinting is a technique used to match signal characteristics to positions[50]. This technique requires a wide backstage work, several signal measures are made, usually at every possible position on the environment. An objective of this procedure is to overcome the problem of adequate determination of distance due to interference of reflections on signal measures, by storing information about signal measures in conditions similar to the usage conditions. To detect position, the signal is measured and related to the stored information about measures, that is, the fingerprinting information. The strength of the fingerprinting information will determine the feasibility of positioning, since differences between fingerprinting conditions and positioning conditions will result into different signal characteristics. The literature also shows that the orientation of the human body interfere with the received signal[7], so the fingerprinting phase should also include measures in different orientations.

3.2.3 Triangulation

Triangulation is the mathematical approach that uses properties of triangles to find intersection points, it is divided into lateration and angulation. Lateration uses distances from a point to references points, and angulation uses angles. Distances can be obtained by received signal strength indicators (RSSI), time of arrivals (TOA), time difference of arrivals (TDOA), roundtrip time of flight (RTOF) or received signal phase. Angulation are obtained with directed signals.

Trilateration is a mathematical approach, similar to triangulation, that does not involve measurement of angles[97].

3.2.4 Proximity

The core principle of proximity algorithms is to use beacons or transceivers with low range. This way, when detected, the user's position is guaranteed to be within that range. The great disadvantage of these approaches is that they usually require a large number of emitters. RFID technology is currently widely used in positioning by proximity approaches.

3.2.5 Mobile Devices

Given the importance of mobile devices nowadays, in particular mobile phones and smartphones, the development of indoor positioning and tracking systems based on those technologies presents great advantages. The main advantage is that users can use their own device to use the system.

An indoor positioning system with Android devices was developed in Faculty of Engineering of the University of Porto, [63]. This study details the usability of Android components in indoor positioning system, such as the accelerometer, compass and gyroscope. Android devices are enabled with several motion sensors, some hardware-based and some software-based. These sensors are natively used to monitor device movements, e.g. tilt, shake, rotation and swing[90]. In fact, [39] already presents a comparison of indoor positioning systems build for mobile phones, including approaches based on Wi-Fi, Bluetooth and GSM.

3.3 Progress beyond State-of-the-Art

This preliminary study supported the development of the system that is the core subject of this thesis. The purpose was to design and develop a system to support blind people when going to public buildings, in particular shopping centers. The study of the state-of-the-art of assistive technologies was divided into technologies to support navigation, technologies to support shopping, and technologies that support both.

The study of technologies specially designed for blind people enabled us to define reasonably the requirements and mechanisms that best fit blind people needs and limitations. These requirements are presented in section 3.1.2 and were used to evaluate the various technologies studied. Definition of these requirements enabled to design and project the *SmartGuia* application in a way that benefits the target users and the deployers. These requirements are related to support access to the building, user positioning, guidance and obstacle detection. From a technological perspective, the systems must use existing technologies, require minimal environment adjustments and have easy portability. Specially defined for shopping assistive technologies, they should enable the user to find the specific product of their interest, and to define a desired products list.

Simultaneously, the other course of this study analyzed indoor positioning technologies. However, the intention of this study was only to provide support for developing a simple system of indoor positioning to use in *SmartGuia*. The main conclusions of this part is that indoor positioning is a complex subject under research and that there are several technologies that may be used for this purpose. When designing an indoor positioning system, it is important to evaluate two important features: accuracy and cost. More accuracy is obtained with beacons of short range, thus requiring a greater amount to cover the whole environment. And a lower cost of deployment can be obtained with beacons of long range, diminishing the quantity required, and thus increasing the probability of errors on positioning.

Deciding which technologies to use relies on the specified accuracy of the system's function, however we can preliminarily conclude that a good approach will be to combine short range and long range beacons, therefore combining a first position calculation with local positioning calculations[45][47][65].

Chapter 4

SmartGuia: System and Architecture

In this chapter we present the *SmartGuia* system and its architecture.

The proposed system architecture follows the scheme presented on figure 4.1. This architecture is divided into five major modules: Voice Module, Information Module, Route Module, Location Module and Bluetooth Module. Each module plays a distinct and fundamental role. They are explained on the following sections, as well as the User's Guide (an assistant) that helps blind users navigate and find what they need inside public buildings.

4.1 Module Division and Integration

The five modules have specific functions and connections assigned. The Voice Module is the only responsible for users interfacing, its inputs or outputs are specified or analyzed by other modules. The Information Module deals with information related to the environment, such as the name of spaces, products or services available. Since the user defined the intended destination[1], the Route Module assumes the leading role to calculate the shortest path to guide the user through. User positioning is assured by the Location Module, that performs several calculation to estimate user position with information collected by the Beacon Module. Location is required for route calculation and to enable delivering of information about user's vicinity when needed. The last module is called the Beacon Module, is related to the beacons sensors deployed on the environment. This module has the main function of scanning beacon signals on the range of the user.

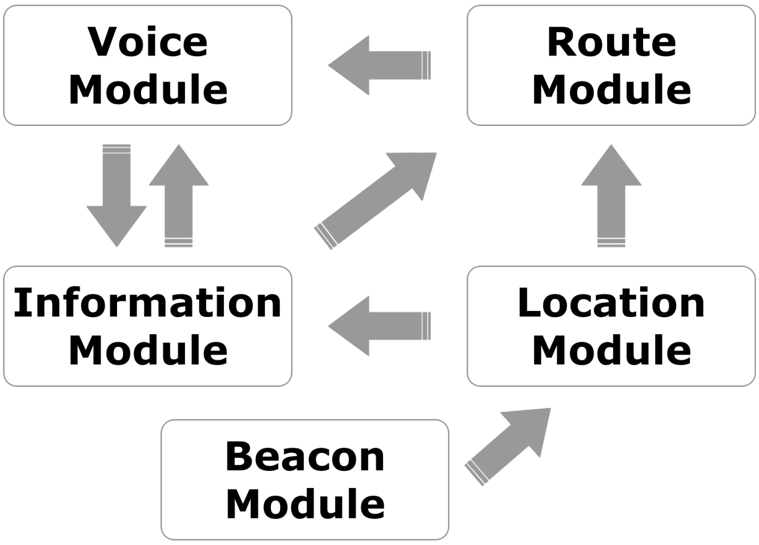

Figure 4.1: Module integration.

SmartGuia integrates the five modules and combines features and functionalities of each one. The purpose of this software is to provide assistance to blind users on selection of a destination among the points-of-interest available in the environment, and to guide them in order to reach the destination. The software uses a weighted graph with vertexes[2] and edges simulating the

[1]Point-of-interest chosen by the user as intended destination.
[2]Point on the building's environment.

environment and the passable routes, some vertexes correspond to points-of-interest which the user may define as intended destinations.

4.2 Voice Module

The main objective of this module is to interface with the blind user, converting text information into vocal instructions and vice-versa. It emphasizes the importance importance of touch independent and vision-independent interfaces for the blind. The voice interface implemented uses Android built-in tools, such as Android Text-To-Speech API for the voice outputs and Google[3] Voice Search API. Text-To-Speech synthesizes speech from text. It is used whenever there is information to be displayed. Currently, a server-client approach is followed by the Voice Module, where the voice recognizer software communicates with the Google server to process information and send it back to the user as text.

4.2.1 Voice Output

Voice outputs are performed by Android Text-To-Speech API[96][77], that synthesizes speech from text. Speech can be stored or immediately played. We have chosen to generate and immediately play voice instructions and information, since less storage space is needed and it is easier to deal with text.

Text-To-Speech engine supports some languages, such as English, French, German, Italian and Spanish, used to define different pronunciations. The latest version of Google Text-To-Speech, updated on last May 27, is used since it already supports Portuguese, albeit with Brazilian pronunciation. As

[3]Multinational corporation of online services and software.

soon as the package is updated with Portuguese pronunciation, the system will be able to synthesize with the intended pronunciation.

The Text-To-Speech Engine uses a central queue to deliver and release messages. The fundamental principle of operation of a queue is the concept of waiting list. When a new action is asked, it enters the last position of the queue, actions are performed in order of arrival. The TTS[4] enables the definition of two different methods of entry into the queue: *QUEUE_ADD* and *QUEUE_FLUSH*. The first sets the instance on the last position of the queue and the second forces the speech of that instance at the moment, even if there is another being spoken.

4.2.2 Voice Input

Recognition and decryption of user voice inputs are performed by Google Speech Input API[95], which uses an intent[5] for speech recognition. This functionality is installed on most Android devices. Voice recognition is performed by starting an activity that will prompt the user for speech and then sends the information for decryption by the engine.

Once again, as the system is built for Portuguese users, the language must be defined to Portuguese. Portuguese from Portugal is already available for usage with this functionality.

4.2.3 Additional Information

Both activities require Internet connection, since both engines use Google servers to accomplish the requests.

Another issue arises when voice recognition starts while voice synthesizer

[4] Text-To-Speech.

[5] *An intent is an abstract description of an operation to be performed*[85].

is delivering a message. That will introduce hard noise on the recognition since the stored sound tape will have both the user's voice and the device voice output. A simple way to overcome this problem is to use headphones, but this constrains the user choices. To avoid this issue, we check if there is voice being synthesized before voice entry.

4.3 Information Module

The Information Module is responsible for the analysis of user inputs and for providing every needed information about the environment. That information is stored in a complex scheme, explained later, and is personalized for each environment.

4.3.1 Information Scheme

To equip the system with information about the environment, and to enable the simple deployment on different environments, information is imported from an XML file. This file contains the information needed to identify a space, the services and products it provides, e.g. *A shop sells mans clothes*.

For importing, accessing and using the information on the XML file, a SAXParser[92] provided by Android operation system is used. SAXParser analyses the XML file row by row, without requiring the whole file to be loaded upstart. A drawback of this utility is the need to define an activity to be performed after reading each line.

Two XML files should be provided to describe a building. The Building-Topology file describes floors, points-of-interest and their location in terms of Cartesian[6] coordinates. Besides these, it relates points-of-interest with

[6]A coordinate system in which the coordinates of a point are its distances from a set

categories, which are described in the other XML input file. The Categories file describes categories and subcategories. These are a taxonomy for the services and products of interest that may exist in the building. Both points-of-interest from the BuildingTopology file and categories from the Categories file can have indication of keywords associated to them.

```
<vertex id="d3.3">
<name>ana sousa</name>
<xpos>25.4</xpos><ypos>5.2</ypos>
<floor>3</floor>
<relativePos>na extremidade Oeste</relativePos>
<orientation>0</orientation>
<categoria>4</categoria>
<subcategoria>2</subcategoria>
<subsubcategoria>2</subsubcategoria>
<tags>roupa,vestuario,saia,saias,camisola,camisolas</tags>
</vertex>
```

The code above is an example of the information present in the BuildingTopology file to a vertex.

In this loading phase, the BuildingTopology and the Categories files are loaded into a set of memory structures that represents points-of-interest, categories and keywords. These structures are built for easy querying.

Figure 4.2 shows the arrangement of information inside the system. Three main structures enable the easy access to every information needed to identify the intended destination. The first structure, composed of all vertexes of the building, enables the system to relate user's position to vertexes, facilitating the start of a new navigation or the delivering of information of

---

of perpendicular lines that intersect at an origin.

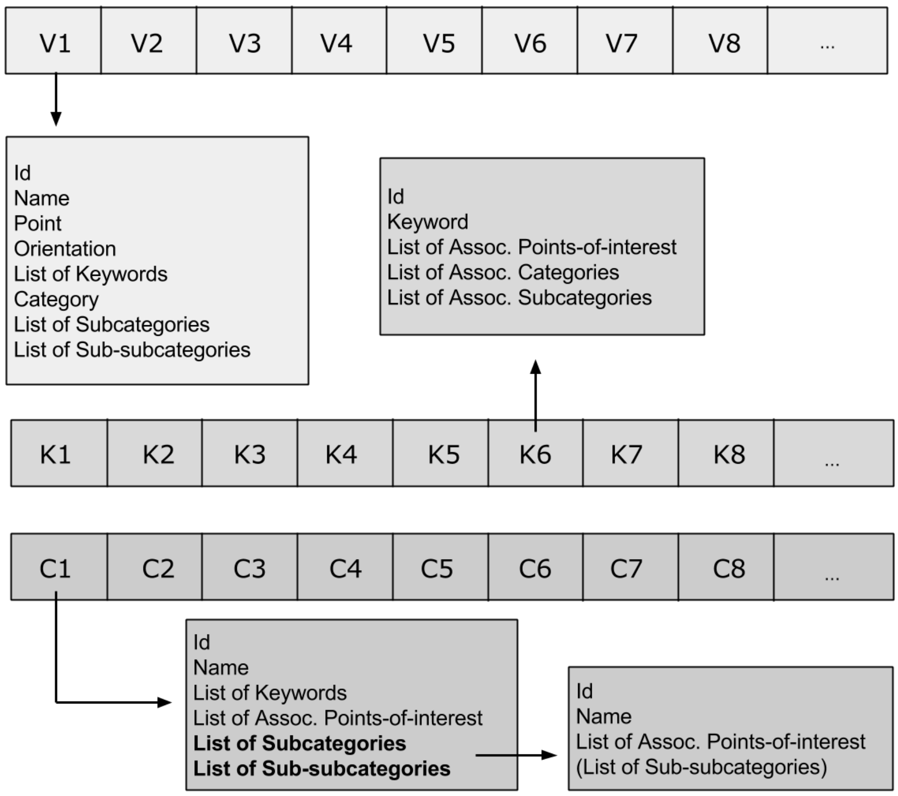

Figure 4.2: Internal organization structures.

points-of-interest in the vicinity. The seconds structure in the image stores all keywords, which are imported with the BuildingTopology and Categories files and are related to points-of-interest, categories or subcategories. This structure is used to search for related points-of-interest, categories or subcategories when the user inserts a keyword. The last structure stores the available categories and is used to deliver categories to the user, which he may choose and receive the related points-of-interest or subcategories.

Available points-of-interest and their categories are imported to the system with XML files, BuildingTopology and Categories. On a real public building, such as a shopping center, there are a lot of points-of-interest that the user must be able to choose. In order to easily find the desired point-of-interest[7], points-of-interest are separated into several categories, and those into several subcategories, and some of those into sub-subcategories.

Example

The presented system simulates a shopping center with some rooms of the Department of Informatics Engineering, so the available destinations are related to shopping environments. Nine categories were defined, such as *Fashion*, *Catering*, *Services*, *Informatics* and *Hypermarket*. Some of those categories, such as the *Hypermarket*, does not have associated subcategories, and so have directly associated available destinations. Other, such as *Services* and *Fashion*, have some subcategories associated. In the same way, some subcategories have associated destinations and some have sub-subcategories. In fact, in this system just the *Clothing* subcategory, that belongs to the *Fashion* category, has associated sub-subcategories. Those sub-subcategories are *Man*, *Women* and *Young*.

In sum, nine categories, thirty-three subcategories, three sub-subcategories, and a total of seventy three available destinations were defined. The schema defined for this work is presented on the appendix A.

4.3.2 Finding a Point-of-Interest

The function flow used to select the desired point-of-interest is diagrammed on figure 4.3. This figure presents and relates the major functions used to deliver and get information from the user.

The first function used is *getUserInput()*, as its name explains it is used to ask for an input from the user. This function prompts the user to answer the question "What do you want to find?", and the user is enabled

[7] Vertex with an assigned store or space.

to introduce any keyword. Once input is received, the information goes to *analyseUserInput()* where it is compared to the stored keywords. If the information matches a known keyword, it travels to *analyseKeyword()*. Once there, the keyword associated destinations and/or categories (or subcategories, or sub-subcategories) are displayed and a new input is prompted to the user. If the user chooses one of the presented destinations, the *selectVertex()* function is used, and the information travels to the Route Module.

If the introduced keyword does not match with anyone on the keywords database on the first place, the user is prompted to introduce a new one, or to select one of the available categories, that are displayed at the moment with the *deliverCategories()* function. Once a category is selected, the associated destinations and/or subcategories are delivered, through the functions *deliverSubcategories()* or *deliverOptions()*. Similarly, when a subcategory is selected the function *deliverSubsubcategories()* or *deliverOptions()* is enabled.

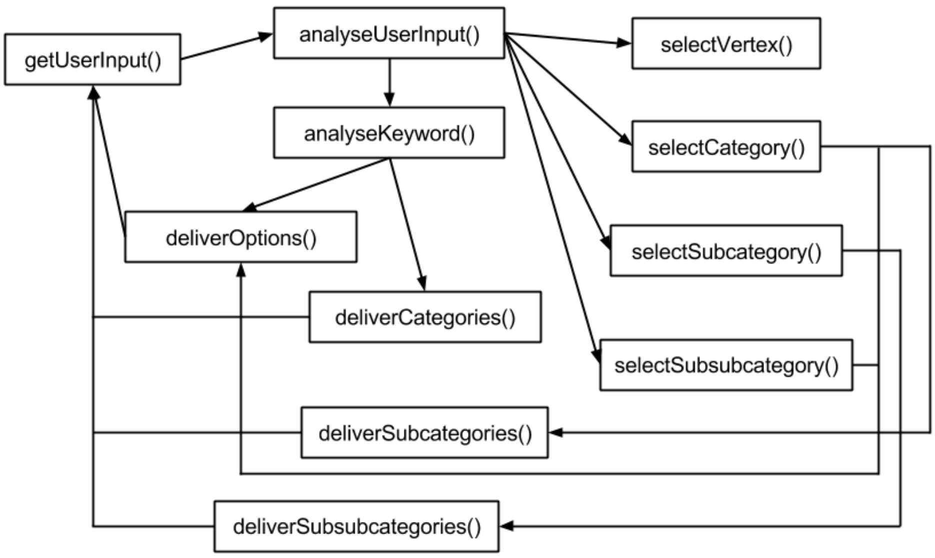

Figure 4.3: Information Module function flow.

At any prompted user input is accepted a new keyword, leading the flow to its beginning. For a simpler distinction between selection of a delivered option and the introduction of a new keyword, the user is asked to select an option by its associated number. The example of a request delivered is: "Select one of the following options or introduce a new keyword: Devernois: One, Dielmar: Two, Gant: Three, More options: 4". The option "more options" is defined to on no occasion have to deliver a list of more that three options, the objective is to make the application the most comfortable possible by delivering shorter lists of available options a time.

There are three ways to find a destination. Two of them were introduced in the previous paragraphs: by introducing a keyword related to the desired destination, and by selecting one of the available categories and subcategories. The third method is the free navigation: when the user does not select a destination, and the system is not on the navigation mode, information about the places is delivered as the user approached them.

4.4 Route Module

The main function of the Route Module is to calculate the shortest path between the actual position of the user and the desired destinations, selected with the Information Module. The building is converted into a weighted graph and each available destination is a vertex of the graph. Vertexes are linked with edges, edges represent the passable ways. The route to guide the user is calculated with the Dijkstra's[8] shortest path algorithm.

Another important task of the Route Module is the generation of navigation instructions for user navigation.

[8] Edsger Wybe Dijkstra, computer scientist, 1930 - 2002.

4.4.1 Graph Construction

As introduced in section 4.3.1, available destinations are imported to the system by the BuildingTopology XML file. That file also stores coordinates to the location of points-of-interest on the building plan.

Another XML file, Edges file, is used, an XML file with information about the edges that connect each vertex to others. The parsing of this file will create edges linking the various vertexes. Only those edges will be available for navigation, since the system will only be able to build paths along existing edges. Each edge has a cost associated to it, which is also stored and used later for shortest path calculations.

4.4.2 Dijkstra's Shortest Path Algorithm

The route between two points is calculated using the Dijkstras shortest path algorithm [24][18][55]. This algorithm uses a start vertex and calculates the distance between it and other vertexes in the graph iteratively. The iterative process stops when a minimal distance between start and end points is found. Once the user defines a destination, the system will calculate the shortest path between the users current position and the destination point. A practical use of this technique is shown in figure 4.4 in the context of Department of Informatics Engineering of University of Coimbra. Black dots and lines are respectively vertexes and edges defining points-of-interest and routes. Assuming that a user is in front of the lift 3 in the and wants to go to D3.20 office, the red route is returned by the system and corresponds to the shortest path from the lift to the D3.20 office.

Although this algorithm serves the intended purpose on this application, it has several limitations, such as that it cannot be used with negative weights

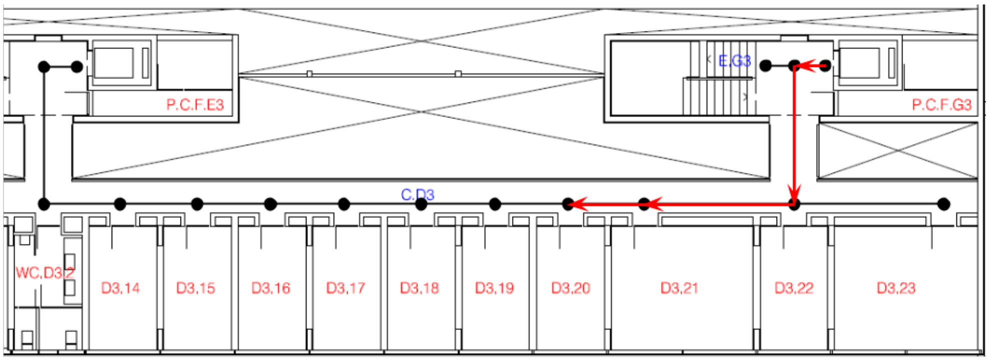

Figure 4.4: Practical example of route calculation.

or that it does not enable to find all the shortest paths[82]. The algorithm stops whenever a minimal path is found.

4.4.3 Instructions Generator

The system is designed to provide help instructions when the user asks for them. On navigation mode, the instruction delivered supports the navigation, that is, the distance to the next changing direction point is calculated and the previous navigation instruction is delivered with the actualized distance. Outside navigation mode, the help button provides information about the actual position of the user on the building. Instructions are also delivered when the navigation requires the user to change direction.

As the system does not include any device or apparatus to detect user's orientation, this relies somewhat on user's abilities to self orient. In fact, each vertex has stored a predefined orientation, that is, the system assumes that if a person starts a new navigation on a stored vertex, his/her actual orientation is the one stored on the vertex. Orientation associated with each vertex is defined as if the user is leaving the place, that is, it is assumed that the user is aware of his own orientation and that he/she has his/her back to the entry of the place.

During navigation, the direction is calculated with the coordinates of each vertex. When the user has to go forward, the coordinates of each vertex on the way have the same x or y. For each position, the coordinates of the next position are related to the current position and the previous one[9], and when it is detected that the user's route has to change direction, a new instruction is delivered without any user interaction.

4.4.4 Mental Image

System delivers a mental image of the building when a new navigation is started. This information intends to provide support on user's orientation and self-positioning on the building. As an example, the mental image for the simulated building (see appendix B) explains that the building is oriented to the south, measuring one hundred meters east-west, four hundred meters north-south, and that it is composed of three floors. After the mental image is delivered, the current position of the user is also delivered, enabling him to self-position on the building.

4.5 Location Module

The Location Module calculates user's position with the RSSI values delivered from a Beacon Module. This module is enabled to provide location with one, two, three or more RSSI's. When a precise position can not be delivered, the system delivers a known location and the estimated distance over there.

Bluetooth emitters have a precise position and the system is aware of that

[9]Current walking direction is stored and used to calculate the direction the user should take at any changing direction point.

position. A Beacon XML file with information related to emitters is parsed by the system. This XML file also contains the fingerprinting information associated to each emitter. Fingerprinting is a technique used to relate RSSI values to distance by manually recording RSSI values at different distances[10].

4.5.1 Wall Conditions

The Location Module computes locations inside a building. A building is not an open space, therefore it has walls, corridors and various structures. That information must be part of the location determination process. Given walls and other building structures, some locations computed by the Location Module may be infeasible, such as beyond walls and off the building spaces.

Wall conditions are those spacial demands imposed by structure of the building. Wall conditions are introduced to the system by a Walls XML file, and are defined by two major means:

1. A minimal or maximal coordinate, such as x or y, to a specific floor.

2. And a range of available coordinate values for a specific area.

4.5.2 Location Algorithm

Figure 4.5 describes the function flow of the location algorithm. Prior to navigation it is necessary for the system to load the location and identifiers of beacons and wall conditions (1, 2, 3). During navigation, the beacon's RSSI's and identifiers received from the Beacon Module are matched with the information collected in 1, 2 and 3. If none of the scanned signals matches known emitters, the position cannot be estimated, therefore the algorithm returns "Unknown Position" (A). If one match is found, the module first

[10] See section 3.2.2.

determines the distance to the emitter. If that distance is less than γ (2 meters by default), the location algorithm returns an assumed position of the person (B) corresponding to position of the beacon, therefore assuming that the user is standing by the beacon. This is also the idea associated with proximity beacons. Proximity beacons are beacon with a short range, so that, when they are detected, it is assumed that the person is standing by the beacon. If the distance is larger than γ, currently the algorithm returns "Unknown Position" (A), since the significant distance to the beacon means that the person could be in quite disparate locations (theoretically, the user could be standing in any position of a circumference centered on the beacon and with ratio γ).

In future work, this step of the algorithm will be improved to use additional contextual information in order to return "Known Position" (C) even when there is one signal and the distance to the beacon is larger than γ. It will be necessary to reason based either or both dynamics - inferring the current position based on the previous known position and the distance to the beacon - and wall conditions - wall conditions eliminate most potential positions, making it possible to use only the remaining possible positions in order to determine positions.

If there are two matched signals, the system first computes the two possible positions (6), corresponding to the intersections of the two circumferences (centered on beacons and with ratio equal to the distance). Then wall conditions are used to try to eliminate one of the options (9). If so, the algorithm returns "Known Position" (C). If not, the algorithm chooses the beacon with best RSSI (10) and proceeds as in the previous one signal case. The calculations for finding the two possible positions when there are two beacons are explained in the subsection 4.5.5.

If there are more than two matched signals, the position is calculated based on triangulation (7 or 8), as explained in subsection 4.5.4.

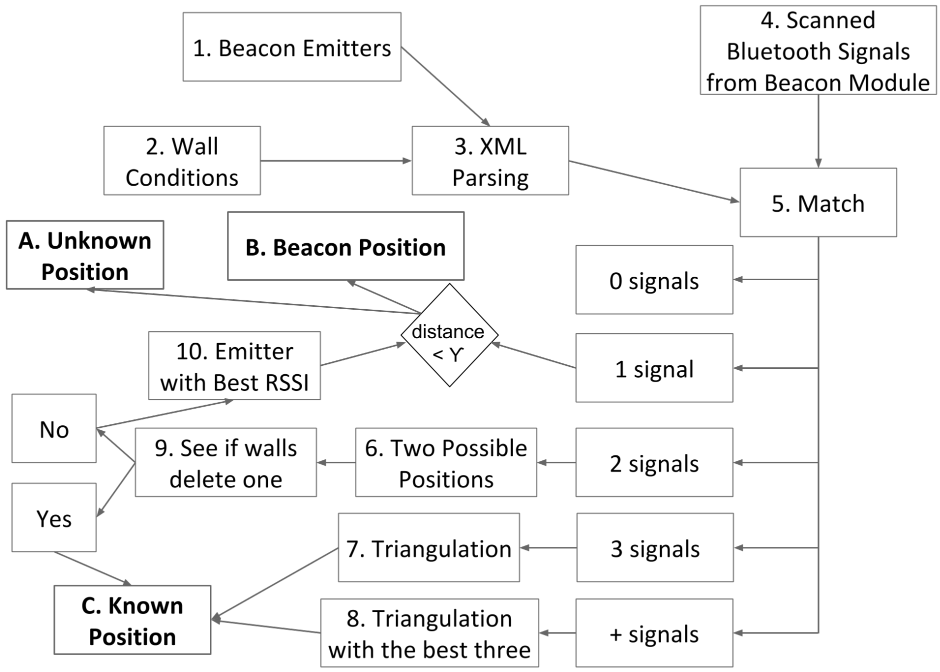

Figure 4.5: Location Module function flow.

4.5.3 RSSI to Distance Conversion

RSSI relation to distance from the emitter is a complex issue under study [15][60][35][61][36][11][27], therefore we assumed that the fingerprinting information associated to each emitter could give a trustful relation between RSSI and distance to emitter. As introduced before, fingerprinting information on the XML file provides the measured RSSI values at known distances from each emitter. The fingerprinting information covers the complete range of the emitter, therefore the distance to the emitter of a scanned signal is more likely to could be estimated.

If an RSSI value is lower or greater than the lowest measured RSSI value the distance can not be known. Lower or greater values are related to random errors. If the RSSI value matches one of the stored values, the distance is considered the distance used to take that measure on the fingerprinting phase. In the situation of the RSSI value being greater than the lowest stored, lower than the stored, and do not match any stored value, the distance is estimated with interpolation.

Interpolation is a mathematical method of constructing new data points within the range of a discrete set of known data points[87]. Considering x the distance and y the RSSI value, the interpolation equation to find the x to a known y is:

$$y_k < y < y_1 \Rightarrow \frac{x - x_0}{y - y_0} = \frac{x_1 - x_0}{y_1 - y_0} \Rightarrow x = x_0 + (x_1 - x_0)\frac{y - y_0}{y_1 - y_0} \qquad (4.1)$$

4.5.4 Triangulation

There are several algorithms developed for triangulation with beacons, [25] [9][40][56]. However, for the purpose of the module, a simple algorithm was built applying simple mathematical properties and conditions. The algorithm built is described bellow.

The distance to a known emitter actually places the user over a circumference around the position of the emitter with radius of that distance.When there are three emitters in range, with precise and known locations, the location of the receiver can be calculated by triangulation. The algorithm used finds the intersection point of three circles with known center coordinates and radius. The intersection point is found by iterating over points on the three circumferences. The algorithm follows the following order:

1. Determination of the angle used for iterations over each one of the

circles. For distances until 4 meters, the angle used is 30°, for distances from 4 to 12, the angle used is 10°and for distances over 12 meters, the angle is 5°. The smaller the angle, the better the precision[11].

2. Iteratively calculate position of a point on each circle with the defined angle of iteration for that circle.

3. Calculate the perimeter of the triangle defined by the tree points.

4. Compare the perimeter with the stored minimum perimeter.

5. If the perimeter[12] is smaller than the stored, actualize the stored value with the actual, and store the three points.
   If the perimeter is bigger than the stored, advance to next iteration.

6. After all iterations, a minimal perimeter for the referred triangle is stored and there are three points associated. The position estimated for the user location is the mean of the three points.

[11] See appendix C

[12] Perimeter was chosen over area to prevent the usage of areas of triangles with one edge zero sized. Those areas would be very small even if one point is far away to the others.

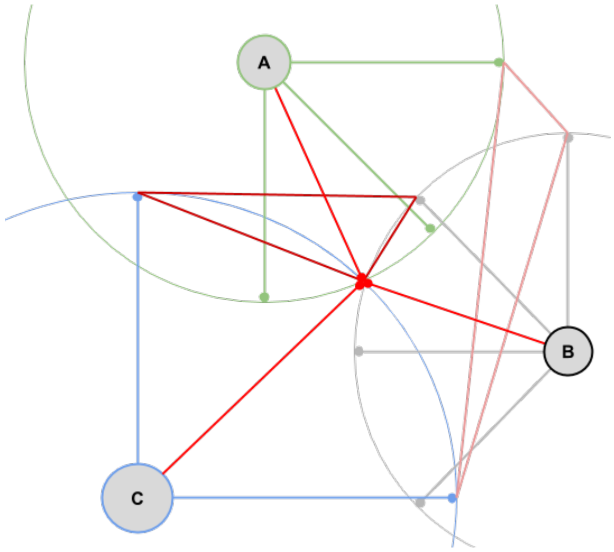

Figure 4.6: Triangulation algorithm.

Theoretically, the three points should be just one, the intersection of the three circumferences, see figure 4.6. However, due to the approximation introduced with the angle of iteration and the RSSI approximations, the approximation on the mean of the three points must provide a faithful approach of the user location. The example figure shows the usage of the algorithm with emitters A, B and C. Radius of each circumference were estimated by the RSSI to Distance function, explained in last subsection. There are defined two relevant triangles that correspond to smallest perimeters found in past iterations. The red dots indicate the three points forming the triangle with the smallest perimeter.

When the system matches more than three RSSI values, the best three are used to triangulate.

4.5.5 Location With Two RSSI Values

In the case of having only two scanned signals of known emitters, two circumferences can be drawn. If the circumferences intersect, a location can be estimated. Otherwise, the system can not estimate a location and retrieves the distance to the nearest emitter. To confirm that the two circles intersect, the two radius are summed and the distance between the emitters is calculated. If the sum of distances is greater than the distance between emitters, or the absolute difference of the distances is greater that the distance between emitters, or if the two emitters are placed at the same location, there is no intersection.

When there is an intersection, the following equations are used to find the two intersection points. Considering c_0 and c_1 the centers of the emitters, c_{0x} and $c0y$ are the coordinates of the first one, and c_{1x} and c_{1y} the coordinates of the second. The distance between the center is d, r_0 and r_1 are the two radius, and the mean point of the two intersections is P. a is the distance of P to the c_0 center, and h is the distancte between the intersections.

$$a = \frac{r_0^2 - r1^2 + d^2}{2d} \tag{4.2}$$

$$h = \sqrt{r_0^2 - a^2} \tag{4.3}$$

$$P_x = c_{0x} + a\frac{c_{1x} - c_{0x}}{d}; P_y = c_{0y} + a\frac{c_{1y} - c_{0y}}{d} \tag{4.4}$$

$$I_{1x} = P_x + h\frac{c_{1y} - c_{0y}}{d}; I_{1y} = P_y - h\frac{c_{1x} - c_{0x}}{d} \tag{4.5}$$

$$I_{2x} = P_x - h\frac{c_{1y} - c_{0y}}{d}; I_{2y} = P_y + h\frac{c_{1x} - c_{0x}}{d}[88] \tag{4.6}$$

Once the two intersection points are found, the system checks if wall conditions can invalidate one. In that case, the user is positioned at the other intersection. If none can be invalidated, the module will deliver the distance to the nearest emitter and its location, as has been said before.

4.6 Beacon Module

As introduced in the beginning of this chapter, the Beacon Module interfaces with the environment. The most important function is the genesis of fingerprinting information. A secondary function is the scan for Bluetooth signals. This module is an external appendix that was not properly integrated in this work. However, its viability has been properly tested.

4.6.1 Fingerprinting

Fingerprinting is an the extensive correlation of measured RSSI values with the distance to the emitter. This study was made to prove the existent relation between distance and signal strength. The procedure was to place the emitter in a fixed position and to make several measurements of RSSI values at different distances from the transmitter[13].

4.6.2 Scan Bluetooth Signals

Scan for Bluetooth devices on the vicinity is available for every Bluetooth enabled device. As the application is built for Android devices, this functionality was evaluated also on Android devices ensuring its compatibility with other modules.

For this purpose is used the BluetoothAdapter[79] Android object that enables interaction with Bluetooth apparatus on the device, including here the

[13]See appendix F.

access to information about the scanned signals. The movement of information is performed through an IntentFilter[86] and a BroadcastReceiver[80].

An important requirement for this functionality is the continuous performance, enabling constant positioning of the user, so when the BroadcastReceiver receives information that BluetoothAdapter just finished the scanning for signals, it is forced to start scanning again.

4.7 How it Works

The *SmartGuia* is an information and navigation assistant that helps blind users navigate and find what they need inside public buildings. The first prototype that was developed as part of this thesis helps blind users to navigate and find what they need in shopping centers. A point-of-interest is a place where the user may want to go. The system assists the user choosing a point-of-interest to navigate to.

The system is designed to be very intuitive and simple to use, anyone can use it without prior instructions. The user interface contains just two buttons spanning the whole screen, which is important for accessibility. Figure 4.7 shows the main interface. All interactions between the user and the system (both ways) are voice interactions (except start/stop/help commands).

4.7.1 How to Define a Destination

A word or phrase must be provided to search for related points-of-interest over those available in the building. The bottom button (Start/Stop) is pressed to start searching for a desired destination. After pressing the button, the system will ask the user to say a word, or phrase, related to the desired destination ("O que pretende encontrar?" (in Portuguese)). Based on the

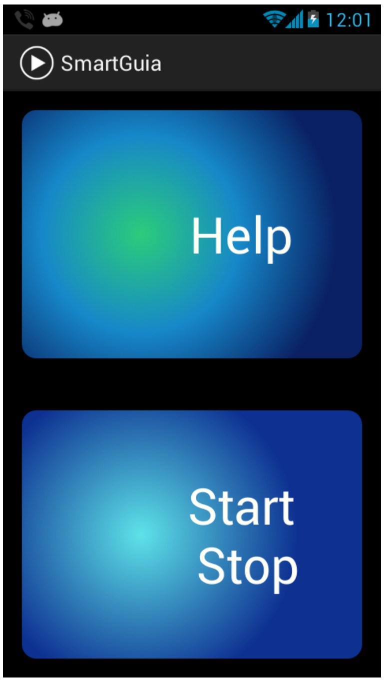

Figure 4.7: *SmartGuia*.

user's input, a list of related points-of-interest are delivered by voice, n at a time (n = 3 by default).

The system searches its information system to retrieve the list of points-of-interest related to the keyword. It can also retrieve categories of services, spaces or products (e.g. the user says "óculos"[14] and the system replies "1 - Categoria Saúde"[14] and "2 - Categoria Moda"[14]), in order to allow the user to specify with more detail.

The figure 4.8 summarizes the flow for selection of a destination.

[14]In Portuguese.

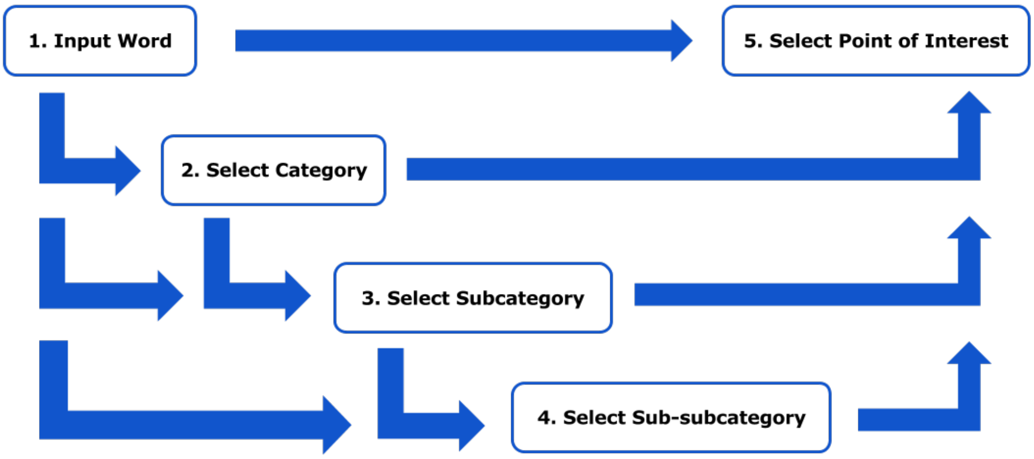

Figure 4.8: Defining a destination scheme.

On start, the user introduces a work that the system will use to find related points-of-interest, which are then delivered to user. Then user will select one of the options, that may include select a point-of-interest (step 5), select a category (step 2), select a subcategory (step 3) or select a sub-subcategory (step 4). If the user selects a point-of-interest the navigation will start guiding the user to that position. If the user selects a category/subcategory/sub-subcategory, the related options are delivered to him, which may be related points-of-interest or subcategories/sub-subcategories. The same scheme is used when he selects a subcategory or sub-subcategory. Independently of the current point in the flow of figure 4.8, the user can at any time say a new keyword or phrase, going back to step one of the figure.

4.7.2 How to Navigate

After a destination has been chosen, firstly, the application provides, to the user, a mental image of the building and his relative position within the building. The mental image intends to assist the user concerning orientation and relative location in the building (e.g. "O edifício mede 100 metros segundo Este-Oeste e 50 segundo Norte-Sul, e tem 3 pisos. Encontra-se na extremidade este, no piso 2." (in Portuguese)). After that, navigation instructions will be delivered as needed in order to guide the user to the defined destination.

Navigation instructions are given step-by-step, where each step is valid until the next change of direction. The instruction indicates the direction the user should take and an approximate distance to walk in that direction. The next instruction will be automatically given when the system detects that the current position of the user is a direction change.

When the user arrives at a destination, the system indicates that he arrived and ends the navigation. The bottom button can also be used to stop the navigation whenever desired.

4.7.3 How to Get Help

The top button provides help information anytime, that information intends to assist the user on location and orientation in the building. During a navigation, pressing help will return a replay of the last navigation instruction but reflecting the updated position.

Outside a navigation, help returns the current location of the user.

Chapter 5

Modules: Test Cases and Tests

We developed a prototype of the architecture that was described in the previous chapter. In terms of experiments, we developed a set of test cases and tested both each module and the whole application according to those tests specifications. In this and the next chapter we describe those experiments.

In order to do that, we related the requirements for each module, test cases and performed tests. A detailed list of requirements, test cases and test results is presented for each module on the appendices.

As explained before, the system is composed of five different modules with distinct functions. In order to test the functionality and ensure the quality of each module, we developed small test applications for each one. The final application is the integration of all modules, see section 5.6.

The testing phase is used to evaluate the functionality of the systems. In this phase the five modules were evaluated individually. In the case of the Beacon Module, we only made preliminary tests to prove that it works and can be used. More comprehensive tests of this module will require acquiring and deploying a carefully chosen set of transceivers, with the objective of ensuring quantity and quality.

In the following sections we summarize the scenarios, application and test cases used for testing each module, together with a brief analysis and conclusions. The detailed information of each individual test is listed in the appendices.

5.1 Voice Module

The main function of the Voice Module is speech synthesis and voice recognition. A secondary function is the confirmation of the previous user input, which requires both speech synthesis and voice recognition. This module uses Google APIs for both the synthesis and the recognition. Requirements defined for this module are presented in appendix D.1.

5.1.1 Test Cases

The test cases were defined to validate the capability of the module to synthesize speech and to decrypt speech to text. Another function assigned to this module is the confirmation of the previous introduced information, which comprises both recognition and synthesis. This confirmation is used, in the user application, to request user confirmation for the selected destination.

A simple application was created for testing the Voice module. This application includes just the three main functions of this module: synthesize text to speech, recognize speech and print it as text, and the confirmation of introduced information. A screenshot of the application is shown in figure 5.1.

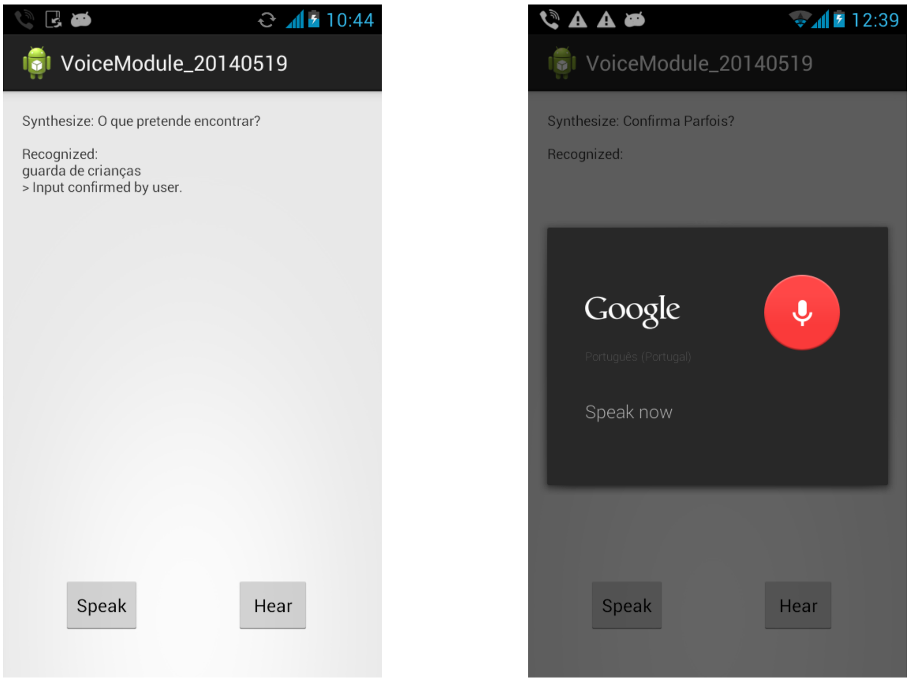

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Figure 5.1: Screenshots of the application built to evaluate the Voice Module.

The application has two buttons, *Speak* and *Hear*. The first is used to start the voice recognition, and the second to synthesize the predefined phrase. After the information is input, the confirmation is activated, which synthesizes a phrase requesting the user to confirm the previously introduced information. The example presented on the screenshot delivered “Confirma guarda de crianças?”[1], and the recognition activity is started to receive user confirmation. Then the application prints a on the screen that the information was confirmed by user.

Defined text cases to verify the functionality of speech synthesis included the synthesis of different phrases, inflections and words, namely Portuguese words and foreign words. Inflections and foreign words were tested in phrases such as “Confirma multibanco?”[2], “The Athlet’s Foot”[2], “Parfois”[2], “Con-

[1] In Portuguese.

firma Parfois?"[2].

5.1.2 Test Results

In what concerns speech synthesis, the tests proved the capability of the system to synthesize various phrases and Portuguese words. Some foreign words were also correctly synthesized, such as English words.

The application passed all tests concerning recognition of Portuguese words. However, foreign words were not correctly recognized. This is of course due to the fact that the recognizer is configured for a single language.

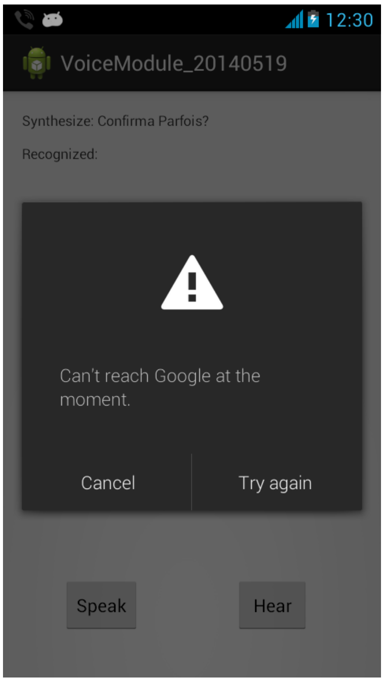

Figure 5.2: Pop-up shown when there is a connection error.

5.1.3 Limitations

Although most tests were successful for this module, we detected several limitations that constrain its usability by blind users. First of all, both activities, synthesis and voice recognition, require Internet connection. Voice synthesis is sufficiently fast, but voice recognition can be slow due to Internet connection properties and the Android device.

Another limitation of the voice recognition API is that the user has to indicate, by pressing a button, when the voice input finishes. This button is shown in the screenshot on the right, figure 5.1. As this button is placed at half of the screen height, however it must be marked as a negative characteristic.

When a connection or server error is detected, the voice recognition Google's API launches a pop-up window requesting the user to choose either *Cancel* or *Try Again* options, figure 5.2. This is impractical for blind users, since they will not be aware of the pop-up appearing and, even if they would be aware, it would be difficult to find the buttons.

5.2 Information Module

The Information Module assists the user in the selection of a destination among the available points of interest in the building. Once the user defines the intended destination, this module sends that information to the Route Module and the navigation mode is activated.

The requirements defined for the Information Module are related to the creation and organization of information schema and to support the user selection of a destination. The full list of requirements is presented in appendix D.2. In summary, the Information Module has to accept the specification of an arbitrary word, called keyword, then the module has to help the user to select the desired destination. The module stores a list of known keywords, which are imported from BuildingTopology and Categories files, and must be able to search the keyword introduced by the user among the stored keywords. Since keywords have destinations associated with them, those must be presented to the user. The user interface must be as simple as possible, since the system is intended for blind people.

5.2.1 Test Cases

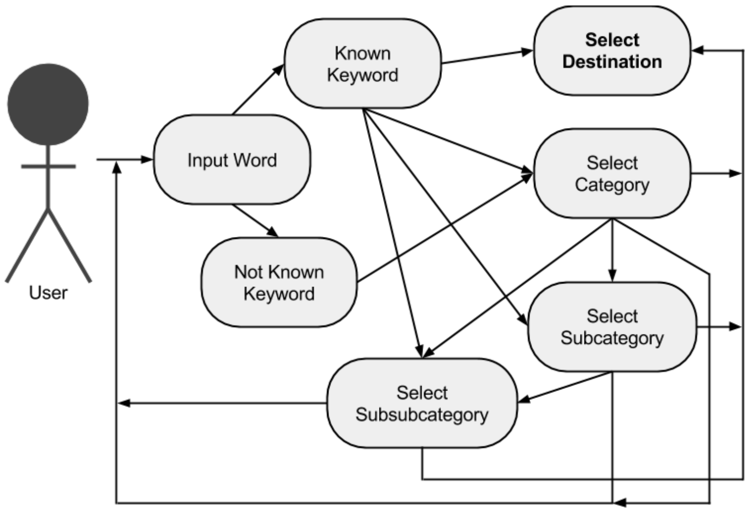

Figure 5.3: Test cases diagram for the Information Module.

Figure 5.3 shows in detail every available action for the user at each point. Test cases were designed to ensure that every available choice is actually available for selection at the right moment. When the user inputs a word, the system must deliver the destinations related to that keyword. If the keyword does not match any of the stored keywords, the system must ask for another keyword or allow the user to select one of the available categories. If the keywords has associated categories or subcategories, the system must deliver the available destinations associated to those categories or subcategories. In case the category has associated subcategories, the user must select the desired subcategory.

At the same, the user must be able to introduce a new word at anytime, even if a category or subcategory was already selected. The various test cases performed are reported in the appendix H.

5.2.2 Test Results

An application was created for the testing this module, figure 5.4 presents a screenshot. The tests must certify that each user input is well accepted, recognized and the system behavior is as expected.

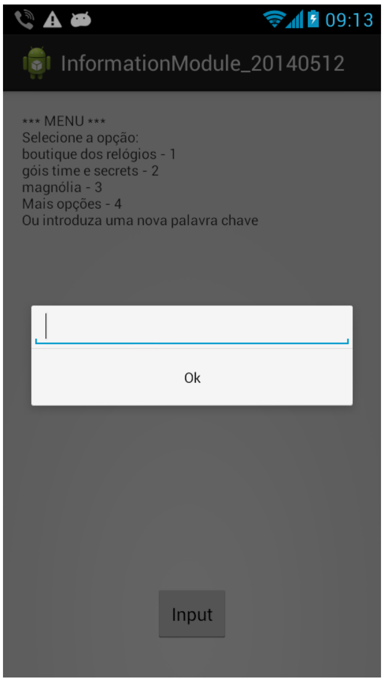

Figure 5.4: Application created to evaluate the Information Module.

Various tests were performed and the results have shown that the Information Module's function is accomplished. Tests ensured that the module enables the user to:

- Input keyword and select destination among the ones presented.

- Select category, select associated subcategory and associated sub-subcategory.
- Input a new keyword at anytime.

The applied test cases covered almost every available user behavior, from introducing various and multiple keyword, to selection of inexistent options. Tests proved that the Information Module is robust enough to deal with every tested situation, this tests were

5.3 Route Module

The Route Module has to calculate the shortest path between the user's current location and the desired destination, a point of interest chosen previously. Therefore, this system interacts with the Information Module and Location Module for the background functionalities, and with the Voice Module to deliver navigation instructions to the user.

5.3.1 Test Cases

The Route Module was evaluated with a simulated building, which used the plant of the Department of Informatics Engineering. This simulated building is detailed in appendix B, and an extended test cases list is found in appendix H.

Test cases for this module intend to verify that the calculated route is actually the shortest between the start and end points, and that the module is strong enough to deliver the right navigation instruction at the right moment. At any time the system has to be prepared to deliver help instructions. Help instructions may be related to the user's current location or, in case a navigation is being performed, related to navigation orientations.

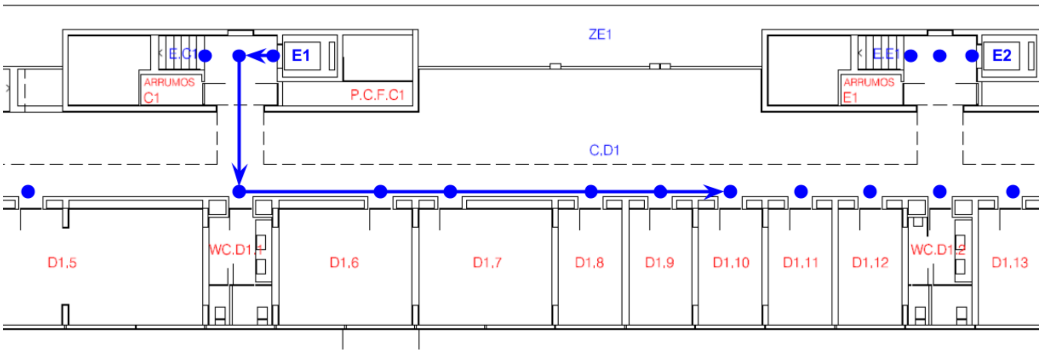

Figure 5.5: Test case defined for the Route Module.

A specific test case is presented on figure 5.5. In this test case the start point is the lift E1 and the target point the D1.10 room. The module is supposed to calculate the shortest path between the points and to deliver instructions to assist the user to go from the start to the target point. In this situation the system is supposed to deliver the mental image of the building, the relative current position on the building and the first navigation instruction. In this situation, the first navigation instruction should indicate the user to walk 5 meters to the left, since the system assumes that the user has his/her back to the lift E1.

The first arrow of the path in the figure is merely representative, since that representation is used just on the algorithm to generate navigation instructions. That arrow on the real building corresponds to a distance up to one meter. The system does not deliver instructions to walk for just a meter.

For this route, other performed tests are related to the request of help at any time and location on the path, or to stop and start a new navigation at any time and location.

5.3.2 Test Results

The Route Module was evaluated over the simulated building on the Department of Informatics Engineering. An application was built with this module, and since the location system is not tested here, a button has added for simulating the user's movement. Other two buttons simulate the two buttons on the final application: *Start* to start/stop navigation, and *Help* to request help instructions.

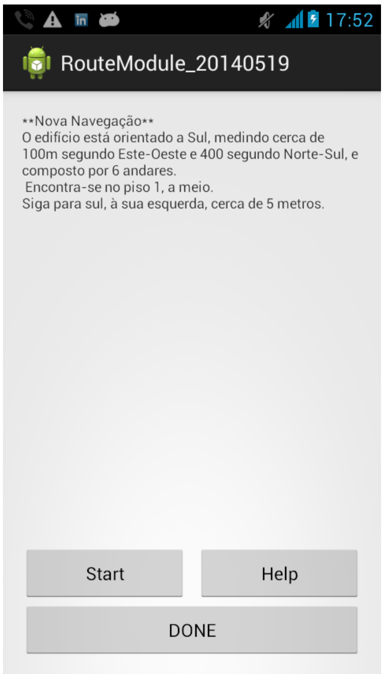

Figure 5.6: Application created to evaluate the Route Module.

The main functionality of this module is the creation of a route and the guiding the user through that route. Another function is to provide help whenever the user request it. The performed tests are presented on appendix H. Those tests ensure that the Route Module is capable of determining a shortest route between two points on the building, generate and deliver navigation instructions at the needed or requested position, and enable the user to start and stop navigation whenever wanted.

5.3.3 Limitations

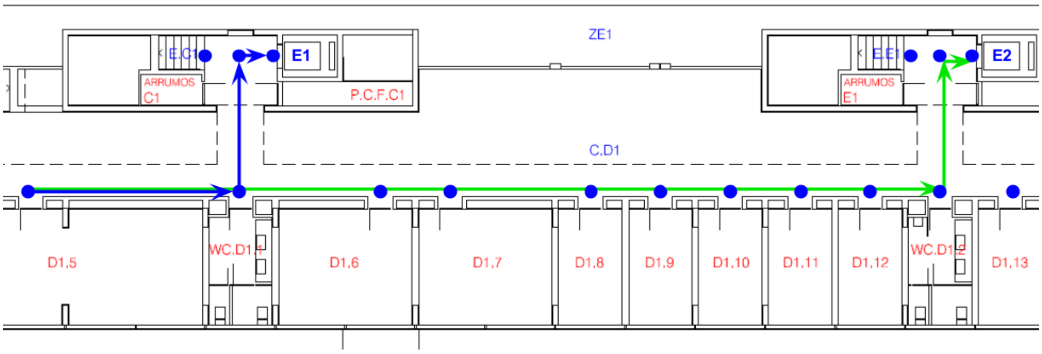

Figure 5.7: Special test case defined for the Route Module.

A specific test case is demonstrated on figure 5.7. The start point is the room D1.5, identified on the figure, and the target vertex is a point on another floor that is to right of E2, causing the existence of two routes possible with the same cost. The algorithm does not enable the user to choose over the available routes.

This limitation of the module is caused by the Dijkstra's shortest path algorithm, which ends calculations since a shortest path is found. The algorithm does not signal whenever there are other available shortest paths. This limitation was identified but is not considered relevant to compromise the module's functionality.

Another identified limitation is the orientation of the user. For the current version of the system, we do not assume that the system must have an embedded orientation device, and simple heuristics are followed instead. This can be improved with the embedding of a orientation device. As it is, the system has the following limitations concerning orientation:

Starting a navigation from a point of interest: The system currently assumes a user will always start navigating from some point of interest (including entrances of the building). At this moment, the system assumes the user is facing back the entrance of the point of interest (the vertex has stored this orientation) when he starts a new navigation. A blind person may have difficulties with guaranteeing that he finds that orientation.

During a navigation: the system assumes that the user is facing the direction of walking. The user is expected to follow the directions indicated by the system. If he changes direction inadvertently, the system is not yet equipped with the appropriate means to handle that situation. Therefore, the user would be expected to start a new navigation, facing backwards to the entrance of a point of interest.

Starting a navigation from anywhere except a point-of-interest: currently, the system is only prepared to guide a person that starts navigating from some point that is not a point of interest if the person is facing north. This is because the system does not have an orientation device, therefore it cannot determine which direction a person is facing.

These limitations can be solved by including an orientation module. As future work, we plan to add the Orientation Module, which returns the current orientation of the person. This module can use some existing device that provides the orientation or, in systems that do not have one, may ask the user.

5.4 Location Module

The Location Module calculates the location of the user. This module receives beacon RSSI values from the Beacon Module and has to deliver the location to the Route Module. Whenever possible, the Location Module also delivers the current vertex of the graph (each location defined on the building is a vertex on the graph constructed). If the location cannot be calculated, the Location Module delivers the position of the nearest transceiver and the distance to that position. If the Beacon Module does not deliver any RSSI values, the Location Module does not have any way to calculate, estimate or generally indicate user's position.

5.4.1 Test Cases

Two scenarios were designed to test the Location Module. They are presented in figures 5.8 and 5.9. Precise positions of emitters and locations were defined and so the distances between each point can be calculated. Defined tests have the responsibility of evaluate the ability of the module to handle every possible situation, and whenever it is minimally possible the capability of delivering a more or less precise location.

The various test cases try different positions, different number and positions of beacons within range, and various wall conditions. These will test if the distance is correctly calculated from RSSI values and if XY location is adequately computed for various cases.

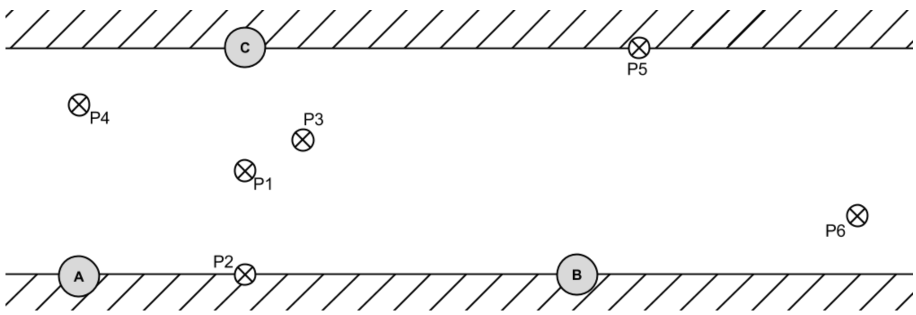

Figure 5.8: Scenario 1 for test of Location Module.

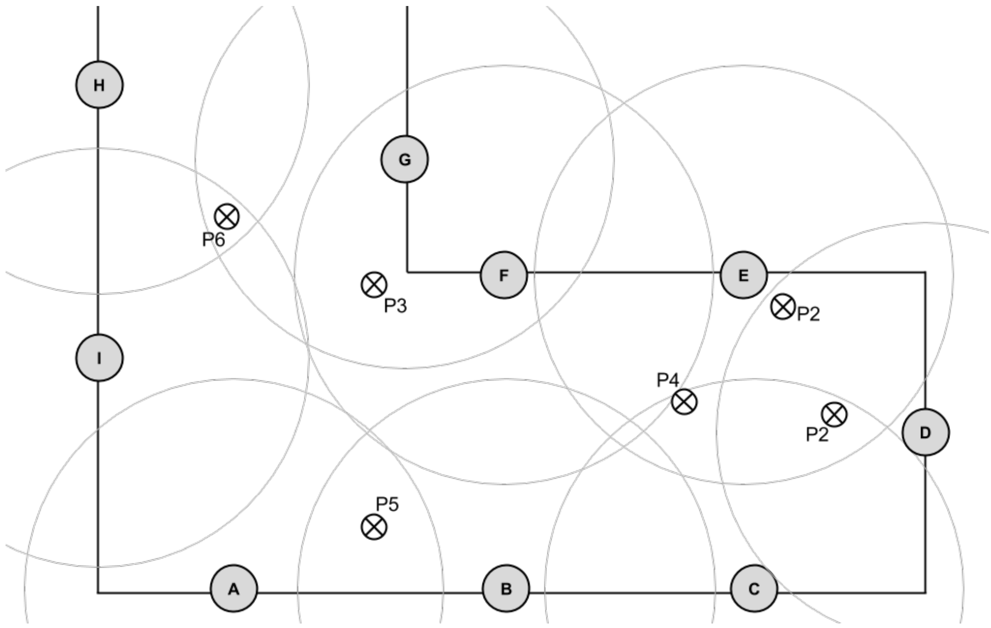

Figure 5.9: Scenario 2 for test of Location Module.

In the scenario 1, points P1 to P3 test the triangulation algorithm, that is, calculation of location with three RSSI values. Points P4 and P5 test the location with two RSSI values. The intersection of two circles provide the definition of two intersection points, which on the experimental system will correspond to two possible locations for the user (beacon receiver apparatus). Wall conditions are used on this situations to try to invalidate one of the locations. In P4 none of the possible locations can be deleted with wall conditions, meaning that the person may be in two different positions. On the contrary, P5 will have one of the possible locations invalidated with wall conditions.

The second scenario, figure 5.9, evaluates the module in a more complex setting, further confirming the system is able to person adequately.

5.4.2 Test Results

Once again, an application was built with the Location Module al. Two scenarios were designed to evaluate this module as explained before, see figure 5.8 and 5.9.

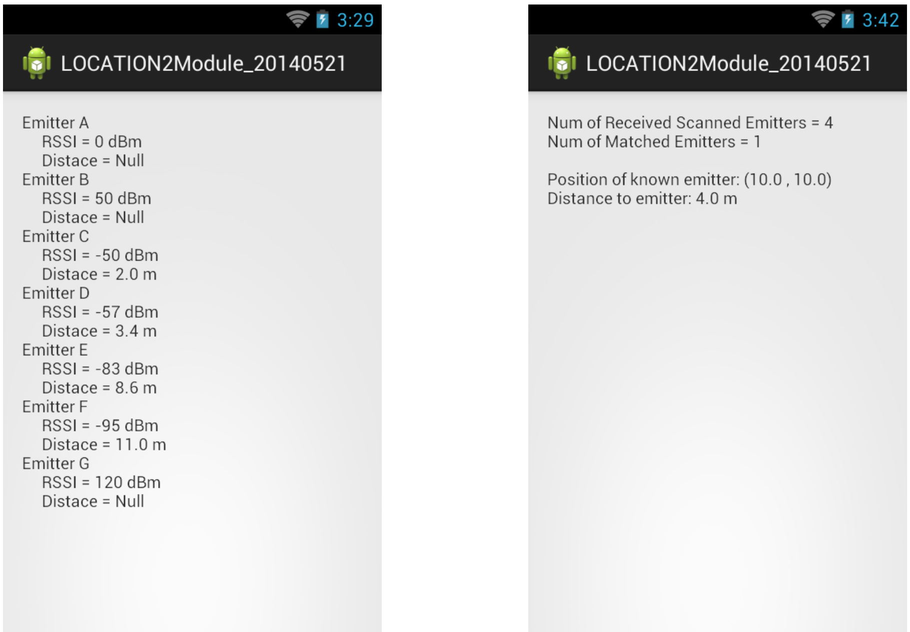

Figure 5.10: Screenshots of the application built to evaluate the Location Module.

The RSSI values used were calculated with interpolation, see equation 4.1, of the fingerprinting information associated to each transceiver. The simulated fingerprinting data is presented on table 5.1, and it is assumed that all transceivers have equal properties, so the fingerprinting information is the same for all. For a detailed description of the inputs used for each test, namely the calculation of RSSI values used, see appendix E.

Distance (m)	0	1	2	3	4	5	6	7	8	9	10	11	12
RSSI (dBm)	-40	-45	-50	-55	-60	-65	-70	-75	-80	-85	-90	-95	-100

Otherwise, P5 will have one of the possible locations invalidated with wall conditions.

Table 5.1: Fingerprinting information defined for the transceivers.

We tested the interpolation of RSSI values to distance, as well as many possible RSSI values, including erroneous ones (e.g. positive values). Those tests were all well succeeded. In what concerns finding the correct position on the defined scenarios, the module always delivered the expected result: precise location, distance to a point or null position/distance. Detailed test result are in

5.4.3 Limitations

In some situations, the location delivered differs in 0.1 or 0.2 m from the actual location. This was detected on P1 and P3 in the scenario 1, and P3 and P6 on the second scenario. This nonconformity was considered of low severity and therefore the tests were considered passed. It was considered that a distance of 10 or 20 centimeter is not relevant for the main objective of determining locations in a more general level.

This discrepancy has two possible sources: the approximations used to convert distance to RSSI values (a simulation artifact), and the approximations used on the location algorithms. In fact, three of the four cases where this is detected correspond to situations where the location is obtained with triangulation.

Since actual RSSI values are always integer numbers, RSSI values obtained from conversion of distance values were converted to integer values. These approximations are detailed on appendix E. One of the algorithm error sources may be the approximation used to find the location on triangulation, since the algorithm calculates location with the mean point of the three closest points on the three circumferences obtained with the three RSSI values (see section 4.5.4). The other possible error source on the algorithm is the approximation used to iterate over points on the three referred circumferences (see appendix C).

5.5 Beacon Module

The Beacon Module detects beacons on the range of the user and delivers that information to the Location Module. That information has to comprise RSSI values and Beacons identifiers. This module has only tested in order to prove its feasibility. More comprehensive tests will require acquisition and deployment of a set of beacons that must be chosen to guarantee quantity and quality.

An application was created with the module, figure 5.11. The beacons used in this instance were Bluetooth devices, such as Bluetooth enabled mobile phones and computers. This application just prints on the screen RSSI values and transceivers identifiers.

Figure 5.11: Application created to evaluate the Beacon Module.

5.5.1 Test Results

We did a fingerprinting study with intention to prove the relation between distance and RSSI values. Figure 5.12 presents the relationship. Additional studies need to be done to test the integration of the Beacon Module on the rest of the integrated system.

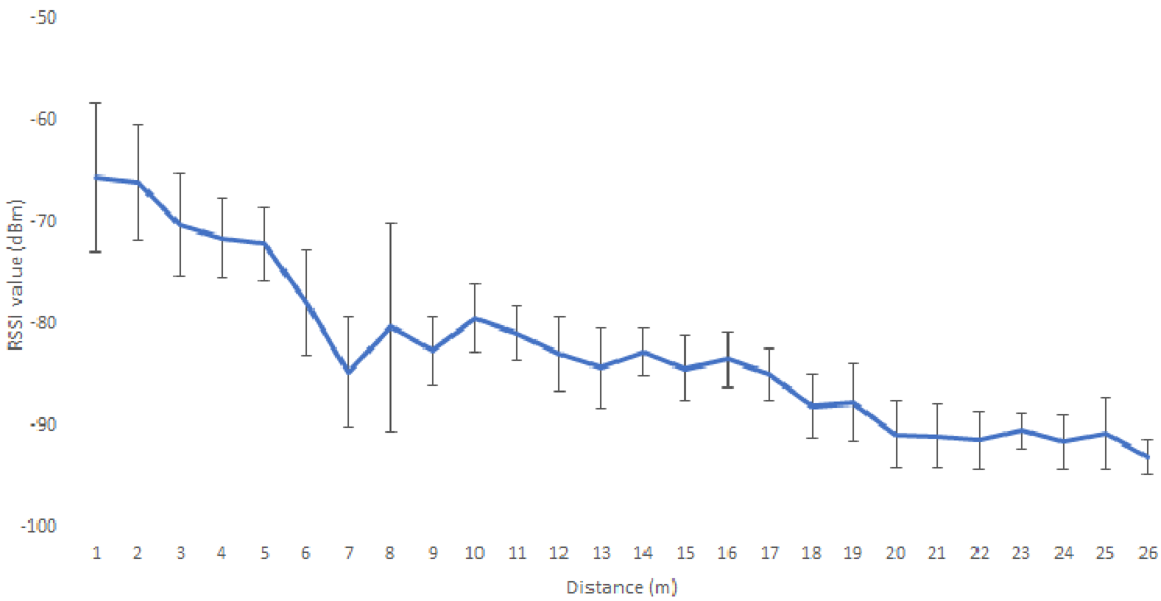

Figure 5.12: Relation between distance and RSSI values.

The above graph includes error bars that show the standard deviation. This study has performed with a Bluetooth enabled mobile phone under conditions that minimize signal reflections, such as walls or closed spaces. For each position we took 50 samples of the RSSI value. The standard deviation is significant which means that, in order to have an accurate, we will have to take a reasonable number of samples. We will propose taking at least ten samples, removing those furthers (noise) from the mean.

The standard deviation values are clearly huge for the intended purpose. The maximum standard deviation value was obtained for the distance of 8 meters. A detailed results table is found in appendix F where some statistical values are presented to each distance.

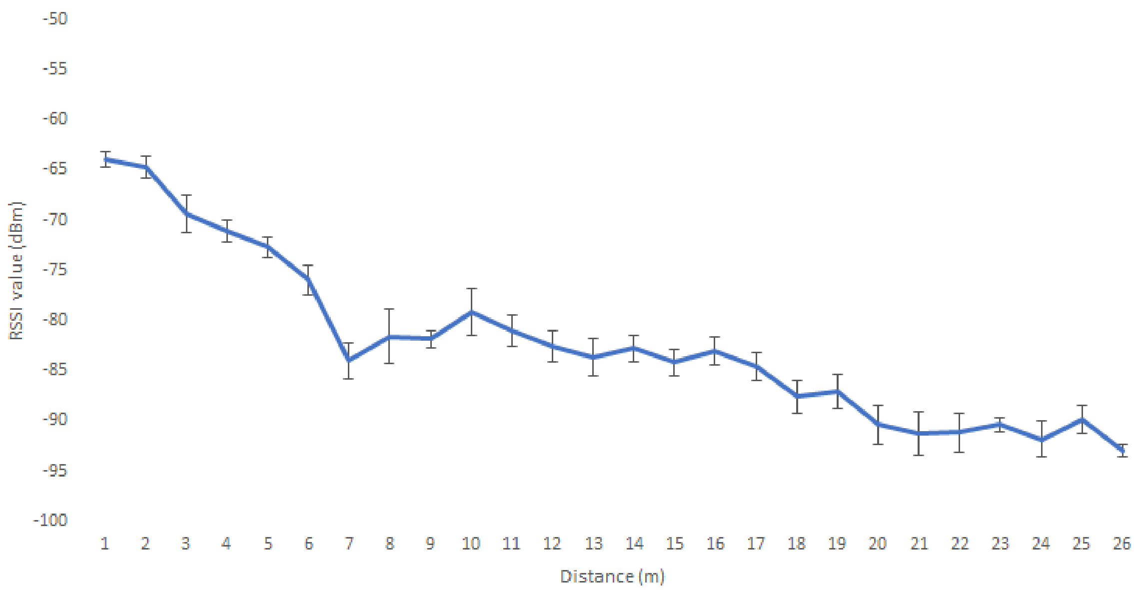

Figure 5.13: Filtered relation between distance and RSSI values.

Figure 5.13 presents the same relationship, following an outliers elimination procedure, where twenty samples were extracted for each distance to the beacon (the ten highest and the ten lowest). With this approach the standard deviation is decreased significantly. This approach also enabled to conclude that the peak obtained at the distance of 7 meters is not exclusively related to noise, it corresponds to some interference of the environment, for instance an obstacle that reflected the beacon signal.

RSSI	Measured Distances	Considered Distance	Lower Limit	Upper Limit
-62.5	< 1	1	0	1
-65	2	2	2	2
-67.5	2,5	2.5	2	3
-70	3, 4	3.5	3	4
-72.5	4, 5	4.5	4	5
-75	6	6	6	6
-77.5	6, 10	-	6	10
-80	8, 10, 11	-	8	11
-82.5	6, 7, 8, 9, 11, 12, 13, 14, 15, 16	-	**6**	**16**
-85	7, 13, 15, 17	-	**7**	**17**
-87.5	18, 19	-	18	19
-90	20, 21, 22, 23, 24, 25	-	20	25
-92.5	20, 21, 22, 24, 26	-	20	26

Table 5.2: Relationship between RSSI values and distances.

The table above shows the relationship between RSSI values, in dBm, and distances. The second column registers all distances were the corresponding RSSI value can be found, concerning the standard deviation observed. This approach shows that the RSSI presents some reliability for short distances, however for greater distances that is not observable. The stronger variability is found for RSSI values of -82.5 and -85 dBm, where the range of distances may be of ten meters.

The issue of RSSI to distance correspondence, and more generically indoor localization, are complex subjects that deserve further study. Our work in this thesis concerned the design and development of the assistive system for blind people, therefore we leave further work on the subject of indoor localization for future work. One of the most interesting issues is how to handle uncertainty, due to ambiguity of the correspondence between RSSI and distances.

5.6 Software Integration

This section presents the final software, which comprises the five modules previously detailed. The next sections test the whole software in a specific setup. This corresponds to a software integration test, where all modules are tested working together in a real case scenario.

The requirements for the final application include the requirements of each separated module, and therefore are not referred here. In the next section we present the designed test cases for the software integration, and in the last section of this chapter we present the results of the performed tests.

5.6.1 Test Cases

Three test routes were designed to evaluate the final application, they are presented on figures 5.14 and 5.15. The software must enable the user to define a point-of-interest to navigate to, and must deliver the according navigation instructions that enable him/her to walk to that point.

In these experiments, the integrated Beacon Module does not perform its main functions detailed before, as the environment was not filled with beacons that enable the system to work. The values that would be delivered by this module were previously calculated and stored on that module, which then delivered them to the respective modules when adequate. As soon as we acquire the necessary quantity of beacons, this experiment can be reproduced with the Beacon Module scanning the real beacons.

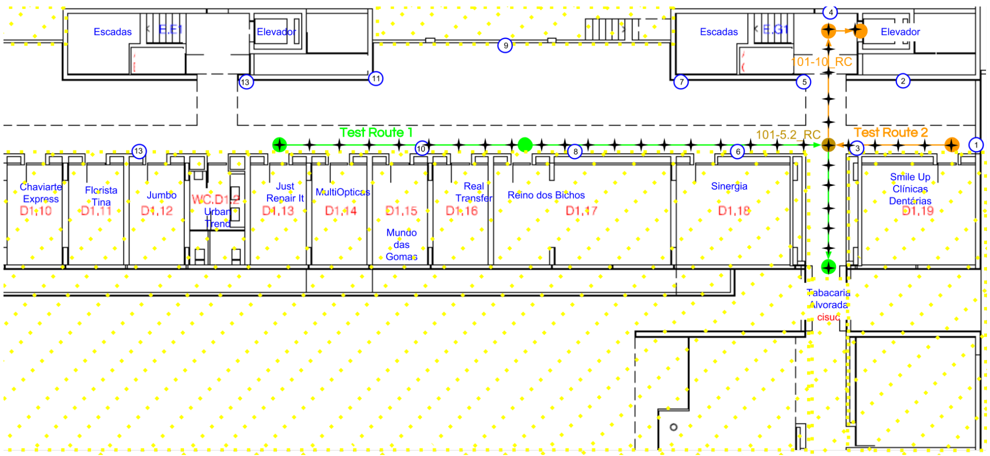

Figure 5.14: Defined test routes on DEI's first floor.

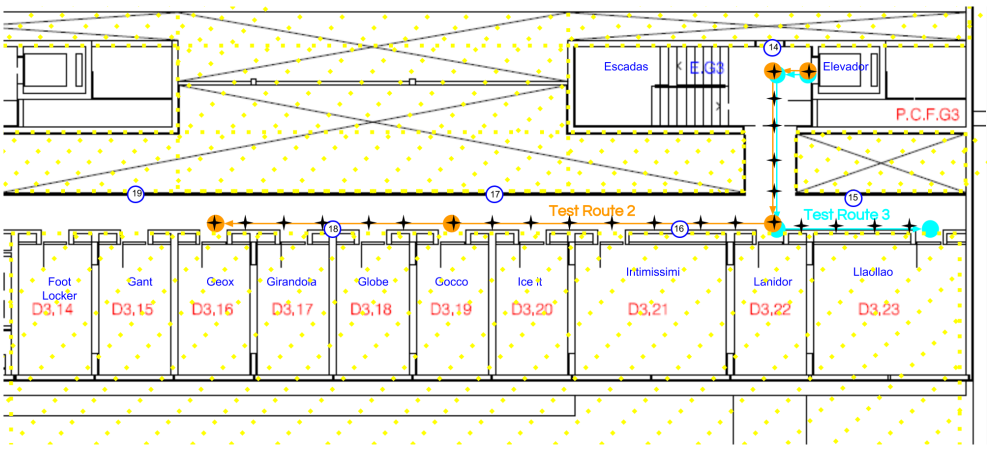

Figure 5.15: Defined test routes on DEI's third floor.

As the figures show, there were defined three routes: one from Just Repait It (*d1.13*) to Tabacaria Alvorada (*cisuc*), another from Smile Up (*d1.19*) to Geox (*d3.16*), and the last one similar to the second, but on the Lanidor (*d3.22*) the user will arbitrary turn left, to Llaollao (*d3.23*). The first two routes must be perfectly accomplished by the application, and the third one must deliver the user the information that he exited the defined route and therefore the a new navigation must be started.

To evaluate the information system on the application, user inputs must be:

1. "Tabacaria"[2] → "Um"[2] (to select *Tabacaria Alvorada*[2] point-of-interest) → "Sim"[2] (to confirm the selected destination).

2. " " → "Um"[2] (to select *Moda*[2] category) → "Um"[2] (to select *Sapataria*[2] subcategory) → "Quatro"[2] (for more options) → "Um" (to select "Geox" point-of- interest) → "Confirmo"[2] (to confirm the selected destination).

3. "Animais"[2] → "Um" (to select *Reino dos Bichos*[2] point-of-interest) → "Não confirmo"[2] (to cancel the selection) → "Sapatilhas"[2] → "Três"[2] (to select *Geox* point-of-interest) → "Sim"[2] (to confirm selection).

The black stars on the figures represent the points where the Beacon Module scans for beacons on the range, and yellow dots determine locations invalidated by wall conditions. Transceivers positions are signaled with blue circles.

5.6.2 Test Results

A screenshot of the software integration application is presented bellow. As the application is intended for blind people, this is the only screen layout that the application has.

Since we were not using real beacons, the system is not adequately equipped with beacons, the Beacon Module was simulated by converting distances to beacons into RSSI values, which are delivered to the Location Module when asked. The RSSI values for each position can be found in appendix G. The

[2] In Portuguese.

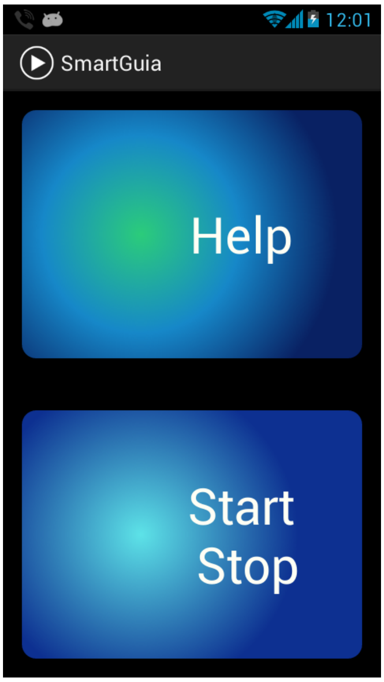

Figure 5.16: Screenshot of the final application.

return button, present by default on Android devices, was used to iterate over the simulated user positions for each route, the black stars in figures 5.14 and 5.15. The function of the buttons presented in the application layout are explained in detail in chapter 4.7. Summarily, these buttons are used to start the searching for a destination point (Start/Stop button), by launching the Information Module, and consecutively start the navigation, and then to stop it whenever the user desires to; and to request help (Help button).

The tests ran successfully, showing that the software worked as intended. Every module performed its assignments correctly and the modules worked fine together.

5.6.3 Limitations

Besides the already discussed limitations identified for each module, the software has the limitation that when the user walks through a different path than the one defined by Route Module, it cannot compute navigation instructions to get the user to the correct position. This limitation is seen in Test Route 3, where the user walks to left when the system delivers instructions to walk right, in vertex D3.22. Since the Location Module is functioning properly, the system keeps waiting for the user to reach the next vertex on the path, when he is actually somewhere else.

We took note of this limitation and will modify the application to include the functionality of recalculating the path whenever the user reaches a vertex that is not in the calculated path.

Chapter 6

Conclusions and Future Work

In this thesis a set of requirements was performed with three institutions that support people with different needs: cerebral palsy, blindness and diabetes mellitus. After defining the needs of each target group, with the institutions, a scenario was chosen, a proposed system was designed and then presented and discussed with the corresponding institution.

A system for indoor assisted shopping and navigation for blind people was developed. The system provides an interface adapted to blind people with simple mechanisms to allow the person to indicate what he needs and to guide the person to the desired destination. We have defined requirements for the application and its modules, presented the architecture of the proposed system, implemented a prototype and tested it according to test plans that allowed us to conclude that the developed system is working as intended.

6.1 Comparison with Other Technologies

An evaluation criteria to evaluate assistive technologies was defined in the state-of-the-art chapter, see section 3.1.2. Systems presented on the state-of-the-art were evaluated in terms of navigation (R1: Access to the Building, R2: User Positioning,R3: User Guidance, R4: Obstacle Detection)[1], product finding and used technologies (R5: Existing Technologies, R6: Minimal Env. Adjustments, R7: Easy Portable Device)[1]. The following table relates the *SmartGuia* prototype to other indoor navigation assistive systems, already presented in the state-of-the-art section.

	R1	R2	R3	R4	R5	R6	R7	Total
SmartGuia	**0**	**5**	**5**	**0**	**4**	**4**	**5**	**23**
Mobile Phone Based System	0	4	5	0	4	1	5	19
RFID Based System 2	2	4	5	0	2	2	2	17
RG	2	3	5	5	0	2	0	17
BlindAid	0	5	5	0	3	0	4	17
ShopMobile	0	3	5	0	0	3	5	16
BlindShopping	0	5	5	0	1	0	4	15
RFID Based System 1	0	5	5	0	1	0	3	14
ShopTalk	0	3	5	0	0	3	2	13
RoboCart	0	5	5	0	0	0	0	10

Table 6.1: Comparison of *SmartGuia* with other systems.

The criteria used to evaluate these systems is the same used to compare systems on the state-of-the-art, however the two last requirements were not evaluated because the prototype developed is not intended to help the user in finding specific objects.

SmartGuia performs user positioning and guidance, therefore R2 and R3 are achieved. Since the prototype is not enabled to assist the user to reach the entrance of the building and that the obstacle detection and avoidance relies on user's proprioceptive abilities, R1 and R4 are null. Regarding technologies used, the application relies on user's smartphone and beacons deployed on the environment, so, considering that the beacons used is not a new and highly expensive technology, R5 and R6 are almost filled. The easy portable

[1]See section 3.1.2.

device, R7, is fulfilled since the user's device is his own smartphone, and therefore it is assumed that the cost to learn how to use a new device and need to carry an additional device are null.

Other systems were previously rated in sections 3.1.3, 3.1.5 and 3.1.5. Systems based in RFID technology require a great amount of beacons in the environment (assuming the usage of the RFID low range beacons, which are the most common and cheapest), and the user's device has always to comprise an RFID reader to decrypt RFID's identifications. The great majority of systems evaluated are based on RFID technology, so the user's device is never as portable as the user's own smartphone is. BlindShopping and ShopTalk are approaches that use image codes, such as barcodes or QR codes, this approaches or use a totally new device and thus failing in R5 (existing technologies) and R7 (easy portable device) or have to append a device to the user's mobile phone to scan barcodes.

The Mobile Phone Based System, similarly to *SmartGuia*, relies on the user's own mobile phone, performs user positioning and guidance, and does not require great environment changes. It uses a phone call and sound beacons on the building to guide the user. This system is almost as well rated as our system, having lower grade in R2, since it is not aware of the user's position, the user has to indicate his position, and R6, since the sound beacons that are deployed in the environment, even having low cost of deployment, will interfere with the public environment.

6.2 Limitations and Improvements

As we developed some critical parts of the application, we notice some limitations of the technologies that we had at our reach, which means that in the future it is possible to improve those technologies to better fit blind users. That was the case of the voice recognizer and voice synthesizer modules. On one hand, both were Google API applications that required Internet access and were slow. On the other hand, the available voice recognizer (by Google) is limited in capabilities concerning blind users, since it presents touch buttons that are not easily located by a blind person.

The system also presents some limitations related to the defined wall conditions, since those conditions restrict the possible user's positions to corridors. This means that if the user is inside a room in the building, instead of being in a corridor, the system is not capable of identifying the position. This limitation can be overcome by detecting that the user is in a room, and providing instructions to navigate to the corridor when necessary. This would mean the need to store the layout of the rooms, which is not included currently. Navigation inside spaces (rooms or stores) in the building currently relies entirely on the user.

Another limitation of the developed prototype is out-of-path navigation. If the user is performing a navigation and takes directions different from those delivered by the system, it cannot guide the user unless he stops the current navigation and starts a new one. This will be solved in future version by detecting the user is out-of-path and consequently calculating a new route.

As specified in section 5.3.3, the prototype assumes predefined orientations to define the user orientation. Orientation is used to calculate appropriate navigation instructions. As said before[2] user's orientation can be automatically determined by using an embedded orientation device. As reported in [63], many Android devices already have components that enable orientation detection. A next prototype of the *SmartGuia* should address

[2] In section 5.3.3.

the use of these components to detect orientation.

We would also like to improve location algorithms to deal with several additional issues, such as uncertainty, rooms and other features that can be improved.

6.3 Future Work

It is necessary to create a tool and a procedure for easy-to-use and systematic fingerprinting of buildings. This tool could simultaneously allow the addition of necessary information about points-of-interest, wall conditions and other semantics.

The location algorithm should take into account dynamic conditions, transient inconsistent RSSI readings and other factors to produce a robust solution.

The positioning algorithms may include several conditions that enable estimation of user's position even without appropriate number of beacons on the range of the user. An example of these conditions is the prediction the user's position based on previous positions. For instance, if there are two possible locations for the user and the previous know position is closer to one of them, the user's position is likely the closest one.

More generically, future research work on indoor positioning will include how to deal with the uncertainty that is inherent to positioning mechanisms; dynamic scenarios, where the number of beacons in range changes as the person moves, the amount of uncertainty changes (due to distances to beacons), multiple sources, wall conditions, and the simultaneous use of proximity and other beacons.

Another important line of work would be to investigate alternative and complementary indoor location approaches. For instance, cameras can be used to infer the position of the person.

Currently the prototype can determine the shortest path between user's position and the desired destination, but in a future prototype the system should be capable of determine the shortest path to pass through several points-of-interest in space, allowing the user to define some destinations and be guided through the optimal route that reaches each one. This problem is solved by an adaptation of the Traveling Salesman problem [48], which calculates the optimal route that passes through some points and returns to the starting point.

Finally, the *SmartGuia* can be deployed in every public building as long as the procedures to import information are adequately elaborated, enabling the blind user to navigate in any building. A solution may be to build a central server with information about each building, allowing building owners to add information about their buildings. When a person enters a building registered in the system, the application accesses the correspondent information. On a large scale, *SmartGuia* enables blind user's navigation in any building around the world, as long as the building is registered in *SmartGuia*'s central server. Furthermore, *SmartGuia* can be used not only blind people, but by anyone.

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Appendices

Appendix A

Information Scheme Defined

In this section, the full list of categories used to classify the points of interest on the simulated building are presented. In the following table are presented the categories, related subcategories, assigned keywords, and on the last column is shown the number of points of interest, POI, related to that category, subcategory or sub-subcategory.

Category	Subcategoy	Sub-subcategory	Assigned Keywords	POI's
1. Moda	1.1. Sapataria		sapataria, sapato/s, calado	4
	1.2. Roupa		roupa, vestuário, calças, camisola/s, camisa/s	18
		1.2.1. Homem		2
		1.2.2. Mulher		4
		1.2.3. Jovem		3
	1.3. Acessórios		acessórios, bijuteria, bijutaria, pulseiras, jóias,	4
	1.4. Óculos		óculos, óptica, óculos de sol	1
	1.5. Crianças		crianças, vestuário (para) crianças, roupa (para) crianças	3
2. Saúde	2.1. Óculos		óculos, óptica, lentes de contacto, óculos de sol	1
	2.2. Cabelo		cabelo, produtos, shampˆ	2

Category	Subcategoy	Assigned Keywords	POI's
	2.3. Dietética	dietética, dieta, suplementos alimentares	1
	2.4. Corpo	corpo, produtos corporais, creme/s corpo	1
	2.5. Dentista	dentista, clínica dentária	1
3. Restauração	3.1. Lanche	lanche, snack, café	7
	3.2. Refeição	refeição, almoço, jantar	0
4. Cultura		cultura, livro/s	1
5. Desporto		desporto, vestuário/roupa/acessórios (para) desporto	4
6. Hipermercado		hipermercado, centro comercial, mercearias, compras	1
7. Informática		informática, computador/es, telemóveis, reparações	2
8. Serviços	8.1. Limpeza	limpeza, lavandaria	2
	8.2. WC	casa de banho, banheiro, casinha	6
	8.3. Informações	informações	1
	8.4. Ferramentas	ferramentas, chaves, duplicação de chaves	1
	8.5. Sapateiro	sapateiro, arranjo de sapatos, arranjos	1
	8.6. Cabelo	cabelo, cabeleireiro, barbeiro	1
	8.7. Crianças	crianças, guarda de crianças, atividades para crianças	2
	8.8. Serviços Bancários	banco, serviços bancários, multibanco	2
	8.9. Outros	florista, tabacaria, tabaco, seguro automóvel, escola de msica, msica	4
	8.10. Saída	saída, saídas, porta, portas	2
9. Outros	9.1. Bricolage	bricolage, acessórios	1
	9.2. Lar	lar, decoração	1
	9.3. Eletrodomésticos	eletrodomésticos	1
	9.4. Papelaria	papelaria	1
	9.5. Animais	animais, animais de estimação, gaiola/s	1

Category	Subcategoy	Assigned Keywords	POI's
	9.6. Ourivesaria	ourivesaria, ouro	2
	9.7. Relojoaria	relojoaria, relógio/s	2
	9.8. Joalharia	joalharia, jóia/s, fio/s, pulseira/s	3
	9.9. Perfumaria	perfumaria, perfume/s	2
	9.10. Crianças	crianças, brinquedo/s	2
	9.11. Viagem	viagem, mala/s de viagem, mochila/s, mala/s	1

Table A.1: Information system used in the application.

Appendix B

Simulated Building

In order to simulate the deployment of the system into a real building, the Department of Informatics Engineering, DEI, was converted into a shopping center. Classrooms and offices were tagged as stores and spaces of actual shopping centers. For this were actually used the first three floors of the Department. Furthermore, this assignment enable the actual usage of the system on the department as long as Bluetooth transceiver are deployed in sufficient amount on the environment.

As explained before, the building is converted into a weighted graph, with vertexes being the available points of interest and edges being the passable ways. Therefore in the following figures, blue dots correspond to vertexes and blue lines to edges connecting the vertexes.

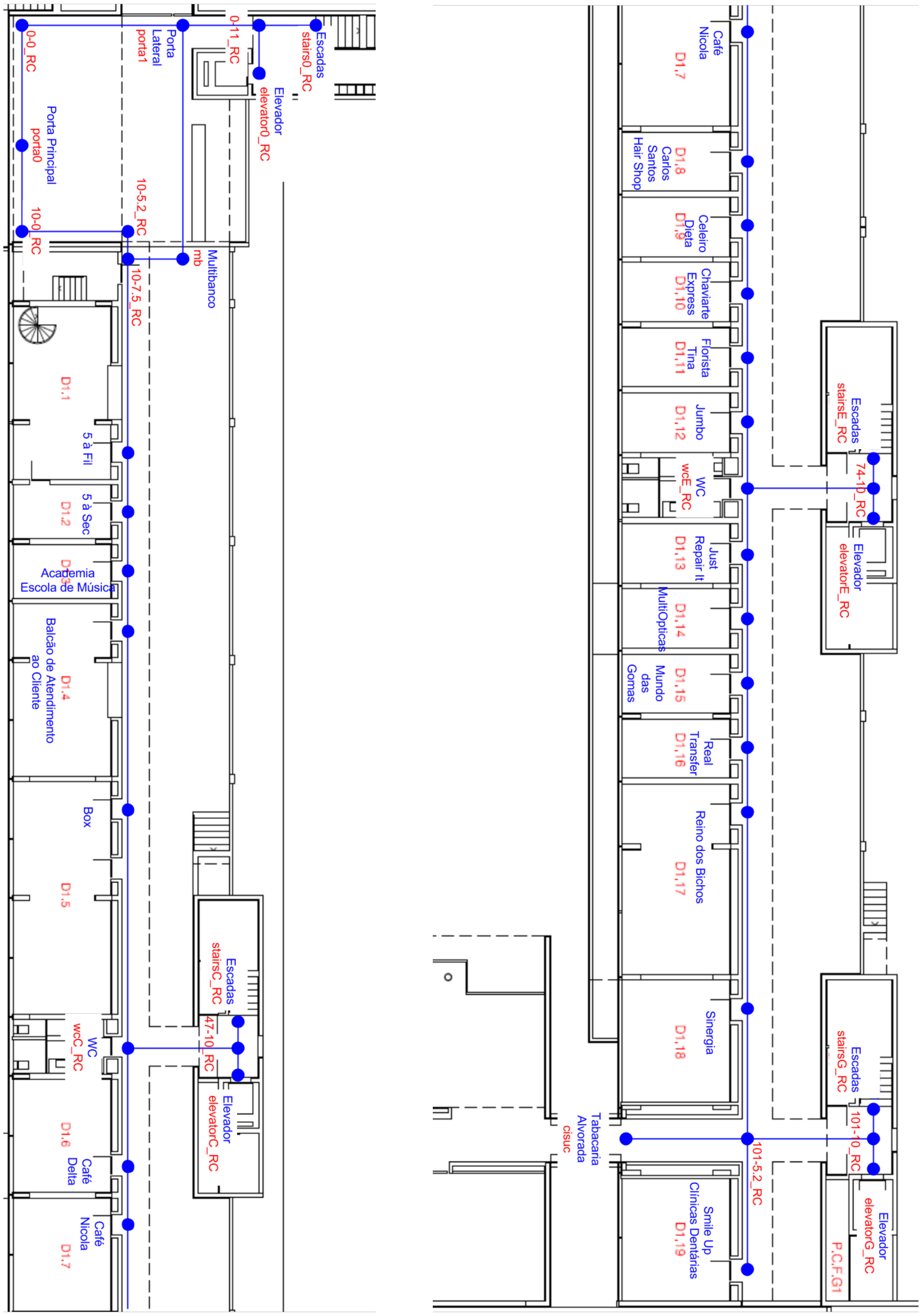

Figure B.1: Scheme of the simulation of a shopping center on first floor of DEI.

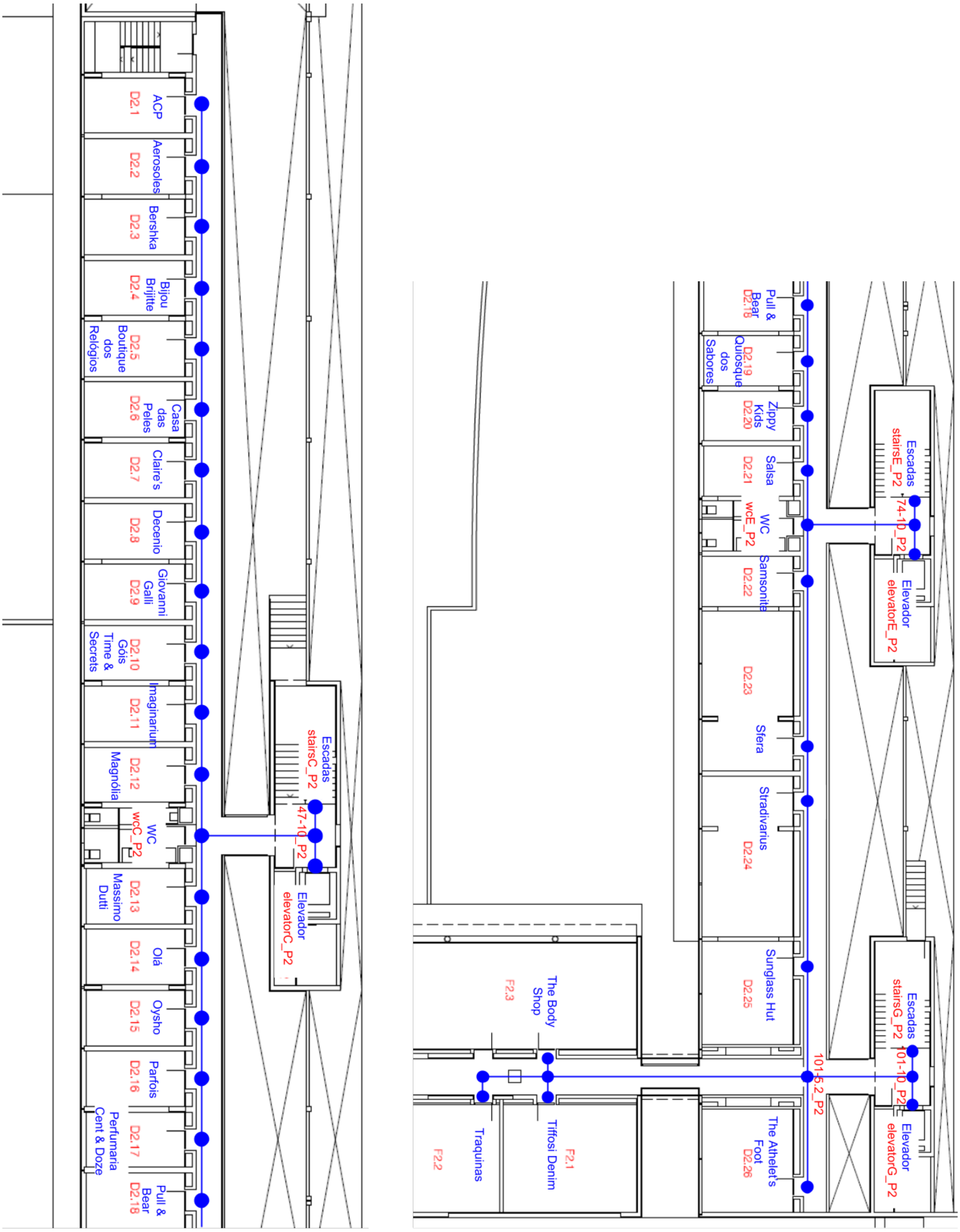

Figure B.2: Scheme of the simulation of a shopping center on second floor of DEI.

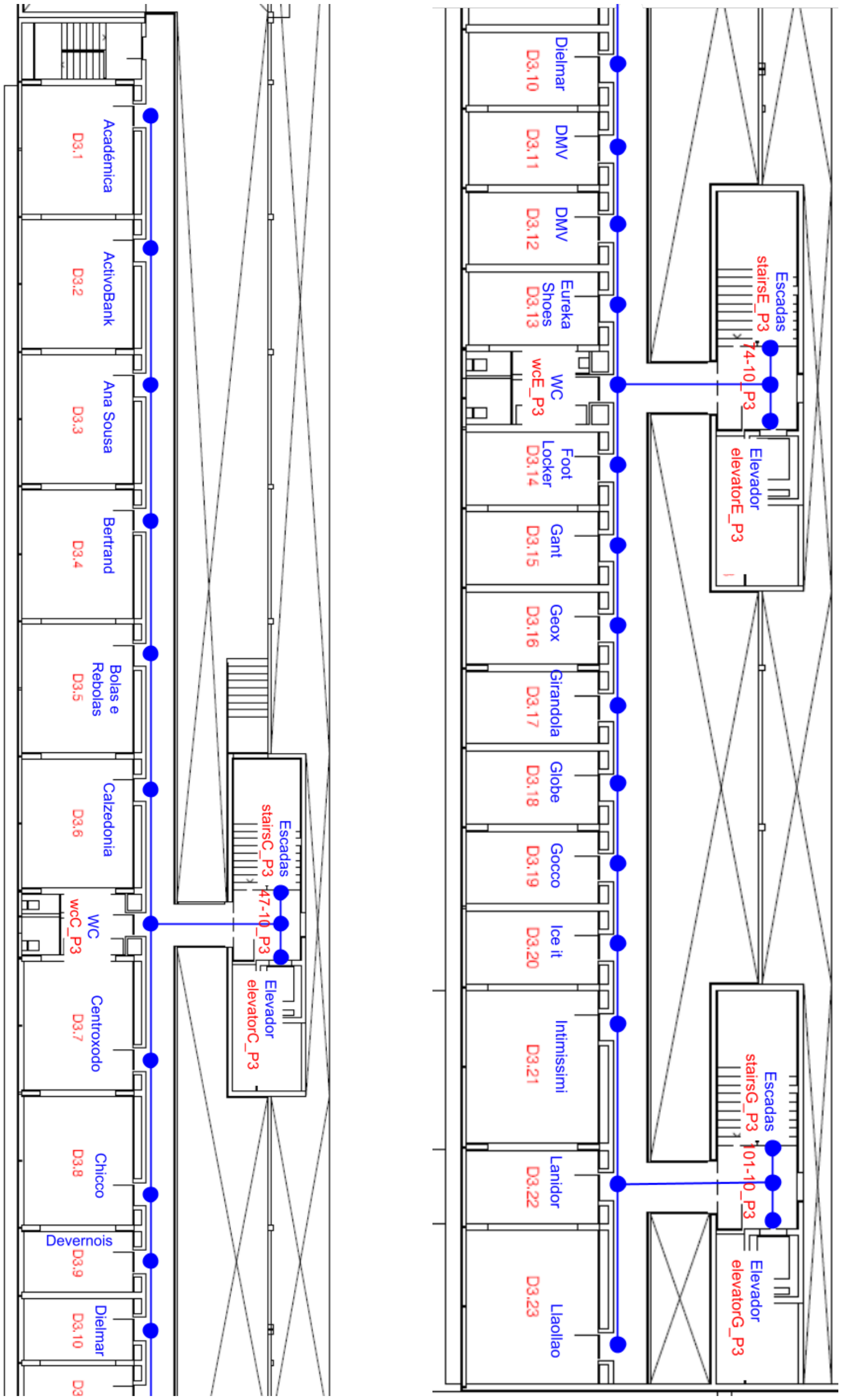

Figure B.3: Scheme of the simulation of a shopping center on third floor of DEI.

Appendix C

Error Introduced with Angle of Iteration on Circles

The definition of an angle of iteration in the algorithm of triangulation[1] introduces an error. The bigger the angle, the bigger the error. Angle of iteration defines the minimal distance between two consecutive points. The figure C.1 schematizes the calculation of error made.

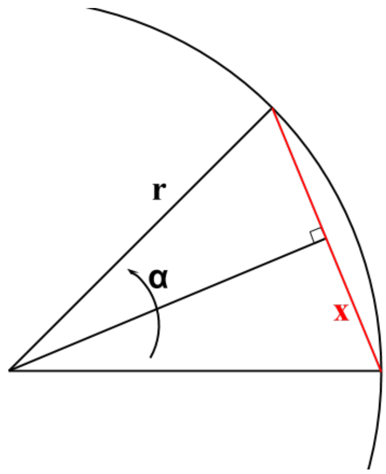

Figure C.1: Error introduced with angle of iteration.

[1]See subsection 4.5.4

The x has calculated with Trigonometry rules:

$$\sin\left(\frac{\alpha}{2}\right) = \frac{\frac{x}{2}}{r} \Rightarrow x = 2r\sin\left(\frac{\alpha}{2}\right) \tag{C.1}$$

Results are presented on the following table. Every number without unit is written in meters.

Radius	**30°**	**10°**	**5°**
0	**0,0000**	0,0000	0,0000
1	**0,5176**	0,1743	0,0872
2	**1,0353**	0,3486	0,1745
3	**1,5529**	0,5229	0,2617
4	2,0706	**0,6972**	0,3490
5	2,5882	**0,8716**	0,4362
6	3,1058	**1,0459**	0,5234
7	3,6235	**1,2202**	0,6107
8	4,1411	**1,3945**	0,6979
9	4,6587	**1,5688**	0,7851
10	5,1764	**1,7431**	0,8724
11	5,6940	**1,9174**	0,9596
12	6,2117	2,0917	**1,0469**
13	6,7293	2,2660	**1,1341**
14	7,2469	2,4404	**1,2213**
15	7,7646	2,6147	**1,3086**
16	8,2822	2,7890	**1,3958**
17	8,7998	2,9633	**1,4831**
18	9,3175	3,1376	**1,5703**
19	9,8351	3,3119	**1,6575**
20	10,3528	3,4862	**1,7448**

Table C.1: Error introduced with different angles of iteration per radius.

This tables explains why the angles 30°, 10°and 5° are used for different distances on the triangulation algorithm. The angle must be the greatest possible to speed up the computation velocity, and the smallest possible to minimize the introduction of error.

C.1 Consequences in the Algorithm

The 30° angle is used for distances up to 4 meters, introducing the maximum error of 1.5 meters. The 10° is used from 4 to 12 meters, introducing the maximum error of 1.9101 meters. And the last angle used, 5°, is used for distances beyond 12 meteres. It is assumed that each emitter does not provide accurate RSSI values for distances over 20 meters.

Appendix D

Detailed List of Requirements

D.1 Detailed Requirements for the Voice Module

	Identifier	Description	Father's ID	Priority
Structure Requirements				
1	VM_S1.0	Prepare voice outputs.		High
2	VM_S1.1	Set Portuguese language.		Medium
3	VM_S1.2	Create TextToSpeech object.		High
4	VM_S2.0	Prepare voice inputs.		High
5	VM_S2.1	Set portuguese language.		High
6	VM_S2.2	Create RecognizerIntent.		High
Functional Requirements				
7	VM_F1.0	Receive user input.		High
8	VM_F1.1	Convert speech to text.		High
9	VM_F1.2	When an sever error is identified, request another input.		High
10	VM_F2.0	Request user confirmation for the information introduced.		Medium
11	VM_F2.1	Understand user confirmation.		High
12	VM_F2.1.1	Confirm and save input.		High
13	VM_F2.1.2	Not confirm the input.		High
14	VM_F2.1.2.1	Request another user input.		High
15	VM_F2.1.2.1.1	Return to VM_F1.0.		High
16	VM_F3.0	Deliver voice output.		High
17	VM_F4.0	Voice synthesis followed by voice recording.		High
Non-Functional Requirements				
18	VM_NF1.1	Receive user input without Internet connection.	VM_F1.0	Low
19	VM_NF1.2	Receive user input with Internet connection.	VM_F1.0	High
20	VM_NF2.0	Conversion from speech to text is correct.	VM_F1.1	High
21	VM_NF3.0	Request through voice instruction.	VM_F1.2	High
22	VM_NF4.0	Request user confirmation after an input is received.	VM_F2.0	High
23	VM_NF5.1	Deliver voice output without Internet connection.	VM_F3.0	Low
24	VM_NF5.2	Deliver voice output with Internet connection.	VM_F3.0	High
25	VM_NF6.0	Wait for stop of voice synthesis to start voice recording.	VM_F4.0	High

Table D.1: Detailed requirements defined for the Voice Module.

D.2 Detailed Requirements for the Information Module

	Identifier	Description	Priority
Structure Requirements			
1	IM_S1.0	Vertexes XML parsing.	High
2	IM_S2.0	Categories XML parsing.	High
3	IM_S2.1	Categories storage on the system.	High
4	IM_S3.0	Merge categories and vertexes information.	High
5	IM_S3.1	Create keywords database.	Medium
6	IM_S3.1.1	Keywords have spaces and categories correctly associated.	High
Functional Requirements			
7	IM_F1.0	Receive keyword from Voice Module.	High
8	IM_F1.1	Search the received keyword on keyword's database.	High
9	IM_F1.1.1	Find keyword on the database.	High
10	IM_F1.1.1.1	Deliver short list of destinations and categories associated to the received keyword.	High
11	IM_F1.1.1.1.1	Deliver more destinations and categories associated to the received keyword.	High
12	IM_F1.1.1.1.2	Request user input for selection.	High
13	IM_F1.1.1.1.2.1	Accept users selection of a specific destination of the delivered options.	High
14	IM_F1.1.1.1.2.1.1	Define user's pretended destination.	High
15	IM_F1.1.1.1.2.2	Accept user selection of a category of the delivered option.	High
16	IM_F1.1.1.1.2.2.1	Deliver short list of destinations associated to the category.	High
17	IM_F1.1.1.1.2.2.1.1	Deliver more destination associated to the category.	High
18	IM_F1.1.1.1.2.2.1.2	Accept user selection of destination.	High
19	IM_F1.1.1.1.2.2.1.2.1	Define user's pretended destination.	High
20	IM_F1.1.1.1.2.2.1.3	Accepted user to input a new keyword.	High
21	IM_F1.1.1.1.2.2.1.3.1	Back to requirement IM_F1.0.	High

	Identifier	Description	Priority
22	IM_F1.1.1.1.2.2.2	Deliver short list of subcategories associated to the selected category.	High
23	IM_F1.1.1.1.2.2.2.1	Deliver more subcategories associated to the selected category.	High
24	IM_F1.1.1.1.2.2.2.2	Accept user selection of subcategory.	High
25	IM_F1.1.1.1.2.2.2.2.1	Deliver short list of destinations associated to the subcategory.	High
26	IM_F1.1.1.1.2.2.2.2.1.1	Deliver more spaced associated to the subcategory.	High
27	IM_F1.1.1.1.2.2.2.2.1.2	Accept user selection of destination.	High
28	IM_F1.1.1.1.2.2.2.2.1.2.1	Define user's pretended destination.	High
29	IM_F1.1.1.1.2.2.2.2.1.3	Accept user input of a new keyword.	High
30	IM_F1.1.1.1.2.2.2.2.1.3.1	Back to requirement IM_F1.0.	High
31	IM_F1.1.1.1.2.2.2.3	Deliver short list of subsubcategories associated to the subcategory.	High
32	IM_F1.1.1.1.2.2.2.3.1	Deliver more subsubcategories associated to the subcategory.	High
33	IM_F1.1.1.1.2.2.2.3.2	Accept user selection of a subsubcategory.	High
34	IM_F1.1.1.1.2.2.2.3.2.1	Deliver short list of destinations associated to the subsubcategory.	High
35	IM_F1.1.1.1.2.2.2.3.2.1.1	Deliver more destinations associated to the subsubcategory.	High
36	IM_F1.1.1.1.2.2.2.3.2.1.2	Accept user selection of a destination.	High
37	IM_F1.1.1.1.2.2.2.3.2.1.2.1	Define user's pretended destination.	High
38	IM_F1.1.1.1.2.2.2.3.2.1.3	Accept user input of a new keyword.	High
39	IM_F1.1.1.1.2.2.2.3.2.1.3.1	Back to requirement IM_F1.0.	High
40	IM_F1.1.1.1.2.2.2.4	Accept user input of a new keyword.	High
41	IM_F1.1.1.1.2.2.2.4.1	Back to requirement IM_F1.0.	High
42	IM_F1.1.1.1.2.3	Accept user selection of a subcategory associated to the category.	High
43	IM_F1.1.1.1.2.3.1	Deliver short list of destinations associated to the subcategory.	High
44	IM_F1.1.1.1.2.3.1.1	Deliver more destination associated to the subcategory.	High
45	IM_F1.1.1.1.2.3.1.1.1	Accept user selection of a destination.	High
46	IM_F1.1.1.1.2.3.1.1.1.1	Define user's pretended destination.	High
47	IM_F1.1.1.1.2.3.1.1.2	Accept user input of a new keyword.	High
48	IM_F1.1.1.1.2.3.1.1.2.1	Back to requirement IM_F1.0.	High
49	IM_F1.1.1.1.2.3.2	Deliver short list of sub-subcategories associated to the subcategory.	High

	Identifier	Description	Priority
50	IM_F1.1.1.1.2.3.2.1	Deliver more sub-subcategories associated to the selected subcategory.	High
51	IM_F1.1.1.1.2.3.2.2	Accept user selection of a sub-subcategory.	High
52	IM_F1.1.1.1.2.3.2.2.1	Accept user selection of a destination.	High
53	IM_F1.1.1.1.2.3.2.2.1.1	Define user's pretended destination.	High
54	IM_F1.1.1.1.2.3.2.2.2	Accept user input of a new keyword.	High
55	IM_F1.1.1.1.2.3.2.2.2.1	Back to requirement IM_F1.0.	High
56	IM_F1.1.1.1.2.3.2.3	Accept user input of a new keyword.	High
57	IM_F1.1.1.1.2.3.2.3.1	Back to requirement IM_F1.0.	High
58	IM_F1.1.1.1.2.3.3	Accept user selection of a destination associated to the subcategory.	High
59	IM_F1.1.1.1.2.3.3.1	Deliver short list of destinations associated to the subcategory.	High
60	IM_F1.1.1.1.2.3.3.1.1	Deliver more destinations associated to the subcategory.	High
61	IM_F1.1.1.1.2.3.3.1.1.1	Accept user selection of a destination.	High
62	IM_F1.1.1.1.2.3.3.1.1.1.1	Define user's pretended destination.	High
63	IM_F1.1.1.1.2.3.3.1.1.2	Accept user input of a new keyword.	High
64	IM_F1.1.1.1.2.3.3.1.1.2.1	Back to requirement IM_F1.0.	High
65	IM_F1.1.2	Not find the keyword on the keywords database.	High
66	IM_F1.1.2.1	Request a new keyword input and deliver a short list of available categories.	High
67	IM_F1.1.2.1.1	Deliver more categories available.	High
68	IM_F1.1.2.1.2	Accept user selection of a category.	High
69	IM_F1.1.2.1.2.1	Deliver short list of destinations associated to the selected category.	High
70	IM_F1.1.2.1.2.1.1	Deliver more destinations associated to the selected category.	High
71	IM_F1.1.2.1.2.1.2	Accept user selection of a destination.	High
72	IM_F1.1.2.1.2.1.2.1	Define user's pretended destination.	High
73	IM_F1.1.2.1.2.1.3	Accept user input of a new keyword.	High
74	IM_F1.1.2.1.2.1.4	Back to requirement IM_F1.0.	High
75	IM_F1.1.2.1.2.2	Deliver short list of subcateogries associated to the selected category.	High
76	IM_F1.1.2.1.2.2.1	Deliver more subcategories associated to the selected category.	High
77	IM_F1.1.2.1.2.2.2	Accept user selection of a subcategory associated to the subcategory.	High

	Identifier	Description	Priority	
78	IM_F1.1.2.1.2.2.2.1	Deliver short list of destinations associated to the subcategory.		High
79	IM_F1.1.2.1.2.2.2.1.1	Deliver more destinations associated to the subcategory.		High
80	IM_F1.1.2.1.2.2.2.1.1.1	Accept user selection of a destination.		High
81	IM_F1.1.2.1.2.2.2.1.1.1.1	Define user's pretended destination.		High
82	IM_F1.1.2.1.2.2.2.1.1.2	Accept user input of a new keyword.		High
83	IM_F1.1.2.1.2.2.2.1.1.2.1	Back to requirement IM_F1.0.		High
84	IM_F1.1.2.1.2.2.2.2	Deliver short list of subsubcategories associated to the subcategory.		High
85	IM_F1.1.2.1.2.2.2.2.1	Deliver more subsubcategories associated to the subcategory.		High
86	IM_F1.1.2.1.2.2.2.2.2	Accept user selection of a subsubcategory.		High
87	IM_F1.1.2.1.2.2.2.2.2.1	Deliver short list of destinations associated to the subsubcategory.		High
88	IM_F1.1.2.1.2.2.2.2.2.1.1	Deliver more destinations associated to the subsubcategory.		High
89	IM_F1.1.2.1.2.2.2.2.2.1.1.1	Accept user selection of a destination.		High
90	IM_F1.1.2.1.2.2.2.2.2.1.1.1.1	Define user's pretended destination.		High
91	IM_F1.1.2.1.2.2.2.2.2.1.2	Accept user input of a new keyword.		High
92	IM_F1.1.2.1.2.2.2.2.2.1.1	Back to requirement IM_F1.0.		High
93	IM_F1.1.2.1.2.2.2.2.2.2	Accept user input of a new keyword.		High
94	IM_F1.1.2.1.2.2.2.2.2.2.1	Back to requirement IM_F1.0.		High
95	IM_F1.1.2.1.2.2.2.2.3	Accept user input of a new keyword.		High
96	IM_F1.1.2.1.2.2.2.2.3.1	Back to requirement IM_F1.0.		High
97	IM_F1.1.2.1.2.2.3	Accept user input of a new keyword.		High
98	IM_F1.1.2.1.2.2.3.1	Back to requirement IM_F1.0.		High
99	IM_F1.1.2.1.3	Accept user input of a new keyword.		High
100	IM_F1.1.2.1.3.1	ack to requirement IM_F1.0.		High
Non-Functional Requirements				
101	RM_NF1.0	Adequate time to merge information on start up.	IM_S2.1	High
102	RM_NF2.0	Fast access to the database.	IMF_1.1	High

Table D.2: Requirements defined for the Information Module.

D.3 Detailed Requirements for the Route Module

	Identifier	Requirement	Priority
Structure Requirements			
1	RM_S1.0	Vertexes XML parsing.	High
2	RM_S1.1	Vertexes storage on the system.	High
3	RM_S2.0	Edges XML parsing.	High
4	RM_S2.1	Integrate edged on the stored vertexes.	High
5	RM_S3.0	Build the weighted graph.	High
6	RM_S4.0	Identify start vertex on the graph.	High
7	RM_S5.0	Identify target vertex on the graph.	High
8	RM_S6.0	Compute shortest path with Dijkstra's algorithm.	High
Functional Requirements			
9	RM_F1.0	Start navigation.	High
10	RM_F1.1	Deliver mental image of the building on starting.	Low
11	RM_F1.2	Deliver first navigation instruction.	High
12	RM_F2.0	Iterate over positions on the built path.	High
13	RM_F3.0	Deliver navigation instruction whenever it is necessary to change direction.	High
14	RM_F4.0	Stop navigation, by reaching the end of the built path.	High
15	RM_F5.0	Stop navigation, by user request.	High
16	RM_F6.0	Receive user location from Location Module.	High
17	RM_F6.1	When not in navigation mode, deliver information about a point of interest on the vicinity.	High
18	RM_F6.2	When in navigation mode, actualize user's location on the built path.	High
19	RM_F7.0	Start a new navigation after stopped one.	High
20	RM_F8.0	Start a new navigation after completing one.	High
21	RM_F9.0	Deliver instructions about the location on the building, when not in navigation mode.	High
22	RM_F10.0	Deliver actualized navigation instructions and location on the building, when in navigation mode.	High

Table D.3: Requirements defined for the Route Module.

D.4 Detailed Requirements for the Location Module

	Identifier	Description	Father's ID	Priority
Structure Requirements				
1	LM_S1.0	Emitters XML parsing.		High
2	LM_S1.1	Store emitters information on the system.		High
3	LM_S2.0	Wall conditions XML parsing.		High
4	LM_S2.1	Store wall conditions on the system.		High
5	LM_S3.0	Vertexes XML parsing.		High
6	LM_S3.1	Store vertexes information on the system.		High
Functional Requirements				
7	LM_F1.0	Receive scanned signals and RSSI values from Bluetooth Module.		High
8	LM_F1.1	Match emitters with the stored ones.		High
9	LM_F1.2	Store matched emitters and associated RSSI values.		High
10	LM_F2.0	Convert from RSSI values to distance.		High
11	LM_F2.1	Access fingerprinting information associated to each emitter.		High
12	LM_F2.2	For those RSSI values that not match the values on fingerprinting, interpolate the correspondent distance.		High
13	LM_F3.0	Calculate receivers location.		High
14	LM_F3.1	With zero matched emitters.		High
15	LM_F3.1.1	Deliver that the location can not be known to the Route Module.		High
16	LM_F3.2	With one matched emitter.		High
17	LM_F3.2.1	Deliver the location of the emitter and the distance to there to the Route Module.		High
18	LM_F3.3	With two matched emitters.		High
19	LM_F3.3.1	Check if the distances obtained with the RSSI values enable definition of location[1].		High
20	LM_F3.3.2	Calculate two possible positions for location.		High
21	LM_F3.3.3	Check if wall conditions can invalidate one.		High
22	LM_F3.3.3.1	If wall conditions delete one, deliver the valid location to the Route Module.		High
23	LM_F3.3.3.2	If wall conditions not delete one, deliver the location of the nearest emitter and the distance to there to the Route Module.		High

	Identifier	Description	Father's ID	Priority
24	LM_F3.4	With three matched emitters.		High
25	LM_F3.4.1	Calculate location with triangulation.		High
26	LM_F3.5	With more matched emitters.		High
27	LM_F3.5.1	Select the best three RSSI values.		High
28	LM_F3.5.2	Calculate location by triangulation with those three.		High
29	LM_F3.5.2.1	Deliver location to the Route Module.		High
30	LM_F4.0	Check if the calcultated location corresponds to any stored vertex.		High
31	LM_F4.1	If yes, deliver vertex as location.		High
32	LM_F4.2	If not, deliver closest vertex and calculated location.		High
Non-Functional Requirements				
33	LM_NF 1.0	Correct interpolated distance.	LM_F2.2	High
34	LM_NF 2.0	Correct calculation of the positions.	LM_F3.3.2	High
35	LM_NF 3.0	Correct triangulation calculations.	LM_F3.4.1	High
36	LM_NF 4.0	Fast computation of triangulation.	LM_F3.5	Medium
37	LM_NF 5.0	Select the actual best three RSSI values.	LM_F3.5.2	Medium

Table D.4: Requirements defined for the Location Module.

D.5 Detailed Requirements for the Beacon Module

	Identifier	Description	Father's ID	Priority
Structure Requirements				
1	BM_S1.0	Create BluetoothAdapter.		High
2	BM_S2.0	Create BroadcastReceiver.		High
Functional Requirements				
3	BM_F1.0	Scan for Bluetooth signals.		High
4	BM_F1.1	Record RSSI value and emitters identifier.		High
5	BM_F1.2	Deliver information to the Location Module.		High
Non-Functional Requirements				
6	BM_NF1.0	Scan periods must be short to enable location at adequate times.	BM_F1.0	High

Table D.5: Requirements defined for the Beacon Module.

D.6 Detailed Requirements for the Software Integration

	Identifier	Description	Father's ID	Priority
Structure Requirements				
1	AA_S1.0	Categories XML parsing.		High
2	AA_S1.1	Categories storage on the system.		High
3	AA_S2.0	Vertexes XML parsing.		High
4	AA_S2.1	Vertexes storage on the system.		High
5	AA_S2.2	Merge categories and vertexes information.		High
6	AA_S2.3	Create keywords database.		High
7	AA_S3.0	Edges XML parsing.		High
8	AA_S3.1	Actualize vertexes on the system with edges.		High
9	AA_S3.2	Build the weighted graph.		High
10	AA_S4.0	Prepare voice inputs.		High
11	AA_S5.0	Prepare voice outputs.		High
12	AA_S6.0	Emitters XML parsing.		High
13	AA_S6.1	Store emitters information on the system.		High
14	AA_S7.0	Wall conditions XML parsing.		High
15	AA_S7.1	Store wall conditions on the system.		High
16	AA_S8.0	The application has to require minimal user interaction with screen.		High
17	AA_S 8.1	The application should have a maximum of two buttons.		High
Functional Requirements				
18	AA_F9.0	Without user interaction deliver the name of points of interest as user approaches them.		High
19	AA_F10.0	Accept user request to start a navigation, may be through a button.		High
20	AA_F10.1	Request user a spoken keyword related to what is the intented destination.		High
21	AA_F10.1.1	If the system recognizes the keyword, deliver the associated places with the synthesizer.		High
22	AA_F10.1.1.1	Accept user selection of a destination, with voice instructions.		High
23	AA_F10.1.2	If the system does not recognizes the keyword, request a new one with the synthesizer.		High

	Identifier	Description	Father's ID	Priority
24	AA_F11.0	Information system have to function as the Information Module functions.		High
25	AA_F11.1	When defined a destination, compute the shortest path to there.		High
26	AA_F11.1.1	Deliver voice instructions to guide the user to there.		High
27	AA_F12.0	Accept user request for help, may be through a button.		High
28	AA_F12.1	Deliver help instructions anytime.		High
29	AA_F12.1.1	If in navigation mode, deliver the actual position and the actualized navigation instruction with the synthesizer.		High
30	AA_F12.1.2	In not in navigation mode, deliver the actual position with the synthesizer.		High
31	AA_F13.0	In navigation mode, accept user request to stop navigation, may be through a button.		High
32	AA_F14.0	In navigation mode, automatically deliver navigation instructions.		High
33	AA_F15.0	After complete or stop a navigation, accept user request to start a new one.		High
34	AA_F15.1	Start a new navigation.		High
Non-Functional Requirements				
35	AA_NF1.0	Keywords have spaces and categories correctly associated.	AA_S2.3	High
36	AA_NF2.0	Adequate computation time to build the graph.	AA_S3.2	Medium
37	AA_NF3.0	System reaction to the user request should be adequate.	AA_F10.1	High
38	AA_NF4.0	Keyword matching should be fast.	AA_F10.1.1	Medium
39	AA_NF5.0	Path computation should have adequate performance.	AA_F11.1	Medium
40	AA_NF6.0	Navigation instructions must be delivered when the user need them.	AA_F14.0	High

Table D.6: Requirements defined for the Software Integration.

Appendix E

Location Module Testing Calculations

Regarding the designed scenarios, figure 5.8 and 5.8, were calculated distances between points and each emitter, which were then converted into RSSI values. Distance is given with equation E.1 and the RSSI values with equation 4.1 from the fingerprinting values, on table 5.1. On the second scenario only were used emitters at a distance no greater than 12 meters from each point. The calculates values are presented on the following tables.

$$D = \sqrt{(x_b - x_a)^2 + (y_b - y_a)^2} \tag{E.1}$$

Equation above delivers the distance, D, between points A(x_a,y_a) and B(x_b,y_b).

E.1 Test Scenario 1

	A	B	C
X	5	20	10
Y	0	0	10

Table E.1: Location of emitters on scenario 1. Positions are presented in meters.

			Distance			RSSI			RSSI used		
	X	Y	A	B	C	A	B	C	A	B	C
P1	10	5	7.071	11.18	5.000	-75.355	-95.355	-65.000	-75	-95	-65
P2	10	0	5.000	10.000	10.000	-65.000	-90.000	-90.000	-65	-90	-90
P3	12	7	9.899	10.630	3.606	-89.498	-93.150	-58.028	-89	-93	-58
P4	5	8	8.000	17.000	5.385	-80.000	-	-65.000	-80	-	-65
P5	22	10	19.723	10.198	12.000	-120.000	-90.990	-100.000	-120	-91	-100
P6	27	3	22.204	7.616	18.385	-	-78.079	-	-	-78	-

Table E.2: Values that lead to the calculation of the RSSI values to be used in testing on scenario 1. Distance values are presented in meters and RSSI values in dBm.

Some RSSI values were intentionally not calculated to evaluate the system on that conditions.

E.2 Test Scenario 2

	A	B	C	D	E	F	G	H	I
X	5	18	32	35	30	18	14	0	0
Y	0	0	0	10	23	23	27	30	15

Table E.3: Location of emitters on scenario 2. Positions are presented in meters.

		P1	P2	P3	P4	P5	P6
	X	34	32.5	13	27	13	5
	Y	11	21	22	10	4	25
Distance	A	31.016	34.601	23.409	24.166	**8.944**	25.000
	B	19.416	25.520	22.561	13.454	**6.403**	28.178
	C	**11.180**	21.006	29.0689	**11.180**	19.416	36.797
	D	**1.414**	**11.281**	25.0599	**8.000**	22.804	33.541
	E	12.649	**3.202**	17.029	13.342	25.495	25.080
	F	20.000	14.637	**5.099**	15.811	19.647	13.153
	G	25.613	19.449	**5.099**	21.401	23.022	**9.220**
	H	38.949	33.723	15.264	33.601	29.069	**7.071**
	I	34.234	33.049	14.765	27.459	17.029	**11.180**
RSSI	A	-	-	-	-	-84.721	-
	B	-	-	-	-	-72.016	-
	C	-95.902	-	-	-95.902	-	-
	D	-47.071	-96.403	-	-80.00	-	-
	E	-	-56.008	-	-	-	-
	F	-	-	-65.007	-	-	-
	G	-	-	-65.007	-	-	-86.098
	H	-	-	-	-	-	-75.355
	I	-	-	-	-	-	-95.902

Table E.4: Values that lead to the calculation of the RSSI values to be used in testing on scenario 2. Distance values are presented in meters and RSSI values in dBm.

P1		P2		P3		P4		P5		P6	
C	-96	D	-96	F	-65	C	-96	A	-85	G	-86
D	-47	E	-56	G	-65	D	-80	B	-72	H	-75
										I	-96

Table E.5: RSSI values in dBm used with each point.

Appendix F

Bluetooth Fingerprinting Primary Results

Distance	Average	Max	Min	Standard Deviation	Percentile 90	Confidence Interval
1	-65.60	-59	-95	7.321	-62	2.029
2	-66.12	-58	-91	5.699	-61	1.580
3	-70.24	-52	-83	5.029	-67	1.394
4	-71.52	-68	-95	3.924	-68	1.088
5	-72.12	-54	-76	3.567	-70	0.989
6	-77.84	-74	-97	5.168	-75	1.432
7	-84.68	-77	-100	5.408	-78	1.499
8	-80.28	-49	-95	10.254	-77.2	2.842
9	-82.58	-78	-95	3.417	-79	0.947
10	-79.46	-75	-87	3.327	-76	0.922
11	-80.84	-75	-88	2.675	-77	0.742
12	-82.88	-77	-92	3.679	-78	1.020
13	-84.30	-79	-94	3.872	-80	1.073
14	-82.80	-79	-87	2.321	-80	0.643
15	-84.36	-78	-92	3.218	-80	0.892
16	-83.48	-80	-91	2.682	-81	0.743
17	-84.98	-80	-90	2.527	-82.9	0.701
18	-88.06	-84	-99	3.158	-85	0.875
19	-87.82	-83	-97	3.837	-84	1.064
20	-90.88	-86	-98	3.268	-87.9	0.906
21	-91.02	-86	-96	3.040	-87	0.843
22	-91.42	-87	-97	2.836	-88	0.786
23	-90.48	-87	-96	1.776	-88	0.492
24	-91.54	-87	-96	2.659	-87.9	0.737
25	-90.70	-87	-99	3.466	-87	0.961
26	-93.02	-89	-97	1.647	-91.9	0.457

Table F.1: Statistical information of the experimental study of relation between RSSI values and distance.

Appendix G

Calculations for Software Integration Testing

ID	X	Y	Floor
E1	107,5	5,2	1
E2	104,5	8	1
E3	102	5,2	1
E4	101	11	2
E5	100	8	1
E6	97	5,2	1
E7	94	8	1
E8	90	5,2	1
E9	87	10	1
E10	83	5,2	1
E11	81	8	1
E12	75	8	1
E13	70	5,2	1
E14	101	11	3
E15	104	7,5	3
E16	97,5	5,2	3
E17	92,9	7,5	3
E18	87,5	5,2	3
E19	79,4	7,5	3

Table G.1: Location of emitters used in the simulation.

G.1 Test Route 1

P1	76,7	5,2	1	P14	92,3	5,2	1
P2	77,9	5,2	1	P15	93,5	5,2	1
P3	79,1	5,2	1	P16	94,7	5,2	1
P4	80,3	5,2	1	P17	95,9	5,2	1
P5	81,5	5,2	1	P18	97,1	5,2	1
P6	82,7	5,2	1	P19	98,3	5,2	1
P7	83,9	5,2	1	P20	99,5	5,2	1
P8	85,1	5,2	1	P21	100,7	5,2	1
P9	86,3	5,2	1	P22	101	5,2	1
P10	87,5	5,2	1	P23	101	4	1
P11	88,7	5,2	1	P24	101	2,8	1
P12	89,9	5,2	1	P25	101	1,6	1
P13	91,1	5,2	1	P26	101	0	1

Table G.2: Location of measure points in Test Route 1. Values are presented in meters.

RSSI values here presented were calculated with equations E.1 and 4.1, already explained.

Emitter	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
E1	-	-	-	-	-	-	-	-	-	-	-	-	-
E2	-	-	-	-	-	-	-	-	-	-	-	-	-
E3	-	-	-	-	-	-	-	-	-	-	-	-	-94
E4	-	-	-	-	-	-	-	-	-	-	-	-	-97
E5	-	-	-	-	-	-	-	-	-	-	-98	-92	-87
E6	-	-	-	-	-	-	-	-99	-93	-87	-81	-75	-69
E7	-	-	-	-	-	-98	-92	-87	-81	-75	-70	-65	-60
E8	-	-	-95	-88	-82	-76	-70	-64	-58	-52	-46	-40	-46
E9	-97	-91	-86	-81	-76	-72	-69	-66	-64	-64	-65	-68	-72
E10	-72	-66	-60	-53	-47	-41	-45	-51	-57	-63	-69	-75	-81
E11	-66	-61	-57	-54	-54	-56	-60	-65	-70	-75	-81	-87	-92
E12	-56	-60	-65	-70	-75	-81	-87	-92	-98	-	-	-	-
E13	-74	-80	-86	-92	-98	-	-	-	-	-	-	-	-

	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26
E1	-	-	-	-98	-92	-86	-80	-74	-73	-73	-75	-77	-82
E2	-	-97	-91	-85	-80	-74	-69	-64	-62	-67	-71	-76	-84
E3	-88	-82	-76	-70	-64	-58	-52	-46	-45	-48	-53	-59	-66
E4	-92	-87	-83	-79	-75	-72	-70	-69	-69	-75	-81	-87	-95
E5	-81	-75	-70	-65	-60	-56	-54	-54	-55	-61	-66	-72	-80
E6	-63	-57	-51	-45	-41	-47	-53	-59	-60	-61	-63	-67	-73
E7	-56	-54	-54	-57	-61	-66	-71	-76	-78	-80	-84	-87	-93
E8	-52	-58	-64	-70	-76	-82	-88	-94	-95	-95	-96	-98	-
E9	-76	-80	-85	-91	-96	-	-	-	-	-	-	-	-
E10	-87	-93	-99	-	-	-	-	-	-	-	-	-	-
E11	-98	-	-	-	-	-	-	-	-	-	-	-	-
E12	-	-	-	-	-	-	-	-	-	-	-	-	-
E13	-	-	-	-	-	-	-	-	-	-	-	-	-

Table G.3: RSSI values used on each measure point in Test Route 1. Values are presented in dBm.

G.2 Test Route 2

	X	Y	Floor		X	Y	Floor
P1	106,4	5,2	1	P17	99,8	5,2	3
P2	105,2	5,2	1	P18	98,6	5,2	3
P3	104,0	5,2	1	P19	97,4	5,2	3
P4	102,8	5,2	1	P20	96,2	4,0	3
P5	101,0	5,2	1	P21	95,0	5,2	3
P6	101,0	6,4	1	P22	93,8	5,2	3
P7	101,0	7,6	1	P23	92,6	5,2	3
P8	101,0	8,8	1	P24	91,4	4,0	3
P9	101,0	10,0	1	P25	90,2	5,2	3
P10	102,0	10,0	1	P26	89,0	5,2	3
P11	102,0	10,0	3	P27	87,8	5,2	3
P12	101,0	10,0	3	P28	86,6	4,0	3
P13	101,0	8,8	3	P29	85,4	5,2	3
P14	101,0	7,6	3	P30	84,2	5,2	3
P15	101,0	6,4	3	P31	83,0	5,2	3
P16	101,0	5,2	3	P32	82,1	5,2	3

Table G.4: Location of measure points in Test Route 2. Values are presented in meters.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
E1	-46	-52	-58	-64	-73	-73	-75	-77	-80	-77	-	-	-	-	-	-
E2	-57	-54	-54	-56	-62	-59	-58	-58	-60	-56	-	-	-	-	-	-
E3	-62	-56	-50	-44	-45	-48	-53	-59	-65	-64	-	-	-	-	-	-
E4	-80	-76	-73	-70	-69	-63	-57	-51	-45	-47	-	-	-	-	-	-
E5	-75	-70	-64	-60	-55	-49	-45	-46	-51	-54	-	-	-	-	-	-
E6	-87	-81	-75	-69	-60	-61	-63	-67	-71	-75	-	-	-	-	-	-
E7	-	-98	-92	-86	-78	-76	-75	-75	-76	-81	-	-	-	-	-	-
E8	-	-	-	-	-95	-95	-96	-98	-	-	-	-	-	-	-	-
E14	-	-	-	-	-	-	-	-	-	-	-47	-45	-51	-57	-63	-69
E15	-	-	-	-	-	-	-	-	-	-	-56	-60	-56	-55	-56	-59
E16	-	-	-	-	-	-	-	-	-	-	-73	-70	-65	-61	-59	-58
E17	-	-	-	-	-	-	-	-	-	-	-87	-82	-81	-81	-81	-82
E18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	P17	P18	P19	P20	P21	P22	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32
E14	-70	-71	-74	-82	-82	-86	-91	-99	-	-	-	-	-	-	-	-
E15	-64	-69	-75	-83	-86	-92	-98	-	-	-	-	-	-	-	-	-
E16	-52	-46	-41	-49	-53	-59	-65	-71	-77	-83	-89	-95	-	-	-	-
E17	-76	-71	-65	-64	-56	-52	-52	-59	-58	-63	-68	-76	-79	-85	-91	-95
E18	-	-96	-90	-84	-77	-71	-65	-60	-53	-47	-41	-48	-51	-57	-63	-67
E19	-	-	-	-	-	-	-	-	-95	-89	-84	-80	-72	-67	-61	-58

Table G.5: RSSI values used on each measure point in Test Route 2. Values are presented in dBm.

G.3 Test Route 3

	X	Y	Floor
P1	102,0	10,0	3
P2	101,0	10,0	3
P3	101,0	8,8	3
P4	101,0	7,6	3
P5	101,0	6,4	3
P6	101,0	5,2	3
P7	102,2	5,2	3
P8	103,4	5,2	3
P9	104,6	5,2	3
P10	105,8	5,2	3
P11	107,0	5,2	3

Table G.6: Location of measure points in Test Route 3. Values are presented in meters.

	E14	E15	E16	E17
P1	-47	-56	-73	-87
P2	-45	-60	-70	-82
P3	-51	-56	-65	-81
P4	-57	-55	-61	-81
P5	-63	-56	-59	-81
P6	-69	-59	-58	-82
P7	-70	-55	-64	-88
P8	-71	-52	-70	-94
P9	-74	-52	-76	-100
P10	-78	-55	-82	-
P11	-82	-59	-88	-

Table G.7: RSSI values used on each measure point in Test Route 3. Values are presented in dBm.

Appendix H

Detailed Test Cases and Test Results

H.1 Test Cases and Test Results for the Voice Module

	Identifier	Description	Expected behavior	Result
1	VM_TC1.0	Say a word.	Deliver recognized word as text.	Pass
2	VM_TC1.1	Say “café”.	Deliver “café”.	Pass
3	VM_TC1.2	Say “roupa”.	Deliver “roupa”.	Pass
4	VM_TC1.3	Say “calças”.	Deliver “calças”.	Pass
5	VM_TC1.4	Say “casa de banho”.	Deliver “casa de banho ”.	Pass
6	VM_TC1.5	Say “WC”.	Deliver “WC”.	Pass
7	VM_TC1.6	Say “crianças”.	Deliver “crianças”.	Pass
8	VM_TC1.7	Say “Tiffosi”.	Deliver “Tiffosi”.	Fail
9	VM_TC1.8	Say “Parfois”.	Deliver “Parfois”.	Fail
10	VM_TC2.0	Type a phrase.	Deliver phrase as speech.	Pass
11	VM_TC2.1	Enter “O que pretende encontrar?”.	Deliver “O que pretende encontrar?”.	Pass
12	VM_TC2.2	Enter “Destino selecionado: Jumbo.”.	Deliver “Destino selecionado: Jumbo”.	Pass
13	VM_TC2.3	Enter “Siga 5 metros em frente.”.	Deliver “Siga 5 metros em frente”.	Pass

	Identifier	Description	Expected behavior	Result
14	VM_TC2.4	Enter "Chegou ao seu destino.".	Deliver "Chegou ao seu destino".	Pass
15	VM_TC2.5	Enter "Dielmar encontra-se 5 metros à sua esquerda".	Deliver "Dielmar encontra-se 5 metros à sua esquerda".	Pass
16	VM_TC2.6	Enter "Selecione uma das categorias: Moda, Saúde, Restauração.".	Deliver "Selecione uma das categorias: Moda, Saúde, Restauração.".	Pass
17	VM_TC2.7	Enter "Não foram encontrados resultados para a sua pesquisa.".	Deliver "Não foram encontrados resultados para a sua pesquisa.".	Pass
18	VM_TC3.0	Say a word to confirmation.	Request confirmation with speech.	Pass
19	VM_TC3.1	Say "café".	Deliver "Confirma café?".	Pass
20	VM_TC3.2	Say "roupa".	Deliver "Confirma roupa?".	Pass
21	VM_TC3.3	Say "calças".	Deliver "Confirma calças?".	Pass
22	VM_TC3.4	Say "casa de banho".	Deliver "Confirma casa de banho?".	Pass
23	VM_TC3.5	Say "WC".	Deliver "Confirma WC?".	Pass
24	VM_TC3.6	Say "crianças".	Deliver "Confirma crianças?".	Pass
25	VM_TC3.7	Say "Tiffosi".	Deliver "Confirma Tiffosi ?".	Pass*
26	VM_TC4.0	Confirm words from VM_UC3.1 to VM_UC3.7.	Deliver word as speech or request input for another word.	
27	VM_TC4.1	Say "sim".	Deliver "café" as text.	Pass
28	VM_TC4.2	Say "confirmo".	Deliver "roupa" as text.	Pass
29	VM_TC4.3	Say "confirmado".	Deliver "calças" as text.	Pass
30	VM_TC4.4	Say "não".	Request another word.	Pass
31	VM_TC4.5	Say "não confirmo".	Request another word.	Pass
32	VM_TC4.6	Say "errado".	Request another word.	Pass
33	VM_TC4.7	Say "incorreto".	Request another word.	Pass

Table H.1: Test cases and test results for the Voice Module.

H.2 Test Cases and Test Results for the Information Module

	Identifier	Description	Expected behavior	Result
1	IM_TC1.0	Input “relógio”.	Deliver “Boutique dos Relógios - 1, Góis Time & Secrets - 2, Magnólia - 3”.	Pass
2	IM_TC1.1	Input “1” for select Boutique dos Relógios.	Define destination and deliver it as text.	Pass
3	IM_TC1.2	Input “2” for select Góis Time & Secrets.	Define destination and deliver it as text.	Pass
4	IM_TC1.3	Input “4” for more options.	Deliver “Categoria Outros - 1, Subcategoria Relojoaria - 2”.	Pass
5	IM_TC1.4	Input “animais”.	Deliver “Reino dos Bichos - 1, Categoria Outros - 2, Subcategoria Animais - 3”.	Pass
6	IM_TC2.0	Input “livros”.	Deliver “Bertrand - 1, Categoria Cultura - 2”.	Pass
7	IM_TC2.1	Input “2” for select category “Cultura”.	Deliver “Bertrand - 1”.	Pass
8	IM_TC2.2	Input “1” for select Bertrand.	Define destination and deliver it as text.	Pass
9	IM_TC3.0	Input “informações”.	Deliver “Balcão de Atendimento ao Cliente - 1, Categoria Serviços - 2, Subcategoria Informações - 3”.	Pass
10	IM_TC3.1	Input “2” for select category “Serviços”.	Deliver “Limpeza - 1, Casa de Banho - 2, Informações - 3”.	Pass
11	IM_TC3.2	Input “1” for delect subcategory “Limpeza”.	Deliver “5 à Fil - 1, 5 à Sec - 2”.	Pass
12	IM_TC3.3	Input “2” for select 5 à Sec.	Define destination and deliver it as text.	Pass
13	IM_TC3.4	Input “cosmética”.	Deliver “The Body Shop - 1”.	Pass
14	IM_TC4.0	Input “vestuário”.	Deliver “Sfera - 1, Stradivarius - 2, Tiffosi Denim - 3”.	Pass

	Identifier	Description	Expected behavior	Result
15	IM_TC4.1	Input "4" for more options.	Deliver "Ana Sousa - 1, Devernois - 2, Dielmar - 3".	Pass
16	IM_TC4.2	Input "4" for more options.	Deliver "Gant - 1, Lanidor - 2, Categoria Moda - 3".	Pass
17	IM_TC4.3	Input "3" for select category "Moda".	Deliver "Sapataria - 1, Roupa - 2, Acessórios - 3".	Pass
18	IM_TC4.4	Input "2" for select subcategory "Roupa".	Deliver "Homem - 1, Mulher - 2, Jovem - 3".	Pass
19	IM_TC4.5	Input "2" for select subsubcategory "Mulher".	Deliver "Casa das Peles - 1, Massimo Dutti - 2, Oysho - 3".	Pass
20	IM_TC4.6	Input "3" for select Oysho.	Define destination and deliver it as text.	Pass
21	IM_TC4.7	Input "correios", a not recognized keyword.	Deliver information that can not find association to that word, and deliver categories available for selection.	Pass
22	IM_TC 4.8	Input "3" for select category "Restauração".	Deliver "Lanche - 1, Refeição - 2".	Pass
23	IM_TC 4.9	Input "9".	Deliver information that can not find association to that word, and deliver categories available for selection.	Pass

Table H.2: Use cases defined for the Information Module.

H.3 Test Cases and Test Results for the Route Module

	Identifier	Description	Expected behavior	Result
1	RM_TC1.0	Define start and target vertex.	Compute shortest path, deliver mental image of the building and deliver first navigation instruction.	Pass
2	RM_TC1.1	Start “porta0” and target “cisuc”.	Compute shortest path, deliver mental image of the building and deliver first navigation instruction “Siga para este, à sua direita, cerca de 3 metros”.	Pass
3	RM_TC1.2	Start “cisuc” and target “porta0”.	Compute shortest path, deliver mental image of the building and deliver first navigation instruction “Siga para norte, em frente, cerca de 5 metros”.	Pass
4	RM_TC1.3	Start “d2.19” and target “d1.11”.	Compute shortest path, deliver mental image of the building and deliver first navigation instruction “Siga para este, à sua direita, cerca de 8 metros”.	Pass
5	RM_TC1.4	Start “d3.18” and target “d2.23”.	Compute shortest path, deliver mental image of the building and deliver first navigation instruction “Siga para oeste, à sua esquerda, certa de 14 metros”.	Pass
6	RM_TC1.5	Start “d1.12” and target “d3.7”.	Compute shortest path, deliver mental image of the building and deliver first navigation instruction “Siga para este, à sua direita, cerca de 3 metros”.	Pass
7	RM_TC2.0	Iterate over path positions.	Deliver navigation instructions when it is necessary to change direction.	Pass
8	RM_TC2.1	Reach the vertex “10-0_RC”.	Deliver “Siga para norte, à sua esquerda, cerca de 5 metros”.	Pass
9	RM_TC2.2	Reach the vertex “10-5.2_RC”.	Deliver “Siga para sul, à sua esqueda, cerca de 5 metros ”.	Pass
10	RM_TC2.3	Reach the vertex “d2.20”.	Deliver “Siga para este, em frente, cerca de 5 metros”.	Pass
11	RM_TC2.4	Reach the vertex “d3.17”.	Deliver “Siga para oeste, em frente, cerca de 11 metros”.	Pass
12	RM_TC2.5	Reach the vertex “wcE_P3”.	Deliver “Siga para oeste, à sua direita, cerca de 22 metros”.	Pass
13	RM_TC3.0	Request for help on navigation.	Deliver actualized navigation instruction.	Pass

	Identifier	Description	Expected behavior	Result
14	RM_TC3.1	Request for help on vertex "d1.9".	Deliver "Siga para este, em frente, cerca de 38 metros".	Pass
15	RM_TC3.2	Request for help on vertex "d1.12".	Deliver "Siga para oeste, em frente, cerca de 61 metros".	Pass
16	RM_TC3.3	Request for help on vertex "74-10_P2".	Deliver "Siga pelo elevador à sua direita para o andar 1".	Pass
17	RM_TC3.4	Request for help on vertex "elevatorE_P3".	Deliver "Siga pelo elevador para o andar 2".	Pass
18	RM_TC3.5	Request for help on vertex "d3.12".	Deliver "Siga para oeste, em frente, cerca de 16 metros".	Pass
19	RM_TC4.0	Stop navigation while in navigation mode.	Stop navigation and deliver message confirming it.	Pass
20	RM_TC4.1	Stop navigation on vertex "d1.4".	Stop navigation and deliver message confirming it.	Pass
21	RM_TC4.2	Stop navigation on vertex "10-0_RC".	Stop navigation and deliver message confirming it.	Pass
22	RM_TC4.3	Stop navigation on vertex "d1.12".	Stop navigation and deliver message confirming it.	Pass
23	RM_TC4.4	Stop navigation on vertex "d3.15".	Stop navigation and deliver message confirming it.	Pass
24	RM_TC4.5	Stop navigation on vertex "elevatorE_RC".	Stop navigation and deliver message confirming it.	Pass
25	RM_TC5.0	Reach the destination.	Deliver information message.	Pass
26	RM_TC5.1	Reach the destination "cisuc".	Deliver information message.	Pass
27	RM_TC5.2	Reach the destination "porta0".	Deliver information message.	Pass
28	RM_TC5.3	Reach the destination "d1.11".	Deliver information message.	Pass
29	RM_TC5.4	Reach the destination "d2.23".	Deliver information message.	Pass
30	RM_TC5.5	Reach the destination "d3.7".	Deliver information message.	Pass
31	RM_TC6.0	While not in navigation, request for help.	If location corresponds to a vertex, deliver vertexes name and location on the building. If location not corresponds to any vertex, deliver just location on the building.	Pass
32	RM_TC6.1	Request help on vertex "d3.18".	Deliver "Encontra-se em Globe, a este do piso 3".	Pass
33	RM_TC6.2	Request help on vertex "wcE_P2".	Deliver "Encontra-se em WC, a este do piso 2".	Pass

	Identifier	Description	Expected behavior	Result
34	RM_TC6.3	Request help on vertex "cisuc".	Deliver "Encontra-se na Tabacaria Alvorada, na extremidade este do piso 1".	Pass
35	RM_TC6.4	Request help on vertex "10-5.2_RC".	Deliver "Encontra-se no piso 1, na extremidade oeste".	Pass
36	RM_TC6.5	Request help on vertex "elevatorG_P3".	Deliver "Encontra-se em elevador, na extremidade este do piso 3".	Pass

Table H.3: Use cases defined for the Route Module.

H.4 Test Cases and Test Results for the Location Module

	Identifier	Description	Expected behavior	Result
1	LM_TC1.0	Convert from RSSI values to distance with fingerprinting information of each emitter.	Deliver correct distance.	Pass
2	LM_TC1.1	RSSI value is 0 dBm.	Deliver distance null.	Pass
3	LM_TC1.2	RSSI value is 50 dBm.	Deliver distance null.	Pass
4	LM_TC1.3	RSSI value is -50 dBm.	Deliver distance of 2 meters.	Pass
5	LM_TC1.4	RSSI value is -57 dBm.	Deliver distance of 3.4 meters.	Pass
6	LM_TC1.5	RSSI value is -83 dBm.	Deliver distance of 8.6 meters.	Pass
7	LM_TC1.6	RSSI value is -95 dBm.	Deliver distance of 11 meters.	Pass
8	LM_TC1.7	RSSI value is -120 dBm.	Deliver distance null.	Pass
9	LM_TC2.0	Compute location with zero RSSI values.	Deliver location null.	Pass
10	LM_TC2.1	Compute location with one RSSI value of -60 dBm.	Deliver position of the emitter, defined as (10,10) and distance to there of 4 m.	Pass
11	LM_TC3.0	Compute known locations on scenario 1, figure 5.8.	Deliver known position.	Pass
12	LM_TC3.1	Compute position P1.	Deliver position (10,5).	Pass*
13	LM_TC3.2	Compute position P2.	Deliver position (10,0).	Pass
14	LM_TC3.3	Compute position P3.	Deliver position (12,7).	Pass*
15	LM_TC3.4	Compute position P4.	Deliver position of the nearest emitter, (10,10), and distance to there, 5m.	Pass

	Identifier	Description	Expected behavior	Result
16	LM_TC3.5	Compute position P5.	Deliver position (22,10).	Pass
17	LM_TC3.6	Compute position P6.	Deliver position of the nearest emitter, (20,0), and distance to there, 7.6m.	Pass
18	LM_TC4.0	Compute known locations on scenario 2, figure 5.9.	Deliver known position.	Pass
19	LM_TC4.1	Compute position P1.	Deliver position (34,11).	Pass
20	LM_TC4.2	Compute position P2.	Deliver position of the nearest emitter, (30,23), and distance to there, 3.2m.	Pass
21	LM_TC4.3	Compute position P3.	Deliver position (13,22).	Pass*
22	LM_TC4.4	Compute position P4.	Deliver position (27,10).	Pass
23	LM_TC4.5	Compute position P5.	Deliver position (13,4).	Pass
24	LM_TC4.6	Compute position P6.	Deliver position (5,25).	Pass*

Table H.4: Use cases defined for the Location Module.

H.5 Test Cases and Test Results for the Software Integration

	Identifier	Description	Expected behavior	Result
1	AA_TC1.0	Not in navigation mode, approach a point of interest.	Deliver information about the point of interest.	Pass
2	AA_TC1.1	Approach the “XX1” vertex.	Deliver “XX1 is on your left/right”.	Pass
3	AA_TC1.2	Approach the “XX2” vertex.	Deliver “XX2 is on your left/right”.	Pass
4	AA_TC2.0	Request to start a new navigation.	Request the user a keyword to the intended destination.	Pass
5	AA_TC2.1	Say keyword “café”.	Deliver associated places “Café Delta - 1, Café Nicola - 2, Quiosque dos Sabores - 3”, and request user selection.	Pass
6	AA_TC2.1.1	Say number of the intended destination.	Define destination and start navigation.	Pass
7	AA_TC2.1.1.1	Say “1” for Café Delta.	Deliver “Destino selecionado: Café Delta” and start navigation.	Pass
8	AA_TC2.1.1.1	Say “2” for Quiosque dos Sabores.	Deliver “Destino selecionado: Quiosque dos sabores” and start navigation.	Pass
9	AA_TC2.1.2	Say “4” for more options.	Deliver more options “Categoria Restauração - 1, Subcategoria Lanche - 2”.	Pass

	Identifier	Description	Expected behavior	Result
10	AA_UC2.1.3	Say keyword "roupa".	Deliver associated places "Bershka - 1, Giovanni Galli - 2, Massimo Dutti - 3", and request user selection.	Pass
11	AA_TC2.1.3.1	Say "4" for more options.	Deliver more options "Pull & Bear - 1, Salsa - 2, Sfera - 3".	Pass
12	AA_TC2.1.3.1.1	Say "4" for more options.	Deliver more options "Stradivarius - 1, Tiffosi Denim - 2, Ana Sousa - 3".	Pass
13	AA_TC2.1.3.1.1.1	Say "4" for more options.	Deliver more options "Chicco - 1, Devernois - 2, Dielmar - 3".	Pass
14	AA_TC2.1.3.1.1.1.1	Say "4" for more options.	Deliver more options "Gant - 1, Girandola - 2, Gocco - 3".	Pass
15	AA_TC2.1.3.1.1.1.1.1	Say "4" for more options.	Deliver more options "Lanidor - 1, Categoria Moda - 2, Subcategoria roupa - 3".	Pass
16	AA_TC2.1.3.1.1.1.1.1	Say "2" for Categoria Moda.	Deliver options "Saparatia - 1, Roupa - 2, Acessórios".	Pass
17	AA_TC3.0	Once selection is complete, start navigation.	Deliver mental image of the building, relative actual position on the building, and first navigation instruction.	Pass
18	AA_TC3.1	Test Route 1: Actual position "Just Repair It", destination selected "Tabacaria Alvorada".	Deliver mental image of the building, relative actual position, "Encontra-se no piso 1, a este", and first navigation instruction, "Siga para este, à sua direita, cerca de 24 metros".	Pass
19	AA_TC3.1.1	Request help on vertex D1.17.	Deliver actualized navigation instruction, "Siga para este, em frente, cerca de 14 metros".	Pass
20	AA_TC3.1.2	Reach vertex 101-5.2_RC.	Deliver navigation instruction to change direction, "Siga para sul, à sua direita, cerca de 5 metros".	Pass
21	AA_TC3.1.3	Reach the target vertex.	Deliver end message, "Chegou ao seu destino", and stop navigation.	Pass
22	AA_TC3.2	Test Route 2: Actual position "Smile Up", destination selected "Geox".	Deliver mental image of the building, relative actual position, "Encontra-se no piso 1, na extremidade este", and first navigation instruction, "Siga para oeste, à sua esquerda, cerca de 5 metros".	Pass
23	AA_TC3.2.1	Reach vertex 101-5.2_RC.	Deliver navigation instruction to change direction, "Siga para norte, à sua direita, cerca de 5 metros".	Pass
24	AA_TC3.2.2	Reach vertex 101-10_RC.	Deliver navigation instruction to catch the lift, "Siga pelo elevador à sua direita para o andar 3".	Pass

Table H.5: Use cases defined for the application.

	Identifier	Description	Expected behavior	Result
25	AA_TC3.2.3	Reach vertex D3.19 and stop navigation.	Deliver end message, “Terminou a navegação”, and stop navigation.	Pass
26	AA_TC3.2.3.1	Request help on vertex D3.19.	Deliver vertex name and relative position, “Encontra-se em Gocco, a este do piso 3”.	Pass
27	AA_TC3.3	Test Route 3: in test route 2, choose wrong direction on D3.22 and reach D2.23.	Deliver message reporting the wrong direction, “Direção errada”, and actualized navigation instruction, “Para Geox, inverta a direção, e siga cerca de 24 metros”.	Pass

Table H.6: Use cases defined for the application.

H.6 Tests Not Completely Successful or Unsuccessful

	Test case ID	Result	Severity	Summary	Comments
1	VM_TC1.7	Fail	High	Does not recognize word.	Tries to recognize Portuguese words.
2	VM_TC1.8	Fail	High	Does not recognize word.	Tries to recognize Portuguese words.
3	VM_TC3.7	Pass	Medium	Does not properly say a word.	Speech proffered in Portuguese. "Tiffosi" is not correctly said, but the intended meaning is understandable.
4	LM_TC3.1	Pass	Low	Delivers position (10,4.9).	Delivered position differs 0.1m from the correct, considered not relevant for the usage.
5	LM_TC3.3	Pass	Low	Delivers position (11.9,6.9).	Delivered position differs 0.14m from the correct, considered not relevant for the usage..
6	LM_TC4.3	Pass	Low	Delivers position (13.1,22.1).	Delivered position differs 0.14m from the correct, considered not relevant for the usage..
7	LM_TC4.6	Pass	Low	Delivers position (4.9,25.2).	Delivered position differs 0.22m from the correct, considered not relevant for the usage..

Table H.7: Detail of the tests not completely successful or unsuccessful.

Appendix I

Accepted Papers

Assistive system for Blind People on Shopping

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Abstract. An assitive system to assist blind people on shopping is proposed. *abstract* environment.

Keywords: Blind Systems, Assistive Technology, Indoor Location, Blind People

1 Extended Abstract

Public buildings are changing constantly, often people have to take different routes to reach known destinations. New spaces and services are appearing or disappearing according to the market roles. This feature is clearest on shopping centers, as brands and store owners are constantly changing spaces, structures and services to attract and please customers. These changes are almost always signaled and labeled with visual marks and signs. Sometimes other useful information is available through visual means. In this context, blind and partially sighted people are deprived from a strong and widely used information channel, leading to their exclusion from the society.

In this context we propose an assisting technology to help visually impaired persons on theirs trips to public buildings, particularly in shopping centers. The system incorporates robust knowledge capable to guide a person to a specific destination or even to choose one.

Currently, there are several systems designed to assist visually impaired persons in supermarket. For instance, ShopTalk [1], BlindShopping [2], RoboCart [3] are systems designed to help visually impaired people finding specific products inside a supermarket. Those systems guide the user to the desired product with voice based instructions. Typically, they were designed for specific hardware and cannot be easily applied in other contexts.

Different systems based on RFID technology [6] were also proposed to assist visually impaired persons (e.g. BlindAid [4], Smart-Robot [5]). They allow users to travel through the space and to find objects or points of interest as long as they are tagged with an RFID identifier. Each tag is documented and has associated a voice instruction used to guide users. The users device consists on a RFID reader and a headset. A central server is used to perform decoding of identifiers and send back the users device the respective information. Outdoor positioning is also supported by some of those systems, using GPS signal.

The main objective of our system is to provide all the information to blind people that they may need to comfortably use public spaces. Our system improves the autonomy, and thus self-esteem, of visually impaired people by enabling them to explore public spaces without the need to ask for help. Another valuable feature is that the user's device is the personnel smartphone, dispensing the cost of learning to use a new device.

The whole shopping is equipped with Bluetooth BLE devices that provide shop and services information. The Bluetooth signal is also used to determine the user positioning. All visual content is translated into textual information and stored into a database. An internet of things infrastructure and synthesizer are used to retrieve the most important information from the database and translate it to voice tips.

The proposed system is composed by four different modules with different characteristics and functions. Voice Module: responsible for the voice interface, remarking the importance of a touch independent and visual independent interface as the system is designed for blind and partially sighted people. Information Module: responsible for providing information about spaces, products or services available. Categories and subcategories are used to cluster points of interest, and one has associated a concise description that may be delivered to the user. Location Module: monitors user's position constantly. It uses Bluetooth BLE technology using a hybrid approach with signal strength and signal recognition for short range emitters. Route Module: responsible for the creation of a weighted graph and the elaboration of routes to guide the user.

In this work, an assisting system based on Bluetooth and normal smartphones is proposed. It aims to enable blind people to autonomously go to an unknown public building and explore it, without feel the need of asking for help.

Acknowledgements

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Information and Assisted Navigation System for Blind People

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***Abstract*—Nowadays public buildings are changing constantly, often people have to take different routes to reach known destinations. At the same time, new services and places are made available to attract more people to the shopping center. This dynamic environment is usually signalled and labelled with visual marks and signs which are not appropriated for blind persons. Therefore, blind users are unintentionally deprived of a full participation in the society. With the purpose of equalize the access to services and spaces among all persons, this work proposes an innovative indoor navigation and information system for public buildings, namely shopping centers, based on existing technologies not used for this purpose. Intending to allow a comfortable and helpful aid on blind persons trips to the shopping center, this proposal system relies on users smartphone and wireless sensors deployed in the environment.**

Index Terms*—*Assisted Navigation, Indoor, Blind People, Blind Assistive Technology

I. Introduction

The World Health Organization estimates that there are 285 million visually impaired people worldwide, mainly in developing countries. Visually impaired persons are defined as those with reduced visual capacity. They can be blind or partially sighted people. These conditions often limit peoples capabilities to perform common tasks and affect their quality of life.

On the spectrum of daily activities and needs of visually impaired people, navigation plays a fundamental role since it enables, or disables, the person to independently move or safely walk. Currently, there is several visual information that helps visually enabled people to move in a right way (e.g. takes a right direction, avoid obstacles, choose the shortest path to a destination). Text information and arrow indications are frequently used, however this information is inaccessible to visually impaired people. Often blind people are unintended withdrawn from the society with the lack of an alternative path for information. Based on this real context we focused our work on developing assisting technologies that may help blinding people bringing them back to the society.

In order to improve the quality of life for visual impaired people, in this work we focused on new technologies to help those persons in the access of public buildings, in particular shopping centers. Shopping centers have the great feature of display a lot of visual information to attract customers and orient them into the building. Therefore this work intends to play a special role in this field providing as much information as possible for visual impaired people, allowing them to take a comfortable navigation (e.g. short paths, shops, products) inside the building. To build a prototype focused on users and their interests, we are developing this study in partnership with the national association of blind and partially sighted people, ACAPO - *Associação dos Cegos e Amblíopes de Portugal*, and a sociology research group from University of Coimbra, CES - *Centro de Estudos Sociais*. This work aims to build a system to assist people with disabilities. The system intends to help them and not solely be an appendix providing information or useless knowledge. One important requirement is ease deployment and usage, in other words the developed system and support application (software) must be able to be used with much ease and low cost hardware by visual impaired persons. Generally speaking, this study is intended to contribute for the enhancement and independence of visually impaired people in society, as well as their inclusion and participation.

The next section brings up a brief overview over state of the art of technologies designed for assist blind people on similar environments. The third and fourth sections explain in detail our proposed system and its various modules and functions. The last section is the conclusion and future work.

II. Related Work

There are several systems designed to assist visually impaired persons on daily tasks. For instance, ShopTalk[12] is a system designed to help visually impaired people finding specific products inside a supermarket, the system guides the user to the vicinity of the desired product with vocal instructions. A directed graph representing the topological map of the store is used for route calculations whose nodes are decision points like aisle entrances. Instructions delivered are set as done by user with a keypad, so the system is unaware of the user's position or orientation. Product recognition is performed by scanning barcodes on the shelves, once a barcode is scanned and identified, user's actual position is known. Although this system allows user positioning, guiding and finding specific products, it is a whole new device composed of a processor, a numeric keypad and a barcode scanner. ShopMobile is a proposal updated version of ShopTalk running on a mobile phone. Barcode scanning is performed by mobile phone's camera[9].

BlindShopping[10] is another system designed to assist blind persons on the supermarket. The floor is covered of Radio-Frequency IDentification (RFID) tags creating an RFID map used for user's location and guidance. When a route is calculated the user is guided to the destination through voice instructions and once in the vicinity of the wanted product it can be found by QR (Quick Response) code, RFID tag or barcode. The user will use personal smartphone and an RFID reader attached to the white cane. Information travels via wireless network and central server processes all information.

RoboCart[4] is a robot that guides the user to the vicinity of the selected product and helps finding it by scanning product barcodes on the shelves. As other systems, the floor of the store is converted into an RFID-enabled surface, where each RFID tag had its own 2D coordinates. This RFID tags are used as recalibration areas, when the robot reaches a recalibration area its localization is well known.

A different system places voice emitters near sections on the supermarket that displays information when a person approaches them[5]. Detection of proximity of a person is performed by infrared sensors, and the proximity distance can be set from 10cm to 50cm depending on establishment preferences. Information displayed can be used for costumer guidance, not only blind or visually impaired costumers. This system just delivers additional information to the blind user path, being the path definition customer's responsibility.

A different system based on RFID technology[13] allows the user to travel through the space and to find objects or points of interest as long as they are tagged with an RFID identifier. Each tag is documented and has associated a voice instruction or information used to guide users. The user's device is an RFID reader and a headset, and a central server is used to perform decoding of identifiers and send back the user's device the respective information. A strength of this system is that the central server enables easily modifications on information, in contrast the environment must be fully covered of RFID tags.

A smartphone and RFID based system, BlindAid[11], uses an external RFID reader and the user's own smartphone to guide them to a specific destination. An effective tags placement enables user localization everywhere and direction of travel calculation in order to plan route and deliver the right instructions to the user. Path calculation is performed by Dijkstra's shortest path algorithm. User inputs are received through voice inputs or mobile phone's keypad.

Smart-Robot is presented as wider system enabling navigation indoors and outdoors[14]. Indoor navigation is performed using RFID technology and outdoor by GPS. The robot is equipped with an analog compass for orientation, ultrasonic and infrared sensors for obstacle avoidance, a speaker and a vibrating glove for instructions delivery, and a keypad for user inputs. A great advantage of this proposal is the obstacle and user's orientation detection, for this the robot is equipped with an analog compass, ultrasonic and infrared sensors.

Another robotic solution is RG, a robot intended to escorts the user in unknown environments[7]. Indoors navigation is performed by potential fields and by finding empty spaces around the robot. Potential fields is an algorithm that calculates robot motion by attracting it to the desired end and repulsing it from obstacles. This technique enables the robot to follow corridors without orientation sensors. RFID may be added to robot positioning and navigation.

III. Proposed System

In this work we propose a system to assist blind and partially sighted people in the accessing of public buildings, in particular a shopping center. The system must provide sufficient information to the blind user, avoiding the need of asking for assistance. The system must be able to perform navigation through the building and find available services, stores or spaces as well as desired destinations or points of interest, without high volume of information that can confuse the user. The main objective of the proposed system is to enhance autonomy of visually impaired people and to make resources (e.g. text information, direction arrows) available for everyone, especially those usually only presented by visual means.

Another important feature of the system is that it is based on low cost and common technologies, facilitating the deployment on public buildings and the access to users. The system relies on existing technologies which allow users use their own smartphone, eliminating the cost of acquisition and learning to use a new device. However, the environment where the system is deployed must be equipped with sensors enabling localization of the user, as well as a complete database that is used to select the information given to users during their navigation inside the shopping center.

Following this context and the project goals, several studies were made in order to estimate the best location sensor to be used. In presented proposal we are using Bluetooth emitters. A great advantage of this technology is its market acceptance, low cost and its presence in a major group of smartphones.

The following table (table I) exposes the identified advantages and disadvantages of the presented Bluetooth based system.

TABLE I: Pros and cons of the proposed system.

Advantages	Disadvantages
Performs navigation inside the building.	Does not provide assistance on getting to the building.
Constant user positioning where the sensors are placed.	May present several errors on positioning related to space, crowd or sensors.
User guidance through calculated routes.	Position update may not follow the walking speed of the user.
Based on existing technologies, such as smartphone and Bluetooth emitters.	The environment must be equipped with sensors.
Strong information system enabling the user to know available spaces and services.	Obstacle detection relies on user abilities.

IV. Module Description

The proposed system architecture follows the scheme presented on figure 2. This architecture is divided into four major modules: voice module, information module, location module and route module. Each module plays a distinct and fundamental function. They are described next.

A. Voice Module

Figure 2 emphasizes the Voice Module remarking the importance of touch independent and visual independent interfaces as the system is designed for blind and partially sighted people. The voice interface implemented uses Android built in tools, such as TextToSpeech for the voice outputs and the Google Voice Recognizer API.

TextToSpeech synthesizes speech from text. It is used whenever there are information to be displayed. A server-client approach is followed by voice module, where Voice Recognizer part communicates with the server to processes information and send it back to the user as text.

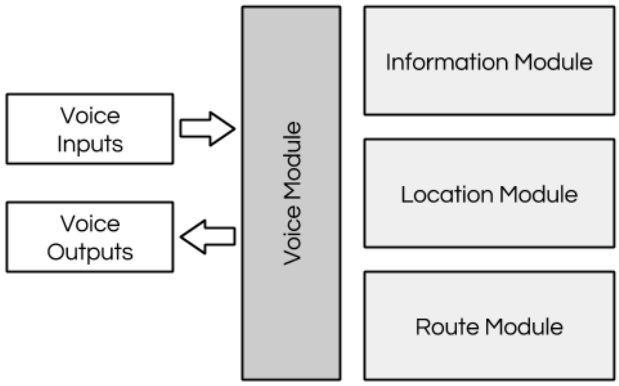

Fig. 2: Proposed architecture.

B. Information Module

The information module comprises all data related to points of interest in the building. Every location, store or service is associated to one specific category, subcategory or sub-subcategory. Most categories have subcategories sectioning the amplitude of category. Additionally, tags or keywords, that identify the subject of the category, are associated to each category and subcategory.

Complementary, each store and service has a unique description provided by the brand or store owner. This information must be clear and concise once it will be used for the selection of stores or services. It will be delivered to the user by synthesized speech.

Search a store or service: Since our work intends to help visual impaired persons in their navigation inside shopping centers, four methods to find a point of interest (e.g. store, restaurant, toilets, lifts, etc) were defined.

The first method enables the user to select a category among the full list of categories, then a subcategory related to the selected category. In some cases there are also sub-subcategories that are also presented for selection. As soon as the chosen category, subcategory or sub-subcategory is selected, a list of associated points of interest is presented and the user can select the desired destination.

The second method uses words introduced by the user to find the related categories or subcategories that are then presented to the user for selection. Once a category or subcategory is selected, the associated stores or services are presented.

The third method uses the introduced words to find specific stores or services: a short list is presented to the user and he/she may select the desired destination.

The last method enables users to find stores or services on the vicinity. When user walks through the environment receives information about stores or services that are near of his/her position. If the user desires, he/she can hear a short description associated to the store or service.

The voice module is used by all of these methods to interact with users.

C. Location Module

The localization module was designed to, constantly, monitoring the position of a user. The presented solution is based on Bluetooth emitters and triangulation techniques using Bluetooth signal strength.

The fundamental mathematical idea is that knowing at least three signal strength (that are roughly related to distance) and the precise position of each signal emitter, the user's position may be estimated, with some accuracy.

D. Route Module

This module has two major functions: creation of the weighted graph and calculation of the shortest path between two points.

Information about the vertexes and edges used to build a graph are imported from XML files, enabling to easily modify information about the space or points. Each vertex is associated with spatial coordinates and, may include information about stores or services there near of its coordinates. Each edge links two vertexes with a specific cost (related to distance and user preferences, such as to pick stairs or lifts). It also includes a list of other vertexes and its links associated with correspondent costs.

The route between two points is calculated using the Dijkstra's shortest path algorithm. This algorithm uses a start vertex and calculates the distance between it and other vertexes in the graph iteratively. The iterative process stops when a minimal distance between start and end points is found. Once the user defines destination, system will calculate the shortest path between user's actual position and the destination point.

A practical usage of this technique is shown in figure 1. Black dots and lines are respectively vertexes and edges defining points of interest and routes. Assuming that a user is in front of the lift 3 in the Department of Informatics Engineering of University of Coimbra and wants to go to D3.20 office, the red route is returned by the system and corresponds to the shortest path from the lift to the D3.20 office. We are effectively installing the developing system on Department of Informatics Engineering of University of Coimbra.

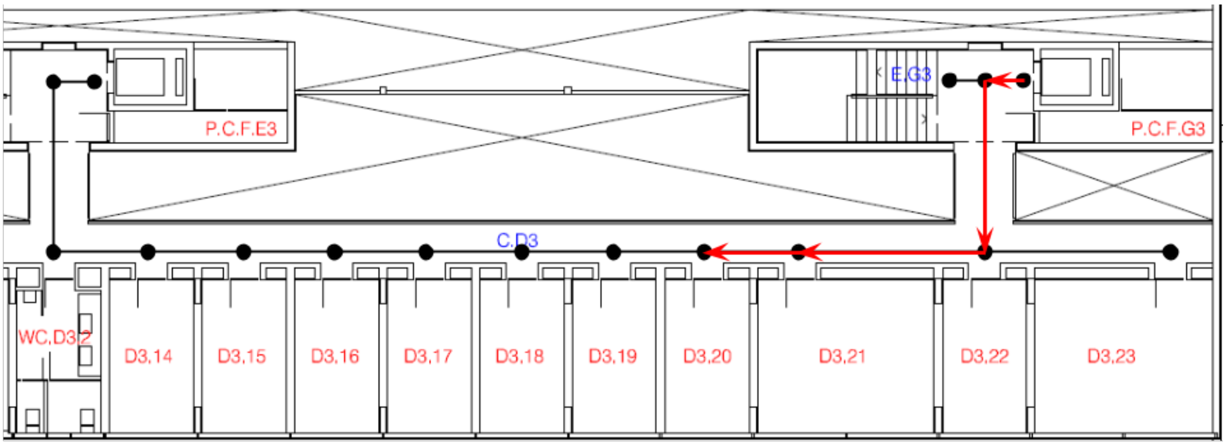

Fig. 1: Applied weighted graph.

V. Conclusion and Future Work

Blind people are frequently faced with the lack of approachable and appropriate signaling when visiting public buildings. Such difficulties often lead blind people to avoid spaces ideally designed for everyone. Thus, with the intention to promote the integration of blind people in society, we proposed a new approach based on Bluetooth and normal smartphones.

Among the related work stands out the relevance of recurrence of RFID technology, which allows simple and inexpensive location and identification. However, to use this technology the system must integrate an RFID reader device to recognize the presence of RFID tags. The system presented in this paper aims to highlight the user's device integrating it with devices and technologies already used by users, as their own smartphone. So the location system is being developed based on Bluetooth technology, present in most parts of the mobile phones.

After the environment is equipped with sufficient sensors, the system is able to locate the user and send him/her instructions that lead to the desired destination. Another important feature of the system is the accessible information system: the system allows the user to receive information about available stores, services or spaces.

In a future version of the proposed system it may be interesting to allow the introduction of marketing information in the user's application, allowing blind users to easily be aware of recent promotions and products. A functionality with this objective must be optional and enable introduction of user preferences, ensuring that excessive or uninteresting information is not delivered. This additional feature may brings commercial relevance to brands and store owners since it enables publicity of services and products to a wider audience.

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Appendix J

Report of Institutions Needs

by Elis Regina and Karen Duarte

RELATÓRIO DO LEVANTAMENTO DE REQUISITOS NAS INSTITUIÇÕES ACAPO, APCC e SEDM/CHUC

Coimbra, 25 de novembro de 2013

Sumário

De acordo com a Organização Mundial da Saúde, uma parte da população de aproximadamente um bilião, cerca de 15%, incluindo crianças, vivem hoje com algum tipo de deficiência, seja ela visual, auditiva ou física [35]. Pessoas com alguma deficiência geralmente são dependentes de terceiros para a realização de atividades do quotidiano. Serviços que permitam aos mesmos terem maior autonomia são limitados, impedindo-os assim de serem totalmente inseridos na sociedade.
A Internet das Coisas, IoT - *Internet of Things*, é um novo paradigma da computação e comunicação que pode oferecer a pessoas com necessidades especiais apoio e assistência na realização de tarefas. Desta forma pretende proporcionar uma melhoria significativa na sua qualidade de vida, permitindo a sua inserção na sociedade e participação económica [8]. Além disso, a IoT aplicada a diversos cenários, como casas inteligentes, poderá simplificar a realização de tarefas do quotidiano, garantindo independência e autoconfiança a pessoas com deficiência.
No âmbito da IoT, foi criado um grupo de trabalho do Departamento de Engenharia Informática da Universidade de Coimbra, DEI/UC, que terá como desafio propor soluções que possam melhorar a qualidade de vida de pessoas com deficiência. O DEI/UC em parceria com algumas instituições de Coimbra, como a ACAPO -Associação dos Cegos e Amblíopes de Portugal-, APCC -Associação de Paralisia Cerebral de Coimbra-, e o SEDM/CHUC -Serviço de Endocrinologia, Diabetes e Metabolismo do Centro Hospitalar Universitário de Coimbra-, pretende propor e aplicar as soluções em cenários práticos nestas instituições.
Neste contexto, o presente relatório fará uma abordagem geral das necessidades recolhidas em reuniões realizadas com profissionais e pessoas das diversas instituições.

Conteúdo

Lista de Figuras

A Internet das Coisas

A Internet das Coisas idealiza uma rede de dispositivos inteligentes, onde tudo está interligado, onde os objetos do quotidiano passam a ser inteligentes, capazes de efetuar interpretações e reações com o meio ambiente[8]. Com esta tecnologia será possível a gestão remota das coisas do quotidiano, estanto elas entre si interligadas e em comunicação. Estabele-se uma permanente conexão entre entre os objetos e o mundo virtual que vai permitir a manutenção de todo o espaço remotamente.
Para muitos autores, a internet das coisas é a internet do futuro uma vez que esta cobre todas as aplicações, proporcionando e incentivando o desenvolvimento e ascensão de outras aplicações. Essas novas aplicações poderão ser do campo da logística de transporte, saúde, casas, cidades e fábricas inteligentes, entre outros.

Dentre os campos de aplicação, destacam-se projetos relacionados com casas e cidades inteligentes. Um exemplo disso é o projeto *USEFIL - Unobtrusive Smart Environments For Independent Living* que tem como objetivo gerar sistemas e serviços através de uma abordagem simplificada com soluções de baixo custo para pessoas idosas, fazendo uso das Tecnologias da Informação e Comunicação, TIC. O projeto *USEFIL* desenvolverá uma plataforma com várias caraterísticas: um protótipo móvel capaz de reconhecer as atividades diárias e correlacionar informações do perfil do usuário, dispositivos de comunicação *wireless* para monitorizar parâmetros emocionais e fisiológicos, e um sistema de apoio à decisão para o processamento de informação de sensores, entre outros[3]. Pretende-se que a aplicação possa ajudar idosos a manter sua independência e atividades diárias, não requerendo de adaptações na residência.
Já para cidades inteligentes, destaca-se o projeto europeu *OpenIOT*, que pretende facilitar o uso de sensores em serviços baseados em TIC não só para cidades inteligentes, como também na fabricação e agricutura com soluções fundadas em serviço de redes de sensores[4]. Este projeto visa combinar objetos ligados à Internet e computação em nuvem, para que assim as empresas de TIC possam criar soluções de serviços baseados em sensores inteligentes. O projeto desenvolverá uma plataforma de tecnologia aberta para aplicações em IoT.

Além dos campos de aplicação já citados, os cuidados de saúde são um ponto crucial a destacar em aplicações IoT, devido o papel que podem desempenhar no controlo e preservação da saúde. A tecnologia da internet das coisas tem diversas aplicações na área saúde com a utilização de *smartphones* e sensores de RFID para monitorização de parâmetros fisiológicos e administração de medicamentos. O projeto *Commodity12* visa desenvolver um sistema inteligente para a análise de dados médicos combinados. Pretende tornar possível a disponibilização de informação medicinal direcionada ao tratamento de um paciente singular[6]. A pesquisa é realizada em pacientes com diabetes tipo 1 e 2 através da monitorização contínua com sensores na pele do paciente, fornecendo ao sistema valores específicios do nível de glicose no sangue.
Aplicações para *eHealth* têm intenção de reduzir custos médicos, tanto em ter-

mos de tempo, questões económicas e barreiras de acesso a cuidados de saúde. Muitas soluções equadram-se em serviços de comunicação remota com o ambiente doméstico dos utentes, sistemas de tele-alarme, administração de medicamentos, monitorização de pacientes e controlo de sinais vitais. Fazendo uma avaliação permanente do estado de saúde das pessoas pretende-se diminuir as despesas em cuidados agudos.
Outro cenário interessante seria apoiar pessoas com limitações físicas no deslocamento em diferentes espaços, podendo haver interação com objetos reais. Assim proporcionar maior qualidade de vida, confiança e acesso aos seviços disponíveis.

Capítulo 1

Cegueira e Ambliopia

1.1 A Cegueira e a Ambliopia

A cegueira é caraterizada pela falta de perceção visual, podendo ter origem causal (traumatismo, doença, malformação, nutrição deficiente), natural (congénita, adquirida ou hereditária), ou ambas. Doenças geralmente originárias de cegueira são a catarata, glaucoma, opacidade da córnea, retinopatia diabética, e muito abundantemente a degeneração macular relacionada com a idade.
A ambliopia é uma disfunção definida pela redução ou perda de visão num dos olhos, raramente em ambos, sem que seja detetada alguma alteração estrutural. É desenvolvida durante o período de maturação do sistema nervoso central, até cerca dos seis ou sete anos de idade.
A função visual é agrupada em quatro níveis: visão normal, deficiência visual moderada, deficiência visual severa e cegueira.

Segundo a Organização Mundial de Saúde, estima-se que 285 milhões de pessoas em todo o mundo tenham deficiência visual: 39 milhões completamente cegos e 246 milhões com visão baixa. 90% das pessoas com deficiência visual vivem em países em desenvolvimento, e 82% têm 50 ou mais anos. Para as causas da diminuição da função visual, estima-se que 43% sejam erros refrativos não corrigidos (como a miopia, hiperopia e astigmatismo), 33% sejam cataratas não operadas e 2% sejam devido a glaucomas.

A Associação dos Cegos e Amblíopes de Portugal, ACAPO, é uma Instituição Particular de Solidariedade Social, IPSS, que visa a integração completa de pessoas cegas e com baixa visão na sociedade, garantindo a sua expressão e exercício da cidadania. As IPSS's são instituições promovidas por particulares sem fins lucrativos com o fim de dar expressão organizada ao dever moral de solidariedade e de justiça entre os indivíduos.
A ACAPO surgiu da fusão da Associação de Cegos Louis Braille, a Liga de Cegos João de Deus e a Associação de Cegos do Norte de Portugal. Esta instituição divide-se em treze delegações por todo o território nacional. A delegação de Coimbra, onde se realizou o primeiro contacto com a instituição, presta uma série de medidas direcionadas à integração plena das pessoas com deficiência visual, sendo elas informação, aconselhamento, apoio psicossocial, habilitação/reabilitação (que poderá incluir treino de orientação e mobilidade, apoio nas atividades do quotidiano, aprendizagem de leitura e escrita de braille), apoio ao emprego e formação profissional, entre outros.
Foi contactada a delegação de Coimbra da ACAPO, e discutiu-se a informação em bruto do presente relatório com o diretor técnico da delegação, José Mário Albino, e o técnico de informática Micael Lopes.

1.2 Necessidades

No primeiro contacto efetuado com a instituição debateram-se algumas das necessidades enfrentadas por esta população, que poderão vir a ser local de intervenção do projeto. Essas necessidades foram seccionadas em quatro partes.

1.2.1 Mobilidade

As pessoas com deficência visual terão dificuldade em movimentar-se autonomamente, já que o ambiente aleatório que envolve cada percurso será naturalmente mais difícil de detetar que para uma pessoa com capacidade visual. Comumente são utilizados bengalas e cães guia para detetar obstáculos ao longo do percurso.

1.2.2 Ambiente Doméstico

Os eletrodomésticos e dispositivos utilizados necessitarão de funcionar sem *display* visual e, muitas vezes, fornecer feedback auditivo da instrução recebida. A evolução da tecnologia tende a criar dipositivos *touch* que são inacessíveis para quem se guia por relevos.
No acesso à televisão, as novas interfaces de utilização são um obstáculo porque permitem muitas opções que são identificáveis apenas visualmente.
A identificação das cores é um aspeto importante que está inacessível a estas pessoas, bem como a deteção de luzes acesas, nos casos de cegueira de maior severidade.

1.2.3 Acesso ao Computador

Para o acesso ao computador, é necessário que toda a informação seja transmitida por outra via que não a visual. Normalmente, é utilizado um leitor de écran e um sintetizador de voz para informar o utilizador com diminuição da capacidade visual. Informação e botões em formato de imagem serão um entrave para estes utilizadores, já que o leitor de écran não os conseguirá ler.
O teclado *qwerty* adotado em portugal, e utilizado para *inputs* do utilizador, não é um entrave para esta população.

1.2.4 Espaços Públicos

Na utilização das vias públicas, é importante que os semáforos forneçam mais que a convencional informação visual, como já está implementado em alguns a utilização de um *bip* que se ouve quando o semáforo fornece passagem aos peões.
Relativamente à utilização de espaços públicos de grandes dimensões, será importante que a pessoa com deficiência visual se consiga orientar e movimentar dentro deste sem a atualmente necessária interação com os outros utilizadores.
No caso particular da utilização das caixas automáticas de levantamento e transferência de dinheiro, esta população necessitará que a informação seja transmitida por um meio adicional, como já é efetuado em algumas caixas pela opção da utilização de auriculares para a transmissão de informação.

Shopping

Especificamente, na utilização de supermercados de grandes dimensões, é impossível pra uma pessoa com diminuição da capacidade visual efetuar autonomamente as suas compras. Além de lhe ser difícil identificar onde se localiza cada setor. Dentro do setor, será complicado encontrar a prateleira e produto que pretende sem precisar de importunar os outros clientes.
A emergência das caixas automáticas de pagamento dentro do estabelecimento comercial será também um entrave à autonomia desta população, já que são utilizados écrans *touch* para a interação do utilizador.

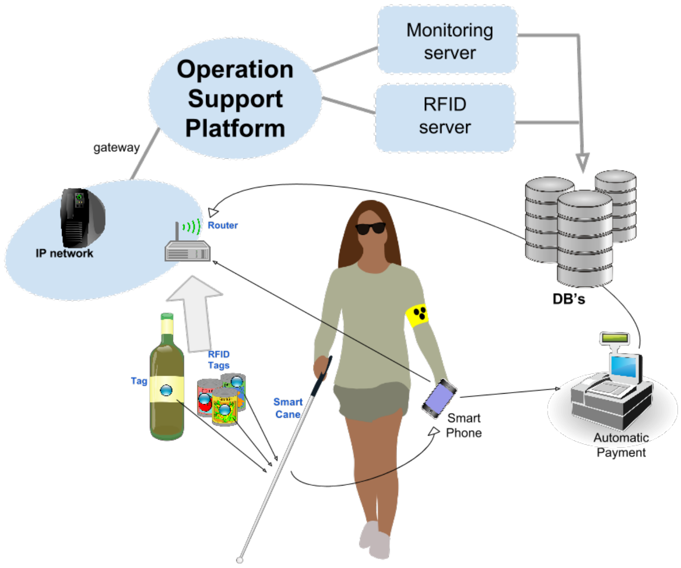


Figura 1.1: Arquitetura possível de integração de um sistema de localização e identificação de produtos num supermercado.

1.3 Estado da Arte

1.3.1 Mobilidade

Foram apresentadas já várias alternativas à bengala branca convencional utilizada. Mohd Wahad apresenta uma bengala inteligente com a capacidade de informar o utilizador por voz e vibração dos obstáculos que encontrará à frente. A bengala utiliza sensores de ultrassons para detetar os obstáculos e a sua distância [9]. Do mesmo modo Jayant Sakhardande propõe o sistema *Obstacle Detector System*,uma bengala que utiliza ultrassons para detetar obstáculos e o toque para avisar o utilizador [10]. Os ultrassons são utilizados em detrimento

dos outros recursos disponíveis uma vez que são menos afetados pelos materiais ou cores dos alvos e permite encontrar obstáculos com precisão em um metro.
Um dispositivo mais complexo é proposto por Allan Mervin [11], uma plataforma móvel com um *array* de sensores é alocada à bengala comum. O robô guiará o sujeito até um destino previamente introduzido, desviando-se dos obstáculos que encontra. Um robô mais complexo, munido de GPS e bússula, é proposto por Kumar Yelamarthi [12]. Este *Smart-Robot* utiliza sensores com ultrassons e infravermelhos para fazer a deteção de obstáculos; a informação é transmitida ao utilizador através de voz e vibrações numa luva.

1.3.2 Ambiente Doméstico

Para contornar a questão dos eletrodomésticos e dispositivos com menos, ou nenhuns, botões surgem as casas inteligentes. O conceito de casa inteligente coloca em permanente conexão dispositivos (*networking devices*) e equipamentos dentro de casa com o objetivo de melhorar a qualidade de vida, permitindo o controlo de toda a casa através de um dispositivo/aplicação [13]. Outra vantagem será o controlo da casa à distância.
Referidos pela instituição, os identificadores de cores são aplicações que utilizam a câmara do *smartphone* para identificar a cor e transmitir a informação através de voz sintetizada. A título de exemplo, para o sistema operativo Android existe a aplicação *Color ID*, grátis, e para o sistema iOS existe a *Color Identifier*, vendida a um preço de 3.59€.
No que respeita ao acesso à televisão, os menus de configuração da mesmo geralmente não apresentam qualquer alternativa à apresentação visual da informação. A *Apple TV* apresenta-se como uma televisão alternativa já que utiliza a conexão à internet para apresentar uma variedade de programas disponíveis online. Esta televisão dispõe já de instruções audíveis desde a primeira configuração necessária [20].

1.3.3 Acesso ao Computador

Para o acesso ao computador são utilizados leitores de ecrãs. *Orca* é um leitor de ecrã, para os sistemas operativos Solaris e Linux, que permite acesso ao ambiente de trabalho gráfico comum dos computadores por combinação de voz e *braille* predefinidas pelo utilizador [21]. *NonVisual Desktop Access*, NVDA, é o único leitor de ecrã completamente gratuito para Windows e está disponível em mais de 43 línguas [22]. Desenhado para o Firefox, pelo que funciona tanto em Windows, Linus ou Machintosh, o *Fire Vox* é uma extensão para este browser, com a capacidade identificar títulos, links, imagens e as estruturas comuns das páginas web[23]. A maioria destes *softwares* é executável apenas através de uma pen-drive USB, o que permite que o *software* seja utilizado não apenas no computador pessoal do utilizador, mas em qualquer computador que este utilize. Em alternativa, o leitor de ecrã *WebAnywhere* é um leitor de ecrã *online*, permitindo a pessoas com diminuição da capacidade visual o acesso à internet a partir de qualquer computador [24].

1.3.4 Espaços Públicos

Em algumas cidades já são encontrados semáforos com *feedback* sonoro que permitem a esta população atravessar a estrada em segurança.
URNA, *Universal Real-Time Navigational Assistance*, é um sistema que transmite infomação ao utilizador através de um dispositivo equipado com *bluetooth*. A informação fornecida descreve a interseção de que o utilizador se está a aproximar e o estado dos semáforos em tempo real. Cada interseção necessita de estar equipada com um módulo *bluetooth* [14]. Um outro método é proposto por Pelin Angin e Bharat Bhargava e utiliza o GPS do dispositivo/*smartphone* do utilizador para detetar obstáculos e comunicar a localização precisa com o servidor. A deteção do estado do sinal de passagem é efetuada pelo servidor por processamento de imagens enviadas constantemente pelo dispositivo [15].
A localização e orientação dentro de edifícios públicos será simplicaficada por relevos no piso, que servirão como guias. No entanto, são poucos os edifícios que estão equipados com estes relevos. Timothy et al. desenvolveram um protótipo que utiliza um magnómetro na anca do utilizador que em comunicação com o *smartphone* monitoriza a sua localização, guiando-o para o destino desejado [16]. Outro método utiliza um sistema de informação geográfica do edifício e pontos de referência visuais para localizar o utilizador e traçar uma rota para o levar ao destino, complementarmente será utilizada a begala branca [17].

Shopping

Vários métodos são propostos para a localização e identificação de produtos em superfícies comerciais. BlindShopping utiliza identificadores RIFD e códigos QR para localizar o produto pretendido, e instruções vocais para guiar a pessoa para perto deste. Uma vez aí, utiliza códigos QR e UPC, códigos de barra, para identificar cada produto [18]. Aqui a superfície comercial necessita de instalar um servidor, uma rede *wifi* e colocar identificadores RFID a mapear o piso. A pessoa com incapacidade visual utilizará o seu smartphone pessoal e um leitor de identificadores RFID que será acoplado à sua bengala branca.
Já Sreekar Krishna et al. propõe um sistema que utiliza EPC, Electronic Product Code, e RFID para fornecer informação sobre os produtos pretendidos. O utilizador utilizará um leitor de identificadores RFID que detetará os códigos EPC dos produtos nas prateleiras perto deste e transmitir-lhe-á informação através de voz sintetizada. A comunicação entre o leitor de RFID e o servidor da loja, onde é analisada a informação dos códigos EPC, é efetuada através da rede wi-fi do estabelecimento. O leitor de RFID estará em constante comunicação com o PDA/smartphone do utilizador, que comunica com o servidor vir TCP/IP [19].

1.4 Conclusão

Do presente trabalho resulta uma serie de áreas de intervenção onde é possível melhorar a qualidade vida das pessoas cegas e com baixa visão. Na genera-

Figura 1.2: Arquitetura distribuída do sistema *BlindShopping*[18].

lidade, relacionam-se com questões de mobilidade e deslocação, utilização dos eletrodomésticos domésticos quando estes são geridos por *displays* visuais ou não permitem a utilização de instruções vocais, e na frequência de espaços públicos autonomamente. Geralmente, pessoas cegas necessitam do apoio de terceiros para a realização de tarefas comuns, o que poderá ser um entrave à plena participação na sociedade e cidadania.

Dentre as várias necessidades levantadas junto da ACAPO, um maior destaque foi dado à possibilidade de efetuar compras em supermercados, com autonomia e independência destas pessoas.

Capítulo 2

Paralisia Cerebral

2.1 A Paralisia Cerebral

A Paralisia Cerebral é caracterizada por um grupo de distúrbios que afetam o sistema motor e de controlo da postura. Em geral, pessoas afetadas possuem limitações nos movimentos coordenados, na fala e até mesmo na movimentação dos pés, o que pode levar a que sejam permanentemente dependentes. Os três tipos principais de paralisia cerebral são o espástico, a disquinésia e a ataxia. Esta deficiência afeta cerca de 2 em cada 1000 indivíduos.

Espástico Caraterizado por paralisia e aumento de tonicidade dos músculos resultante de lesões no córtex cerebral ou nas vias das quais são provenientes.

Disquinésia Os movimentos são involuntários e há variações na tonicidade muscular, resultantes de lesões dos núcleos localizados no interior dos hemisférios cerebrais. É considerado o tipo mais raro.

Ataxia Caracteriza-se pela diminuição da tonicidade muscular e equilíbrio pouco desenvolvido causados por lesão no cérebro ou nas vias cerebelosas.

Embora esses três grupos sejam manifestações mais comuns, a dependência e capacidades variam de pessoa para pessoa. Geralmente, associado à paralisia estão outras deficiências, como a visual, auditiva, na fala e epilepsia.

A Associação de Paralisia Cerebral de Coimbra, APCC, é uma instituição particular de solidariedade social sem fins lucrativos, cujo objetivo é a reabilitação de pessoas com paralisia cerebral e doenças neurológicas afins. O presente relatório foi baseado em contactos e reuniões com profissionais da APCC, nomeadamente o Dr. Carlos Barata, a fisioterapeuta Cristina Soutinho, a terapeuta da fala Carmina Elias e o terapeuta ocupacional Francisco Antunes.

2.1.1 Terapia da Fala

A terapia da fala consiste no desenvolvimento de atividades no âmbito da prevenção, avaliação e tratamento de perturbações na comunicação. Esta terapia engloba todas as funções associadas à compreensão e expressão da linguagem oral e escrita, além de outras formas de comunicação não verbal.
Acompanhou-se uma sessão de terapia da fala de uma criança de nove anos na instituição. A criança tem paralisia cerebral com comprometimento dos membros inferiores e superiores (em menor grau), e incapacidade de falar. As sessões de terapia da fala desta criança são semanais e têm uma duração média de cinquenta minutos. Utilizou-se o software de comunicação alternativa The Grid 2 [33], apresentado abaixo. Na sessão em questão, a terapeuta questiona a criança sobre vários aspetos de seu conhecimento, e esta utiliza o software para responder. Muitas vezes a criança não conseguiu facilmente selecionar a informação pretendida, devido ao comprometimento dos membros superiores, que dificulta o controlo dos movimentos. Foi percetível a utilidade do software

nesta sessão, já que a criança não apresenta qualquer capacidade comunicativa convencional.

2.1.2 Mobilidade

Já que grande parte das pessoas com paralisia cerebral têm complicações a nível do sistema motor, é dada relevância especial às cadeiras de rodas. A paralisia cerebral tem um aspeto amplo, por isso a instituição dispõe de uma enorme variedade de cadeiras de rodas: desde as convencionais, conduzidas através da força de braços, às elétricas, tecnologicamente mais sofisticadas e adaptadas a cada utilizador. Adaptações a cadeiras de rodas poderão ter o objetivo de corrigir e controlar a postura ou movimento do utilizador, estabilizá-lo, praticar desporto, entre outros. Segundo as necessidades e capacidades do utilizador, serão adicionados várias caraterísticas às cadeiras, como um sistema de comunicação ou controlo de ambiente da habitação.

Figura 2.1: Cadeira elétrica adaptada da Vermeiren.[?]

2.1.3 Comunicação Alternativa

A comunicação alternativa é uma forma de comunicação que utiliza imagens, gestos e sons, permitindo a pessoas sem fala, escrita funcional ou desfasagem entre a necessidade comunicativa e a sua habilidade para falar ou escrever, comunicar os com as outras pessoas.

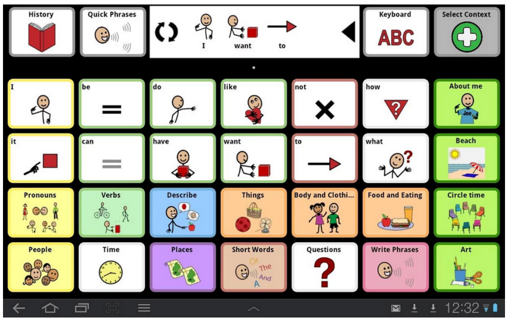


Figura 2.2: Sono Flex[37], aplicação móvel que utiliza comunicação alternativa para expressões comuns.

2.2 Necessidades

2.2.1 Aprendizagem e Desenvolvimento

Em contactos com profissionais da instituição, foi claro que há poucos recursos computacionais que possam ser utilizados por estas pessoas, como o caso do *The Grid 2*, já referido. Especialmente mencionou-se a importância de utilizar jogos para a aprendizagem destas crianças, uma vez que o seu grau de atenção também está normalmente, comprometido. Foi falado pela instituição que há poucos jogos didáticos para estas crianças, seja por computador, seja nos primeiros jogos infantis. Foi também referido que há muitos jogos didáticos disponíveis na internet, no entanto, não possuem o sistema de varrimento, impedindo o acesso às crianças e jovens com que trabalham.

Precisa-se de uma interface simples que permita à pessoa com paralisia cerebral aceder ao computador. No caso particular das crianças, e que foi a incisão maior da reunião, precisa-se de jogos que sejam o acesso das crianças ao computador e que poderá envolver adaptação de hardware, por exemplo, deteção do movimento da cabeça. Foi referido pelas entidades da instituição que a deteção do movimento dos olhos não poderá ser utilizado com estas crianças já que apresentam movimentos muitas vezes descoordenados.

2.2.2 Controlo da cadeira de rodas

No caso da mobilidade, em concreto das cadeiras de rodas, há necessidade de um *kit* de treino que possa ser acoplado a uma cadeira de rodas convencional com o fim de perceber as capacidades e limitações do utente na utilização de uma cadeira elétrica. Essa avaliação passará por perceber se o utente tem percepção dos sentidos, direções, distâncias e obstáculos que poderá encontrar no caminho. Será também tido em conta que nem todas as pessoas poderão utilizar as mãos ou braços para conduzir a cadeira, pelo que antes de qualquer aquisição é sempre necessário fazer essa avaliação. No caso do kit de treino essa questão terá de ser tida em conta.

2.2.3 Comunicação

Recorrendo à comunicação alternativa, comum entre esta população, um *chat* poderá ser um elemento integrador e assim contribuir para a sua autonomia e autoestima.

Abordou-se ainda a possibilidade de um sistema *low cost* que permita aos utilizadores comunicar com as outras pessoas utilizando a voz. Esse sistema poderia ser apenas constituído por vários botões de fácil acesso que ao serem premidos emitiria uma voz.

2.2.4 Controle remoto do ambiente à volta do utente

Abordou-se a questão do controlo remoto do ambiente à volta do utente. A instituição tem conhecimento que há já cadeiras de rodas com sistemas que controlem o ambiente à volta dos utilizadores (temperaturas, persianas, janelas, portas, etc.). A instituição não possui nenhuma dessas cadeiras porque um sistema assim implicaria a adaptação da habitação toda, que se tornaria muito dispendioso.

2.3 Estado da Arte

2.3.1 Comunicação Alternativa

Há aplicações móveis, como é o exemplo da *Proloquo2Go*[38], para iPOS, e a *Sono Flex Lite*[37], para Android, que utilizam a comunicação alternativa como ferramenta para melhorar a capacidade comunicativa de pessoas com incapacidade para falar. As aplicações são semelhantes e permitem ambas que seja emitida um voz com a informação selecionada. Para facilitar a introdução de informação é utilizada a predição de palavras e é possivel editar os botões a apresentar conforme as preferências ou caraterísticas do utilizador, podendo também ser utilizada a câmara do *smartphone* para isso (no caso da aplicação para Android).

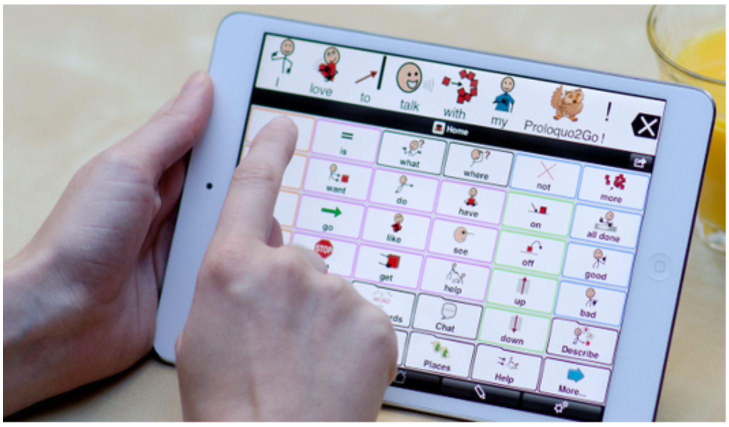


Figura 2.3: Utilização da aplicação *Proloquo2Go*[38].

O software disponível para iOS ainda permite a comunicação com outras aplicações, por exemplo *email*, *facebook* e *twitter*, fornecendo autonomia e inclusão social das pessoas com deficiência. Esta aplicação, *Proloquo2Go* é vendida *online* a um preço de 199€.

2.3.2 Aprendizagem e Desenvolvimento

O *The Grid 2* é um software que permite que pessoas com limitações na fala possam comunicar através do computador. O software funciona através de varrimento, na figura 2.5, permitindo ao utilizador construir frases selecionando a linha e coluna onde a informação desejada está, essa seleção é realizada com a utilização de um *switch*. A informação selecionada é transmitida por um sintetizador de voz. O varrimento é um método em que é apresentada toda a informação a ser selecionada e, num intervalo de tempo definido, as alternativas são percorridas, quando estiver selecionada a informação pretendida é acionado o *switch*[33]. O intervalo de tempo de varrimento é determinado de acordo com as habilidades já conquistadas pela criança. Com funcionalidades semelhantes ao *The Grid 2*, o *Ke:nx*[34] é mais *user-friendly*, permitindo a introdução de nova informação de forma mais fácil. Uma vantagem que esse software apresenta em relação ao *The grid 2* é o tempo inferior que os técnicos necessitam para preparar uma sessão de terapia,permitindo também alterar pequenas informações durante a mesma. A instiuição primeiramente utilizava o *Ke:nx*, atualmente utiliza o *The Grid 2*. Substituiu-se o software utilizado por questões económicas, já que o preço no mercado do *The Grid 2* é muito inferior ao do *Ke:nx*. As famílias das crianças com necessidades educativas especiais conseguem adquirir o *The grid 2* a um preço bastante acessível, através da Fundação PT.

O *Projecto Ideia - Inclusão Digital com Ensino Interactivo Acessível*[36] é um

Figura 2.4: Quadro exemplo do *The Grid 2*.

jogo desenvolvido por uma equipa multidisciplinar composta por educadores, terapeutas e designers. O jogo integra conteúdos do 1º Ciclo das áreas de Matemática, Português e Estudo do Meio, permitindo aos utilizadores o uso do método de varrimento para o acesso aos jogos. Este software é compatível com o *The Grid*.

2.3.3 Acessibilidade Digital - Brinquedos Adaptados

As crianças com paralisia cerebral poderão não possuir capacidade para acionar um brinquedo com os botões com que está equipado, assim são necessários métodos alternativos para tal, por exemplo pela utilização de um *switch*. O *switch* é um interruptor que pode ser acionado por um pequeno pressionamento, podendo ser utilizado por qualquer parte do corpo, o que permite que seja usado por pessoas com comprometimento de movimentos severo. Dessa forma qualquer brinquedo elétrico ou eletrónico pode ser adaptado. A adaptação de brinquedos com sistema *on-off* tem um custo muito baixo, cerca de 0.50€, e permite que o brinquedo seja manipulado por um *switch*. Esta adaptação é uma alternativa, utilizada pela instituição, aos brinquedos adaptados comercializados em lojas especializadas, cujo o preço é em média 70€. Os brinquedos adaptados são utilizados numa primeira fase da terapia, quando as crianças possuem pouca idade, sendo um meio priveligeado de interiorização da noção de causa-efeito.

O *Dial Scan* é conhecido pelos terapeutas como um relógio, já que a mecânica do aparelho lembra a de um relógio tradicional. O aparelho consiste numa tela de acrílico com uma componente mecânica onde é possível ligar o *switch*. São colados ponteiros e figuras na tela correspondente ao tema em que estão a trabalhar. A criança então carrega o *switch* fazendo o ponteiro rodar com o objetivo de guiá-lo até a figura pretendida, trabalhando não só a noção de causa

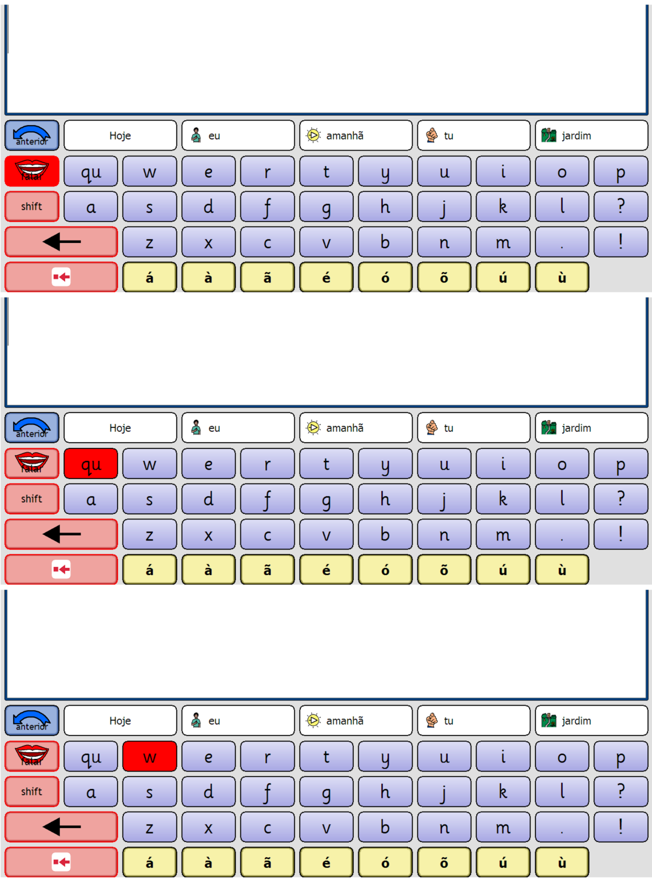


Figura 2.5: Varrimento utilizado pelo *The Grid 2*.

e efeito, como também o controlo do movimento.

2.3.4 Controlo remoto do ambiente

A empresa Dynamic Controls apresenta o *iPortal*[40], uma solução de acesso ao iPhone, iPad e iPod através da utilização de um *joystick* ou *switch*. O acesso ao *smartphone* permite o acesso à gestão do ambiente envolvente desde que este assim esteja configurado. Esta configuração requer adaptação objetos, eletrodomésticos e afins, e a integração de vários sensores no ambiente.
O software *The Grid 2*, já apresentado, permite também a interação com o ambiente, desde que novamente este assim esteja configurando, sendo portanto necessárias diversas alterações. O software não é comummente utilizado com estes fins devido aos custos elevados associados à adaptação do meio.

Figura 2.6: Brinquedo adaptado ativado por *switch*.

2.4 Conclusão

Junto da APCC percebeu-se que ainda é muito desafiante a integração completa destas pessoas na sociedade. São bastantes necessidades eminentes apresentadas pela instituição e merecedoras de intervenção especializada. Resumindo as necessidades recolhidas por temas gerais tem-se a comunicação, em que são necessários métodos que permitam efetivamente a estas pessoas comunicar livremente, e a educação, nomeadamente no mercado de tecnologias disponíveis e jogos didáticos. Adicionalmente abordou-se a necessidade de métodos alternativos de avaliação das capacidades físicas e cognitivas de cada pessoa com deficiência, de forma a agilizar o processo de aquisição de cadeiras de rodas adaptadas ou outra ferramenta semelhante que auxilie a deslocação de pessoas com deficiência.

Dentre as necessidades e áreas de intervenção recolhidas, foi dado maior destaque à pouca disponibilidade no mercado de jogos que utilizem o método de varrimento, jogos esses que são essenciais na aprendizagem das crianças com deficiência. Pretende-se colocar em comunicação o mundo real e o virtual, através de uma aplicação móvel, um jogo digital e sensores em brinquedos adaptados. Com esta proposta pretende-se fornecer autonomia às crianças no momento da brincadeira, além do acesso a um novo panorama tecnológico.

Capítulo 3

Diabetes Mellitus

3.1 A Diabetes Mellitus

Esta patologia é caraterizada por uma elevação anormal do nível da glicose no sangue resultante de defeitos na secreção de insulina pelo pâncreas ou quando o corpo não reconhece a insulina produzida. A quantidade elevada de glicose no sangue, hiperglicemia, estará na origem da deterioração de sistemas e orgãos do corpo, a salientar os vasos sanguíneos, olhos, rins e coração.
Sintomas comuns de hiperglicemia são a poliúria (aumento do volume urinário), polidipsia (excessiva sensação de sede), perda de peso, por vezes polifagia (fome excessiva) e visão desfocada. A longo prazo, a diabetes pode levar a retinopatia com potencial perda da capacidade visual, neuropatia periférica que poderá levar a úlceras nos pés e amputações, e neuropatia autónoma causando disfunções a nível gastrointestinal, genitourinário, cardiovascular e sexual.

3.1.1 Tipo 1

Pessoas com diabetes mellitus do tipo 1 são normalmente insulinodependentes, já que o pâncreas não consegue produzir insulina suficiente para que a glucose seja absorvida da corrente sanguínea e as células sejam alimentadas. Devido ao seu caráter é desenvolvido cedo, em crianças e adolescentes. A causa não é conhecida, mas pensa-se que será um combinação de fatores genéticos e ambientais. Está normalmente associado a emagrecimento rápido, uma vez que as células estão providas da glucose que circula no sangue e o sistema recorre aos adipócitos.

3.1.2 Tipo 2

A diabetes tipo 2 é caraterizada por uma incapacidade do organismo de reconhecer a insulina produzida, geralmente não leva a dependência constante da insulina e é o tipo mais comum de diabetes. Normalmente advém da herditariedade, do excesso de peso, inatividade física e da idade. Para superar a resistência do organismo à insulina e evitar a acumulação de glicose no sangue é necessário que haja um aumento de secreção de insulina.

3.1.3 Reposição da Insulina

Na diabetes do tipo 1 é necessário constantemente fornecer ao organismo insulina, uma vez que o pâncreas não tem capacidade para a produzir, muitas vezes são utilizadas bombas de insulina que a injetam autonomamente na corrente sanguínea em que é mantido constantemente um cateter dentro do corpo. Na diabetes tipo 2 será necessário injeção de insulina para compensar a insuficiência da insulina que o organismo produz. Normalmente são utilizados dispositivos em forma de caneta, que injetam a quantidade indicada pelo utilizador. Uma vez que a insulina é destruida no estômago não poderá ser administrada por via oral, sendo na maior parte das vezes injetada na pele, nos membros superiores, abdómen ou coxa [43].

Existirão cerca de 347 milhões de pessoas com diabetes em todo o mundo, segundo a Organização Mundial de Saúde. Dentre as pessoas com a doença crónica, 90-95% têm diabetes do tipo 2. Estima-se que em 2004 tenham morrido aproximadamente 3.4 milhões de pessoas por consequências de hiperglicemia em jejum, e que 80% destas mortes se localizem em países sub e em desenvolvimento.
A OMS prevê que em 2030 a diabetes mellitus será a sétima causa de óbitos no mundo.

O Serviço de Endocrinologia, Diabetes e Metabolismo do Centro Hospitalar da Universidade de Coimbra é comummente conhecido pelo apoio e acompanhamento que presta a pessoas com diabetes mellitus. Na sua essência, a endocrinologia é uma especialidade médica que estuda o funcionamento do sistema endócrino no organismo humano, responsável pelas hormonas que circulam na corrente sanguínea[52]. Assim sendo, estarão na área de atuação da endocrinologia a diabetes, a obesidade, a tiróide, hipófise e questões relacionadas com o crescimento e puberdade.
Na instituição foi contactada a Dra. Carla Baptista, e as Nutricionistas Maria João Campos e Maria Júlia Teixeira. Através da informação recolhida no contacto com estas profissionais foi elaborada a estrutura base deste relatório.

3.2 Necessidades

Após os vários contactos com o Serviço de Endocrinologia e Doenças Metabólicas do CHUC, foram identificadas três áreas de necessária intervenção. Comum a todas será a medição do valor da glicemia, isto é, valor de glicose na corrente sanguínea no momento da análise. Geralmente quem necessita de fazer esta análise constantemente possui já um dispositivo médico que a efetua sem dificuldade. O dispositivo obtém, em poucos segundos, o valor da glicemia através de um pequeno volume de sangue.

3.2.1 Monitorização Remota da Glicemia

Os dispositivos comuns de medição da glicemia permitem o armazenamento dos valores de algumas medições, no entanto não permitem a uma terceira pessoa conhecer os valores que foram imediatamente medidos. Os valores armazenados em memória poderão ser posteriormente conhecidos pela conetividade que o dispositivo dispuser, por exemplo ligação USB, infravermelho ou bluetooth. Será importante monitorizar os valores de glicemia, já que para valores demasiado altos ou baixos deverão ser brevemente tomadas medidas de estabilização, principalmente no caso de pacientes já com idade avançada que poderão esquecer-se ou menosprezar a situação.

Figura 3.1: *Mobile*, dispositivo convencional de medição da glicemia fabricado pela Accu-Chek.

3.2.2 Hipoglicemia

A hipoglicemia apresenta sintomas facilmente identificáveis, como suores, tremuras, visão desfocada, ritmo cardíaco acelerado, zumbidos ou dormência em volta da boca ou pontas dos dedos. A principal, e mais relevante, consequência da hipoglicemia é o fornecimento inadequado de glicose para o cérebro, que poderá levar à neuroglicopeneia. A neuroglicopeneia afeta a funcionalidade dos neurónios e assim o comportamento do indivíduo e as suas funções cerebrais.
Assim, torna-se necessário um sistema que permita a uma pessoa que identifique tais sintomas, principalmente com idade avançada, alertar facilmente uma terceira.

3.2.3 Previsão da Quantidade de Macronutrientes

Os hidratos de carbono são a principal razão para o aumento da glicose no sangue, pelo que é necessário que pessoas com diabetes do tipo 1 tenham conhecimento geral da quantidade de hidratos de carbono que estão a ingerir, de forma a regular corretamente a quantidade de insulina que vão administrar. A quantidade de hidratos de carbono presente nos alimentos pode ser estimada em gramas ou número de equivalentes, correspondendo um equivalente a cerca de 10g de hidratos de carbono. A quantidade de insulina a administrar será então função do número de equivalentes que serão ingeridos, estando geralmente as unidades de insulina e o número de equivalentes em razão de um para um.
Com a contagem dos hidratos de carbono poder-se-á subestimar outros macronutrientes, favorecendo riscos alternativos, como complicações cardíacas. Portanto

além dos hidratos de carbono, e por indicação do SEDM, deverá ser também contabilizado o número de proteínas, lípidos e calorias.

3.3 Estado da Arte

3.3.1 Monitorização Remota da Glicemia

A Associação Protetora dos Diabéticos de Portugal e a Fundação Vodafone Portugal criaram um sistema de monitorização da diabetes à distância[58], com o objetivo de melhorar o acompanhamento e a qualidade de vida das pessoas com diabetes. O sistema permite aos utentes o registo dos valores de glicemia medidos através de chamadas de voz, SMS ou *email.* O corpo clínico tem acesso à informação introduzida pelos utentes a qualquer momento, e poderá definir alarmes para que possa acompanhar qualquer irregularidade.
A MedSignals desenvolveu um dispositivo de monitorização remota da glicemia[57] semelhante a um dispositivo comum de medição pontual da glicemia. Este dispositivo envia automaticamente, via *bluetooth*, a informação relativa à análise efetuada para o portal da MedSignals online. A comunicação necessitará de um outro dispositivo com comunicação *bluetooth* e internet. Os dados do utilizador são guardados e analisados *online* pelo servidor da MedSignals. O *iPro®2*[53],

Figura 3.2: O dispositivo invasivo de monitorização da glicose, *iPro®2*, em utilização[54].

da Medtronic, é um dispositivo invasivo de monitorização contínua da glicose. Está desenhado para utilização profissional e pessoal. No primeiro caso, o paciente utiliza o dispositivo cerca de 3 dias e permite ao profissional de saúde identificar o efeito de comportamentos do quotidiano no perfil glicémico do paciente, como a dieta, a atividade física e a medicação. O profissional terá acesso aos dados quando o utente regressar ao seu estabelecimento. No caso da utilização pessoal, permite à pessoa com diabetes um registo contínuo do valor da glicemia e poderá ser integrado com uma bomba de insulina que injeta continuamente porções de insulina no organismo.
A Telcare apresenta um dispositivo de medição da glicemia que, além das caraterísticas convencionais, apresenta conetividade *wireless*. A cada medição são enviados dados automaticamente para o servidor da Telcare. O *Telcare BGM* tem um custo de US$ 149.95, e um pack de 50 tiras de teste, que farão a recolha do sangue em cada análise, US$ 55.95 [45].
A OneTouch desenvolveu o *UltraLink*, um dispositivo que vai comunicar com bombas de insulina da Medtronic já utilizadas pelo individuo. As bombas são dispositivos que vão administrar a um período predefinido porções de insulina no organismo. Este medidor vai comunicar com a bomba de insulina permitindo uma dosagem adequada da insulina a cada injeção [46].

Reaction é um projeto europeu que implementa uma plataforma integrada para a monitorização remota da gestão da terapia de pacientes com diabetes. Através da monitorização da glicemia e eventos significativos, a solução poderá detetar riscos ou indicadores de doenças relacionadas, incluindo também suporte à decisão relativa a tratamentos e terapias[5].
Igualmente como projeto europeu, *Mosaic*[7] utiliza modelos e técnicas de simulação para identificar fatores de influência na diabetes. Assim esse projeto pretende identificar pessoas com risco de desenvolvimento da diabetes do tipo 2, usando para isso critérios de diagnóstico atuais focados na identificação de grupos com aumento significativo de complicações microvasculares.

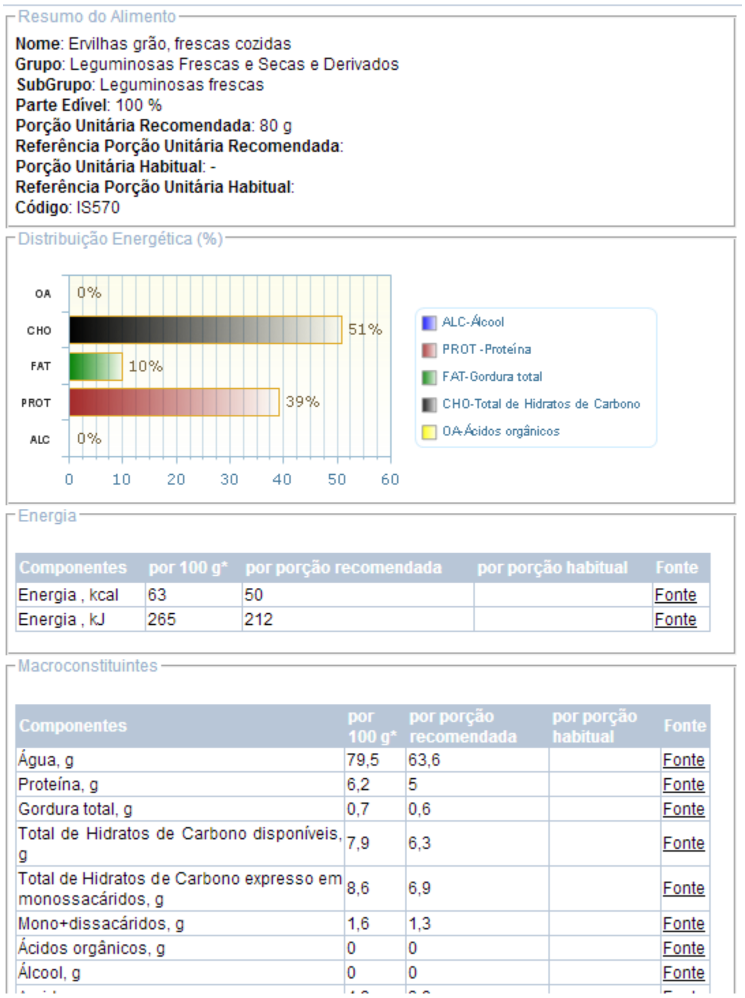
3.3.2 Hipoglicemia

A Medtronic desenhou uma bomba de insulina especializada para prever crises de hipoglicemia, o *MiniMed Paradigm Revel*^{TM}*Insulin Pump*[56]. Esta bomba de insulina monitoriza continuamente a glicose e tem integrado um sistema de deteção e alarme de crises de hipo ou hiperglicemia, permitindo que sejam tomadas medidas de segurança atempadamente.
Crises de hipoglicemia durante a noite são um perigo eminente em pessoas com diabetes cujo nível de glicemia não segue uma evolução estável, já que como está a dormir a pessoa poderá não identificar a crise e não tomar as medidas necessárias a evitar lesões graves. O *mySentry*^{TM}[55] é um monitorizador remoto de glicemia que apresenta informação recolhida por uma bomba de insulina utilizada pela pessoa com diabetes (*MiniMed Paradigm Revel*$^{\text{TM}}$[56], localizada a cerca de 15 metros). O *mySentry*^{TM} apresenta continuamente informação

acerca da bomba de insulina e dos valores de glicemia em tempo real, e ativa os mesmos alarmes que o *MiniMed*.
Foi apresentado na conferência *Portugal technology & Innovation*, em outubro de 2012, o *Telecare*, um serviço para emergências médicas. O Telecare é um telefone com fio com botões grandes, desenhado para pessoas idosas. Apresenta a particularidade de um botão de emergência que quando premido é efetuada uma chama automática para um *callcenter* especializado que provirá a ajuda necessária a cada situação [47]. Uma desvantagem deste equipamento é a necessidade do utente identificar a causa da sua emergência quando comunica com o *callcenter*.

3.3.3 Previsão da Quantidade de Macronutrientes

O método atualmente utilizado pelo Serviço de Endocrinologia, Diabetes e Metabolismo é baseado na observação e comparação dos alimentos e quantidades com valores já tabelados. Os valores tabelados assumidos são os da Tabela da Composição de Alimentos de Ricardo Jorge[59]. Esta tabela é a referência nacional para a composição dos alimentos consumidos em Portugal, onde consta informação sobre o teor de 42 componentes e nutrientes em 962 alimentos, crus, cozinhados e processados. A página online do Instituto Nacional de Saúde é possivel realizar pesquisas nesta tabela, é apresentada uma pesquisa exemplo na figura 3.3. Um método semelhante ao da utilização da Tabela da Composição dos Alimentos, e com o apoio de imagens é o apresentado pela *Carbs&Cals*. Esta empresa dispõe de várias tabelas que relacionam imagens de diferentes alimentos e quantidades a montantes de macronutrientes. Esta empresa comercializa também uma aplicação, para iOS, Android e BlackBerry OS, que permite pesquisas a pesquisa por mais de 2500 fotografias de comidas e bebidas[61]. Esta aplicação pretende disponibilizar um método simples de cuidado da diabetes, contagem de hidratos de carbono e calorias, manipulação da dieta, perda de peso, controlo das quantidades ingeridas e alimentação mais saudável.
A aplicação *Meal Snap*, para o sistema operativo iOS com um custo de US$ 2.99, permite através de uma fotografia receber informação acerca dos alimentos nessa refeição e obter uma estimativa da quantidade de calorias que contém. A aplicação faz um registo das refeições do utilizador, bem como da sua constituição e composição calórica, permitindo observar o seu progresso ao longo do tempo [48].
Recorrendo a espetroscopia e nanofotónica, o *TellSpec* permite obter informação acerca dos alimentos presentes na refeição. É utilizado um dispositivo portátil que emite uma radiação de baixa amplitude que será refletida pelo objeto onde incide, neste caso a refeição do utilizador. A radiação refletida será recebida pelo dispositivo portátil que enviará a informação através do *smartphone* do utilizador para o servidor da TellSpec, onde será analisada. No *smartphone* é recebida posteriormente informação acerca dos alimentos analisados: quantidade de calorias, nutrientes, substâncias química e alérgenas, entre outros. A aplicação regista também continuamente informação acerca das refeições do utilizador permitindo observar a sua evolução [49].


Resumo do Alimento

Nome: Ervilhas grão, frescas cozidas
Grupo: Leguminosas Frescas e Secas e Derivados
SubGrupo: Leguminosas frescas
Parte Edível: 100 %
Porção Unitária Recomendada: 80 g
Referência Porção Unitária Recomendada:
Porção Unitária Habitual: -
Referência Porção Unitária Habitual:
Código: IS570

Distribuição Energética (%)

Energia

Componentes	por 100 g*	por porção recomendada	por porção habitual	Fonte
Energia , kcal	63	50		Fonte
Energia , kJ	265	212		Fonte

Macroconstituintes

Componentes	por 100 g*	por porção recomendada	por porção habitual	Fonte
Água, g	79,5	63,6		Fonte
Proteína, g	6,2	5		Fonte
Gordura total, g	0,7	0,6		Fonte
Total de Hidratos de Carbono disponíveis, g	7,9	6,3		Fonte
Total de Hidratos de Carbono expresso em monossacáridos, g	8,6	6,9		Fonte
Mono+dissacáridos, g	1,6	1,3		Fonte
Ácidos orgânicos, g	0	0		Fonte
Álcool, g	0	0		Fonte

Figura 3.3: Pesquisa efetuada na Tabela de Ricardo Jorge, para Ervilhas grão, frescas cozidas[60].

3.4 Conclusão

Já referido anteriormente, as principais áreas de intervenção apresentadas pelo SEDM enquadram-se em três campos: monitorização remota da glicemia, deteção de crises de hipoglicemia e previsão da quantidade de macronutrientes nos alimentos. Com a evolução do número de pessoas com a doença crónica, torna-se necessária a gestão remota da doença por parte dos profissionais de saúde e familiares das pessoas com diabetes, diminuindo a necessidade de comunicação

Figura 3.4: Contagem de calorias e macronutrientes de diferentes tipos de pão apresentados pela Carbs&cals.[62]

in loco de corpo clínico e utentes.

Deu-se maior relevância à questão da aprendizagem da dosagem da insulina de forma a administrar corretamente a quantidade de insulina necessária. Possivelmente a intervenção do projeto passará pela implementação de uma aplicação que possa de forma intuitiva auxiliar as pessoas com diabetes mellitus a fazer a contagem das calorias e macronutrientes nos alimentos que ingerem.

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Appendix K

Report of Needs of Blind People Identified with ACAPO

by Karen Duarte

RELATÓRIO DE
LEVANTAMENTO DE REQUISITOS
- ACAPO -

Coimbra, 6 de dezembro de 2013

1 Sumário

No âmbito do projeto ICIS, *Intelligent Computing in the Internet of Services*, do Departamento de Engenharia Informática da Universidade de Coimbra, DEI/UC, criou-se um grupo de trabalho vocacionado para a promoção da integração e participação na sociedade e melhoria da qualidade de vida de pessoas com deficiência. Assim é intenção do DEI/UC colaborar com a Associação dos Cegos e Amblíopes de Portugal, ACAPO. Desta parcerias pretende-se colaborações futuras, como estágios, projetos e trabalhos.
Num contacto anterior efetuou-se o levantamento de necessidades reais apresentadas pela instituição e presentemente pretendemos focar o trabalho na questão da realização de compras autónoma em estabelecimentos comerciais. Pretende-se desenvolver e testar o sistema em colaboração com a ACAPO.

Conteúdo

2 Necessidades Recolhidas

No primeiro contacto efetuado com a instituição debateram-se algumas das necessidades enfrentadas pelas pessoas cegas e amblíopes, que poderão vir a ser local de intervenção do projeto. Essas necessidades foram seccionadas em quatro partes: mobilidade, ambiente doméstico, acesso ao computador e espaços públicos.

2.1 Mobilidade

As pessoas com deficência visual têm dificuldade em movimentar-se autonomamente, já que o ambiente aleatório que envolve cada percurso será naturalmente mais difícil de detetar que para uma pessoa com capacidade visual. Comummente são utilizadas bengalas e cães guia para detetar obstáculos ao longo do percurso.

2.2 Ambiente Doméstico

Os eletrodomésticos e dispositivos utilizados necessitarão de funcionar sem *display* visual e, muitas vezes, fornecer feedback auditivo da instrução recebida. A evolução da tecnologia tende a criar dipositivos *touch* que são inacessíveis para quem se guia por relevos.
No acesso à televisão, as novas interfaces de utilização são um obstáculo porque permitem muitas opções que são identificáveis apenas visualmente.
A identificação das cores é um aspeto importante que está inacessível a estas pessoas, bem como a deteção de luzes acesas, nos casos de cegueira de maior severidade.

2.3 Acesso ao Computador

Para o acesso ao computador, é necessário que toda a informação seja transmitida por outra via que não a visual. Normalmente, é utilizado um leitor de écran e um sintetizador de voz para informar o utilizador com diminuição da capacidade visual. Informação e botões em formato de imagem serão um entrave para estes utilizadores, já que o leitor de écran não os conseguirá ler.
O teclado *qwerty* adotado em portugal, e utilizado para *inputs* do utilizador, não é um entrave para esta população.

2.4 Espaços Públicos

Na utilização das vias públicas, é importante que os semáforos forneçam mais que a convencional informação visual, como já está implementado em alguns a utilização de um *bip* que se ouve quando o semáforo fornece passagem aos peões.
Relativamente à utilização de espaços públicos de grandes dimensões, será importante que a pessoa com deficiência visual se consiga orientar e movimentar dentro deste sem a atualmente necessária interação com os outros utilizadores.

No caso particular da utilização das caixas automáticas de levantamento e transferência de dinheiro, esta população necessitará que a informação seja transmitida por um meio adicional, como já é efetuado em algumas caixas pela opção da utilização de auriculares para a transmissão de informação.

Superficies Comerciais

Especificamente, na utilização de superfícies comerciais de grandes dimensões, é impossível pra uma pessoa com diminuição da capacidade visual efetuar compras autonomamente. Além de lhe ser difícil identificar onde se localiza cada setor. Dentro do setor, será complicado encontrar a prateleira e produto que pretende sem precisar de importunar os outros clientes.
A emergência das caixas automáticas de pagamento dentro do estabelecimento comercial será também um entrave à autonomia destas pessoas, já que são utilizados écrans *touch* para a interação do utilizador.

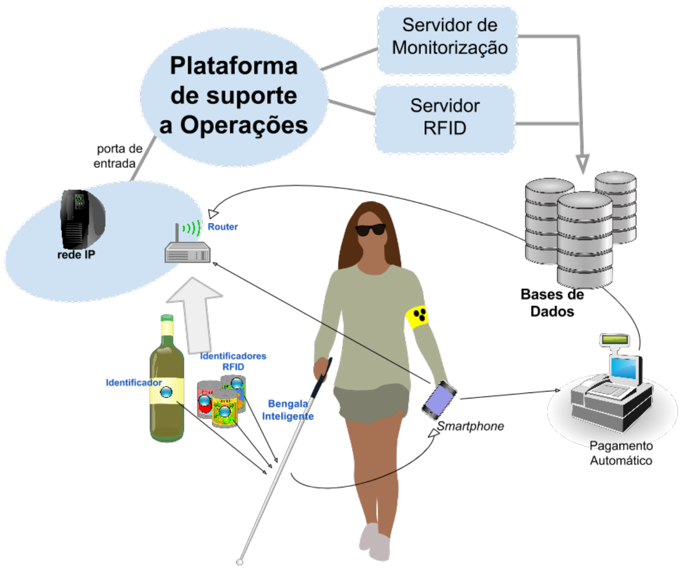

Figura 1: Arquitetura possível de integração de um sistema de localização e identificação de produtos num supermercado.

A imagem apresenta um indivíduo cego num supermercado que transposta uma bengala e um smartphone*. Os produtos do supermercado estão identificados com RFID's e a bengala está equipada com um leitor de identificações RFID; quando a bengala se aproxima dos produtos recebe a sua identificação RFID e comunica-a ao* smartphone*. Por sua vez, este comunica com o servidor do estabelecimento, via* wifi*, e este associa a identificação RFID ao produto específico, através de bases de dados, e devolve esta informação ao* smartphone *que a entrega ao* *utilizador por voz sintetizada. Aquando do pagamento, o* smartphone *efetuará atomaticamente o pagamento por métodos já atualmente utilizados.*

3 Síntese

Do presente trabalho resulta uma série de áreas de intervenção onde é possível melhorar a qualidade de vida das pessoas cegas e com baixa visão. Na generalidade, relacionam-se com questões de mobilidade e deslocação, utilização dos eletrodomésticos domésticos quando estes são geridos por *displays* visuais ou não permitem a utilização de instruções vocais, e com a frequência de espaços públicos autonomamente.
O DEI/UC pretende interagir com a ACAPO no sentido da criação e aplicação de propostas e soluções que possam aumentar a indenpendência e autonomia das pessoas cegas e amblíopes, com especial incisão em cenários do quotidiano.

4 Proposta

No ambito do curso de Engenharia Biomédica, no presente ano letivo está a decorrer um estágio que abordará tema específico dentre as necessidades recolhidas. A escolha recaiu sobre a possibilidade de efetuar compras em superfícies comerciais autonamente e sem a intervenção de terceiros. Seguidamente são apresentadas a ordem de trabalhos e uma breve descrição dos dois cenários apresentados.

Ordem de Trabalhos Proposta

1. Elaboração de proposta de sistema e arquitetura a implantar em superfícies comerciais.
2. *Feedback* da ACAPO e eventuais melhorias e alterações à proposta.
3. Apresentação da proposta a empresa de superficie comercial potencialmente interessada em participar na construção e teste de protótipo piloto.
4. Elaboração de protótipo e testes em colaboração com a ACAPO.
5. Implantação do sistema de testes em ambiente real.
6. Testes ao sistema.
7. Conclusões e escrita do relatório final.

4.1 Descrição do Sistema

A solução proposta baseia-se na utilização de identificadores RFID e de um sistema de navegação baseado em grafos. O utilizador do sistema necessitará de transportar um leitor de RFID, possivelmente disponível na superfície comercial, para reconhecimento das identificações RFID na proximidade. Este leitor poderá ser implantado na bengala já utilizada pela pessoa cega ou amblíope, ou estar implantado numa pulseira, *smartphone* ou outro dispositivo fornecido pelo estabelecimento.

Indentificação por radiofrequência, RFID, é uma forma de comunicação de identidade automática. Cada identificador RFID tem armazenados dados referentes à sua identificação única, e podem ser reconhecidos a poucos, *passive RFID tags*, ou a centenas de metros, *active RFID tags*. As *passive tags* podem custar cerca de 0,11 a 3,67€, e as *active tags* de 11 a 73,44€[24].
O sistema terá implementada uma interface auditíva que permitirá ao utilizador selecionar o que pretende encontrar, gerando rotas de navegação que lhe serão comunicadas.

Supermercado

Num cenário de supermercado, pretende-se que o sistema permita encontrar os produtos precisos que o utilidador deseja. A busca desse produto será efetuada por palavras chave que poderão identificar tanto um produto singular à partida, como uma categoria de produtos, ou produtos de uma determinada marca, permitindo ao utilizador escolher depois o produto exato que pretende.
Segue um caso de uso possível para este cenário:

1. Utilizador chega à entrada do supermercado.
2. Indica ao sistema que pretende encontrar 'batatas fritas'.
3. Sistema guia-o até à secção do produto e proximidade dos produtos nessa categoria.
4. Sistema indica onde se localiza o início dos produtos dessa categoria: 'batatas fritas inicia à esquerda, na prateleira do meio'.
5. Utilizador vai seguindo a prateleira indicada e recebendo a descrição dos produtos pelas identificações RFID reconhecidas.
6. Chegado ao fim da localização dos produtos desse tipo na prateleira, o sistema poderá indicar que terminou a pesquisa ou para seguir para uma nova prateleira: 'Continuar pesquisa por batatas fritas na prateleira de baixo'.
7. Utilizador encontra o produto que pretende e comunica ao sistema que terminou a procura.
8. Volta ao ponto 2 sempre que o utilizador indicar que pretende procurar outros produtos.
9. Utilizador indica que pretende terminar a pesquisa e efetuar o pagamento.
10. Sistema guia o utilizador até ao local destinado ao pagamento.
11. Terminado o pagamento, o utilizador poderá indicar que pretende deslocar-se à saída do estabelecimento e é guiado pelo sistema.
12. Poderá ter a possibilidade de indicar ao sistema que pretende viajar de autocarro ou táxi.

13. Sistema calculará o tempo restante para a passagem de um determinado autocarro ou solicitar automaticamente um táxi para o local.

Shopping

No cenário de shopping, intende-se que o sistema possa permitir ao utilizador deslocar-se autonomamente dentro da superfície comercial, bem como encontrar as lojas e serviços disponíveis. Mais uma vez esta busca poderá ser efetuada por categoria de serviços ou lojas, ou marcas dos mesmos.
Segue-se um caso de uso possível para o cenário:

1. Utilizador chega à entrada do shopping.
2. Indica ao sistema que pretende 'calças'.
3. Sistema devolve as lojas onde poderá encontrar o produto: 'Tiffosi, Salsa, Levis, etc'.
4. Utilizador seleciona a loja que pretende visitar.
5. Sistema guia-o até à entrada da loja.
6. Depois de visitar a loja, o utilizador poderá indicar que pretende visitar mais lojas ou serviços e volta ao ponto 2, ou que pretende sair do edifício.
7. Quando chegar à saída, poderá selecionar se pretende viajar de táxi ou autocarro.
8. Sistema calculará o tempo restante para a passagem de um determinado autocarro ou solicitar automaticamente um táxi para o local.

5 Estado da Arte

5.1 Mobilidade

Foram apresentadas já várias alternativas à bengala branca convencional utilizada. Mohd Wahad apresenta uma bengala inteligente com a capacidade de informar o utilizador por voz e vibração dos obstáculos que encontrará à frente. A bengala utiliza sensores de ultrassons para detetar os obstáculos e a sua distância [2]. Do mesmo modo Jayant Sakhardande propõe o sistema *Obstacle Detector System*,uma bengala que utiliza ultrassons para detetar obstáculos e o toque para avisar o utilizador [3]. Os ultrassons são utilizados em detrimento dos outros recursos disponíveis uma vez que são menos afetados pelos materiais ou cores dos alvos e permite encontrar obstáculos com precisão em um metro.
Um dispositivo mais complexo é proposto por Allan Mervin [4], uma plataforma móvel com um *array* de sensores é alocada à bengala comum. O robô guiará o sujeito até um destino previamente introduzido, desviando-se dos obstáculos que encontra. Um robô mais complexo, munido de GPS e bússula, é proposto por Kumar Yelamarthi [5]. Este *Smart-Robot* utiliza sensores com ultrassons e infravermelhos para fazer a deteção de obstáculos; a informação é transmitida ao utilizador através de voz e vibrações numa luva.

5.2 Ambiente Doméstico

Para contornar a questão dos eletrodomésticos e dispositivos com menos, ou nenhuns, botões surgem as casas inteligentes. O conceito de casa inteligente coloca em permanente conexão dispositivos (*networking devices*) e equipamentos dentro de casa com o objetivo de melhorar a qualidade de vida, permitindo o controlo de toda a casa através de um dispositivo/aplicação [6]. Outra vantagem será o controlo da casa à distância.
Referidos pela instituição, os identificadores de cores são aplicações que utilizam a câmara do *smartphone* para identificar a cor e transmitir a informação através de voz sintetizada. A título de exemplo, para o sistema operativo Android existe a aplicação *Color ID*, grátis, e para o sistema iOS existe a *Color Identifier*, vendida a um preço de 3.59€.
No que respeita ao acesso à televisão, os menus de configuração da mesmo geralmente não apresentam qualquer alternativa à apresentação visual da informação. A *Apple TV* apresenta-se como uma televisão alternativa já que utiliza a conexão à internet para apresentar uma variedade de programas disponíveis online. Esta televisão dispõe já de instruções audíveis desde a primeira configuração necessária [13].

5.3 Acesso ao Computador

Para o acesso ao computador são utilizados leitores de ecrãs. *Orca* é um leitor de ecrã, para os sistemas operativos Solaris e Linux, que permite acesso ao ambiente de trabalho gráfico comum dos computadores por combinação de voz e *braille* predefinidas pelo utilizador [14]. *NonVisual Desktop Access*, NVDA, é o único leitor de ecrã completamente gratuito para Windows e está disponível em mais de 43 línguas [15]. Desenhado para o Firefox, pelo que funciona tanto em Windows, Linus ou Machintosh, o *Fire Vox* é uma extensão para este browser, com a capacidade identificar títulos, links, imagens e as estruturas comuns das páginas web[16]. A maioria destes *softwares* é executável apenas através de uma pen-drive USB, o que permite que o *software* seja utilizado não apenas no computador pessoal do utilizador, mas em qualquer computador que este utilize. Em alternativa, o leitor de ecrã *WebAnywhere* é um leitor de ecrã *online*, permitindo a pessoas com diminuição da capacidade visual o acesso à internet a partir de qualquer computador [17].

5.4 Espaços Públicos

Em algumas cidades já são encontrados semáforos com *feedback* sonoro que permitem a esta população atravessar a estrada em segurança.
URNA, *Universal Real-Time Navigational Assistance*, é um sistema que transmite infomação ao utilizador através de um dispositivo equipado com *bluetooth*. A informação fornecida descreve a interseção de que o utilizador se está a aproximar e o estado dos semáforos em tempo real. Cada interseção necessita de estar equipada com um módulo *bluetooth* [7]. Um outro método é proposto por Pelin Angin e Bharat Bhargava e utiliza o GPS do dispositivo/*smartphone* do utilizador para detetar obstáculos e comunicar a localização precisa com o servidor. A deteção do estado do sinal de passagem é efetuada pelo servidor por processamento de imagens enviadas constantemente pelo dispositivo [8].
A localização e orientação dentro de edifícios públicos será simplicaficada por relevos no piso, que servirão como guias. No entanto, são poucos os edifícios que estão equipados com estes relevos. Timothy et al. desenvolveram um protótipo que utiliza um magnómetro na anca do utilizador que em comunicação com o *smartphone* monitoriza a sua localização, guiando-o para o destino desejado [9]. Outro método utiliza um sistema de informação geográfica do edifício e pontos de referência visuais para localizar o utilizador e traçar uma rota para o levar ao destino, complementarmente será utilizada a begala branca [10].

Shopping

Vários métodos são propostos para a localização e identificação de produtos em superfícies comerciais. BlindShopping utiliza identificadores RIFD e códigos QR para localizar o produto pretendido, e instruções vocais para guiar a pessoa para perto deste. Uma vez aí, utiliza códigos QR e UPC, códigos de barra, para identificar cada produto [11].

Figura 2: Arquitetura distribuída do sistema *BlindShopping*[11].

A imagem apresenta uma arquitetura constituida por um leitor de RFID, um smartphone*, um servidor e um gerenciador. O leitor de RFID recebe as identificações das tags RFID que recolhe e transmite-as ao* smatphone*, via* bluetooth*. Este além de receber essas identificações pode fazer a leitura de códigos QR e comunica com o servidor do estabelecimento via* wifi*. O servidor está associado a um gerenciador web que organiza as ações que realiza. O* smartphone *envia identificações, RFID ou QR, ao servidor e este responde com a informação detalhada do produto associado ao identificador. A interação entre o* smartphone *e o utilizador é efetuada através de instruções vocais.*

Aqui a superfície comercial necessita de instalar um servidor, uma rede *wifi* e colocar identificadores RFID a mapear o piso. A pessoa com incapacidade visual utilizará o seu smartphone pessoal e um leitor de identificadores RFID que será acoplado à sua bengala branca.
Já Sreekar Krishna et al. propõe um sistema que utiliza EPC, Electronic Product Code, e RFID para fornecer informação sobre os produtos pretendidos. O utilizador utilizará um leitor de identificadores RFID que detetará os códigos EPC dos produtos nas prateleiras perto deste e transmitir-lhe-á informação através de voz sintetizada. A comunicação entre o leitor de RFID e o servidor da loja, onde é analisada a informação dos códigos EPC, é efetuada através da rede wi-fi do estabelecimento. O leitor de RFID estará em constante comunicação com o PDA/smartphone do utilizador, que comunica com o servidor via TCP/IP [12].

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