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USING INTERACTIVE AGENTS TO PROVIDE DAILY LIVING ASSISTANCE FOR VISUALLY IMPAIRED PEOPLE

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USING INTERACTIVE AGENTS TO PROVIDE DAILY LIVING ASSISTANCE FOR VISUALLY IMPAIRED PEOPLE

JULIANA DAMASIO OLIVEIRA

Doctoral Thesis submitted to the Pontifical Catholic University of Rio Grande do Sul in partial fulfillment of the requirements for the degree of Ph. D. in Computer Science.

Advisor: Prof. Rafael H. Bordini

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This Doctoral Thesis has been submitted in partial fulfillment of the requirements for the degree of Ph. D. in Computer Science, of the Computer Science Graduate Program, School of Technology of the Pontifical Catholic University of Rio Grande do Sul

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I dedicate my work to my parents.

“Your best and wisest refuge from all troubles is in your science.”
(Ada Lovelace)

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USANDO AGENTES INTERATIVOS PARA FORNECER ASSISTÊNCIA DIÁRIA PARA PESSOAS COM DEFICIÊNCIA VISUAL

RESUMO

Ambient Intelligence (AmI) é considerado como uma visão futura da computação inteligente, onde as pessoas serão apoiadas pelo ambiente que habitam. Com base na AmI, as tecnologias *Ambient Assisted Living* (AAL) surgiram para ajudar a monitorar, auxiliar e promover um ambiente saudável. Essas tecnologias são uma excelente oportunidade para melhorar a vida das pessoas, principalmente aquelas que convivem com alguma deficiência ou doença, como os deficientes visuais, que são o foco desta tese. Nosso principal objetivo neste trabalho é determinar como as interfaces AmI podem se tornar mais adequadas para a interação com usuários com deficiência visual. Para isso, desenvolvemos uma abordagem baseada em um sistema multiagente, uma vez que AAL requer uma forma muito avançada de interação homem-computador, e os sistemas multiagente são adequados para o desenvolvimento de sistemas adaptativos complexos, especialmente os distribuídos e dinâmicos, como AmI. Nossa metodologia é baseada nas quatro etapas do processo de design interativo. Na primeira etapa, identificamos as necessidades de pessoas com deficiência visual, com base em *survey* e entrevistas com os usuários finais e especialistas do domínio. Na segunda etapa, criamos alternativas de design com base em duas investigações na literatura para identificar os recursos e diretrizes usados no design de AmI. Na terceira etapa, desenvolvemos uma abordagem para AAL que inclui um sistema multiagente interativo para auxiliar pessoas com deficiência visual em sua residência. Finalmente, na última etapa, avaliamos nossa abordagem com 7 especialistas em interação homem-computador e 7 usuários finais. Como resultado, determinamos que nossa abordagem possui elementos que permitem uma interação natural com os usuários, bem como identificamos e discutimos melhorias e novas funcionalidades para trabalhos futuros. Acreditamos que nossas descobertas podem apontar direções para construção de sistemas AmI de interação mais natural. Além disso, com importante impacto social para usuários que nem sempre tem garantido o seu direito de acesso à inovações tecnológicas, como pessoas que possuem deficiência visual.

Palavras-Chave: *Ambient assisted living*, *ambient intelligence*, sistemas multiagentes, pessoas com deficiência visual, interação humano-computador.

USING INTERACTIVE AGENTS TO PROVIDE DAILY LIVING ASSISTANCE FOR VISUALLY IMPAIRED PEOPLE

ABSTRACT

Ambient Intelligence (AmI) is considered as a future vision of intelligent computing, where people will be supported by the environment they inhabit. Based on AmI, the Ambient Assisted Living (AAL) technologies emerged to help monitor, assist, and promote a healthy environment. These technologies are an excellent opportunity to improve people's lives, especially those who live with disabilities or illnesses, such as people who are visually impaired (PVI), who are the focus of this thesis. Our main objective in this work is to determine how AmI interfaces can be made more suitable for the interaction with users who are visually impaired. To do so, we developed an approach based on a multi-agent system, since AAL requires a very advanced form of human-computer interaction, and multi-agent systems are suitable for developing complex adaptive systems, especially distributed and dynamic ones, such as AmI. Our methodology is based on the four steps of the interactive design process. In the first step, we identify the needs of PVI, based on surveys and interviews with end-users and domain experts. In the second step, we create design alternatives based on two systematic literature reviews to identify the resources and guidelines used in ambient intelligence design. We then created the first design alternative based on the first and second steps, which we evaluated with a blind user. In the third step, we create an approach to AAL that includes an interactive multi-agent system to assist visually impaired people at home. Finally, in the last step, we evaluated our approach with 7 human-computer interaction specialists and 7 end-users. As a result, we determined that our approach has elements that allow for natural interaction with users, as well as we identified and discussed improvements and new features for future work. We believe that our findings can point to directions for building AmI systems that are capable of more natural interaction with users. Furthermore, with an important social impact for users who are not always guaranteed their rights to access technological innovations.

Keywords: Ambient assisted living, ambient intelligence, multi-agent systems, people who are visually impaired, human-computer interaction.

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LIST OF ACRONYMS

AAL – Ambient Assisted Living
AI – Artificial Intelligence
AMI – Ambient intelligence
AT – Assistive Technology
BDI – Belief-Desire-Intention
CBR – Case-Based Reasoning
CBP – Case-Based Planning
DSR – Design Science Research
GMS – Global System for Mobile
HCI – Human-Computer Interaction
IOT – Internet of things
MAS – Multi-agent systems
OAT – Object Attribute Tables
PAV – Perception-Action Vector
PE – Pose Estimation
PVI – People who are Visually Impaired
RFID – Radio Frequency Identification
RNA – Robotic Navigation Aid
SMS – Short Message Service
SOAP – Simple Object Access Protocol
VCA – Virtual Carer Agent

CONTENTS

1. INTRODUCTION

Making the environment intelligent and responsive to people is a topic that has been gaining attention over the years [45]. Ambient Intelligent (AmI) is seen as a future vision of intelligent computing, where people will be supported by the environment they inhabit [154]. Based on AmI emerged the Ambient Assisted Living (AAL) technologies, which is one of the most promising areas of AmI [1]. AAL can be used to monitor, assist, and promote a healthy environment [146]. These technologies are an excellent opportunity for improving people's lives, especially for those who live with disabilities, illness, or aging [135]. AAL technologies should allow people to interact with them in a natural and personalised way, taking into consideration their specific interests, needs, demands, requirements, and abilities as well as disabilities [116]. AAL represents a new challenge of being relevant and highly individualised to the particular needs of each user.

According to the World Health Organisation (WHO), in 2010, globally, there were approximately 285 million people who are visually impaired (PVI), of which 39 million were blind [127]. Only in Brazil, there are ≈6.5 million PVI [84]. A person who is visually impaired is blind or has low vision. This may be congenital (from birth) or acquired. Most available studies on ambient intelligence are devoted to the elderly, who have some different needs from people who are blind [101]. Gil [68] argues that acquired blindness also entails other emotional losses, of basic skills (mobility, execution of daily activities), professional activity, communication, and the personality as a whole. Congenital blindness can damage development, with educational, emotional, and social repercussions. Furthermore, the PVI needs to know the state of their own home and have difficulty in managing their usual tasks [170]. Also, these people interact with systems via screen reader and voice synthesizer [101]. For these daily living problems, a voice-controlled smart home would answer these specific needs [170], such as conversational agents, chatbots, and virtual assistants.

The complexity of ambient intelligence requires advanced control systems [64]. Multi-Agent Systems (MAS) are considered to be a suitable tool for complex adaptive systems, especially for those that are distributed and dynamic, such as AmI [44, 109]. The use of intelligent agents provides analysing information on distributed sensors [175, 167, 187]. These agents are capable of both independent reasoning and joint analysis of complex situations in order to achieve a high level of interaction with humans [15], enjoying all the characteristics of MAS systems of cooperation, organisation, and intelligence [187].

In Human-Computer Interaction (HCI) the ambient intelligence presents the challenge of removing desktops and embedding computers in the environment, so it becomes imperceptible to humans while surrounding them everywhere [90]. The involvement of HCI in user interface design has an increasingly significant impact on building an effective ambient intelligence such as smart home [8]. People with disabilities, especially those who are visually impaired, could enjoy ambient intelligence if the interfaces were accessible and usable, allowing easy and effective house control [101]. Thus the PVI becomes more independent and less in need of help [16].

1.1 Objectives

The general objective of this thesis is to determine how AmI interfaces can be made more suitable for the interaction with users who are visually impaired. We puts forward an approach based on multi-agent systems and its potential is demonstrated by a prototype. We defined the following specific objectives to accomplish our general objective:

- Identify the needs of people who are visually impaired, which could be supported in an Ambient Assisted Living.
- Identify the resources and guidelines used in ambient intelligence design.
- Design a multi-agent system taking into account the needs of PVI and the guidelines to improve the user interaction.
- Evaluate the interaction of people who are visually impaired with the multi-agent system.

1.2 Motivation

> "For people without disabilities, technology makes things easier. For people with disabilities, technology makes things possible." [142]

This quote demonstrates one of the motivations for carrying out this research because, by making technologies accessible, access barriers are reduced, aiming at a better quality of life for people with disabilities. Ph.D. student Juliana Damasio defined as the end-users of her research the visually impaired people. This interest started in undergraduate studies, when she developed a methodology for evaluating a platform for the navigation of PVI at *Museu de Ciências e Tecnologia* of PUCRS as her undergraduate thesis [48]. This app is named mAbES [36]. We tested the methodology with the end-users. Among the results, we highlighted recommendations for the development of applications to support the mobility of PVI and improvements for the mAbES application itself.

During the undergraduate thesis, in face of the knowledge acquired, there was a motivation to continue studying the Human-Computer Interaction (HCI) field. For this reason, in 2015, the Master's course in Computer Science was started in the HCI research line. As a theme of the master thesis, we defined and evaluated a programming language called GoDonnie for the movement of a robot, which has the purpose of developing O&M skills for PVI [123]. There is also the Donnie programming environment, which has a graphical environment that has a robot called Donnie, which must obey GoDonnie's commands. This language was developed together with the research project " Use of robotics for teaching programming based on a multimodal interface for people who are blind - Phase 2 " and the Laboratory of Autonomous Systems (LSA), both from the School of Technology at PUCRS. During the work, studies were carried out on O&M, pedagogical robotics, and teaching programming. As a result of the master thesis, we presented evidence that GoDonnie and the virtual programming environment Donnie can be used as support for the development of O&M.

In our actual research, we investigate that research have been proposing multi-agent systems to help elderly and disabled people at home [159, 64, 64, 61, 157]. However, despite the initiatives, to the best of our knowledge, there are still no studies that create a multi-agent assistance system for visually impaired people. Further studies on this topic are still lacking. Despite work focusing on elderly people, they propose that the system benefits people with disabilities, but PVI has not evaluated it.

Ambient intelligence technologies represent a new challenge of being relevant and highly individualised to the particular needs of each user and require a very advanced form of human-computer interaction. Moreover, several solutions lack usefulness and ease of use because they are not oriented to the specific requirements of blind users and, therefore, are not accepted by them [42]. One of the goals of AmI is to allow the user to interact with an AmI system as they would do with any other human [93]. In this context, this thesis aims to create a multi-agent system that takes into account the needs of people who are visually impaired in their homes. We have studied ways to make this system more natural to end-users.

1.3 Methodology

In this section, we present the methodology used to achieve the proposed objectives. Figure 1.1 shows our research design, based on interaction design method [152]. We organised our research in the following activities.

Establish requirements: we conducted *Investigations on end-users' needs*, performed by conducting 3 studies:

- Survey with end-users: developed an online survey that was answered by PVI, 27 participants answered it.

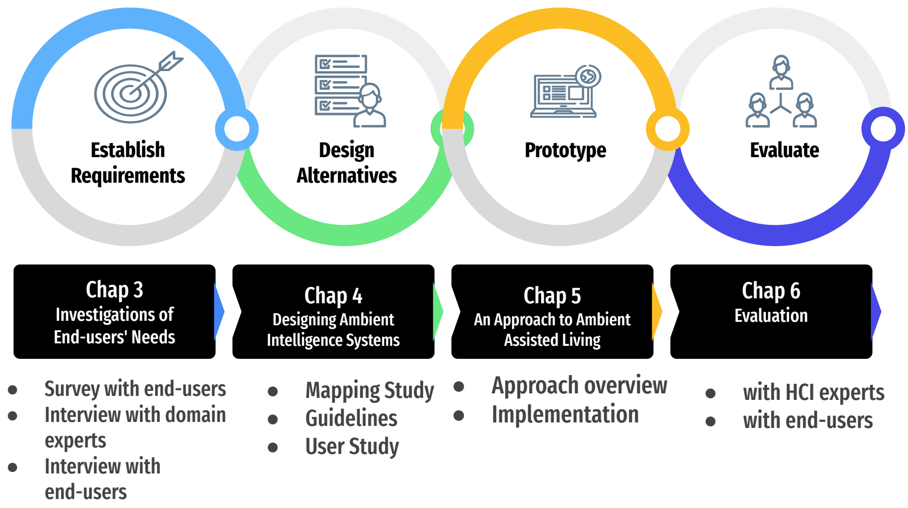


Figure 1.1: Research Design adapted from [152]

- Interview with domain experts: based on survey applied, we interviewed 5 domain experts who teach or have given classes to PVI.
- Interview with end-users: to deepen the understanding of the PVI needs, we invited the survey participants for interviews, from which 3 participants were interviewed.

Design alternatives:

- Mapping study: we performed a mapping study to identify on literature the techniques, technologies, architectures, methodologies, features, and evaluations most used or conducted.
- Then, we performed a systematic literature review to identify *Guidelines to improve user interaction with ambient intelligence systems*.
- We created and evaluated our first design idea that included the main feature pointed out by the end-users. We evaluated with an end-user. This evaluation provided insights to guide our next steps.

Prototypes: we created an approach for Ambient Assisted Living for PVI using a multi-agent system. This approach takes into consideration the established requirements.

Evaluate: Our approach was evaluated by seven HCI specialists and seven end-users.

We analysed all the data collected using the quali-quanti approach. This research has the approval of the ethics committee, the code on *Plataforma Brasil*[1] is CAAE 18419919.0.0000.5336.

[1]https://plataformabrasil.saude.gov.br/login.jsf

1.4 Contributions

Among the contributions of this thesis we highlight: (I) identification of the needs of PVI in AAL, (II) proposition of an approach to ambient assisted living that includes an interactive multi-agent system to assist PVI at home, (III) evaluation protocol of this system with PVI, and (IV) study of ways to provide a more natural interaction to PVI to assist them in their home.

1.5 Thesis publications

During this thesis we produced the following publications:

- “A Survey on the Needs of Visually Impaired Users and Requirements for a Virtual Assistant in Ambient Assisted Living” [124]: related to Chapter 3 in Section 3.1.
- “Ambient Intelligence Technologies for Visually Impaired: A Mapping Study” [126]: related to Chapter 3 in Section 4.1
- “Improving the Design of Ambient Intelligence Systems: Guidelines based on a Systematic Review” [125]: related to Chapter 4.
- “Dial4JaCa – A Communication Interface between Multi-agent Systems and Chatbots” [57]: related to Section 5.2.

1.6 Thesis proposal outline

This document is organised as follows. Chapter 2 presents the theoretical basis related to this work. Chapter 3 details the investigation of the end-users’ needs. In Chapter 4 we show designing Ambient Intelligence Systems, which includes a mapping study and guidelines to improve user interaction with ambient intelligence systems. In Chapter 5 we described our approach to ambient assisted living. Chapter 6 details the evaluations performed. Chapter 7 presents the related work. Finally, Chapter 8 contains our conclusion.

2. BACKGROUND

This chapter presents the background related to this research. The following topics are discussed: Visually impaired people (Section 2.1), Ambient intelligence and Ambient Assisted Living (Section 2.2), Agents and Multi-agents (Section 2.3), Human-Computer Interaction (Section 2.4), and Conversational Agent (Section 2.5).

2.1 Visually impaired people

Visual impairment is defined as the definitive loss or reduction of visual capacity in both eyes, which cannot be improved or corrected with the use of lenses, clinical or surgical treatment [47]. PVI need non-visual stimuli to understand the environment, such as touch and hearing [96]. These people need assistive technologies (AT) that are resources, techniques, and processes to provide assistance and rehabilitation, improving their quality of life [151]. Screen readers are the main AT used by PVI to access information on devices such as computers and smartphones. The screen readers are responsible for reading what is written on the interfaces. For screen reading on computers is used DOSVOX[1], NVDA[2], JAWS[3], Orca[4], for example. While on smartphones, VoiceOver (IOS) and Talkback (Android) are used.

In addition, there are applications to assist PVIs in identifying labels and money. For example, Text Detective[5], DocScannerApp[6], and TapTapSee[7] which use OCR character recognition to read labels and money, this reading is performed through a photo taken by the user. Another interesting app is Seeing AI[8] developed by Microsoft, it reads texts, barcodes, identifies colors, describes people around and emotions, money, and lighting.

2.2 Ambient Intelligence and Ambient Assisted Living

The term Ambient Intelligence originated in Europe, with the European Commission's Information Society Technologies Advisory Group (ISTAG) [154]. Ambient Intelligence is a future vision of the information society where intelligent interfaces enable

[1] http://intervox.nce.ufrj.br/dosvox/
[2] https://www.nvaccess.org/download/
[3] https://support.freedomscientific.com/Downloads/JAWS
[4] https://wiki.gnome.org/action/show/Orca?action=show&redirect=orca
[5] https://play.google.com/store/apps/details
[6] http://www.docscannerapp.com/saytext/
[7] http://www.taptapseeapp.com/
[8] https://apps.apple.com/pt/app/seeing-ai-talking-camera-for-the-blind/id999062298

people and devices to interact with each other and with the environment [138]. This envisaged environment is unobtrusive, interconnected, adaptable, dynamic, embedded, and intelligent [154]. Also, this vision encompasses at least three major areas, such as ubiquitous computing, sensor network technology, and artificial intelligence [154].

AmI seeks the successful interpretation of contextual information obtained from sensors and thus adapts the environment to the needs of the user in a transparent and anticipatory manner [4]. The AmI algorithm can be seen as an intelligent agent that perceives the state of the environment, reason about the data using AI techniques, and acts on the environment using controllers in order for the algorithm to reach its intended goal [45].

Based on AmI, ambient assisted living technologies emerged as one of the most promising areas of AmI [1]. AAL is used to support people with special needs, such as elderly and disabled people. Some care provided by AAL is related to preventing, curing, and improving the wellness and health of these people [146]. AAL is an evolution of Assistive Technology. AT includes hardware, software, and peripherals, which help people with disabilities access computers or other information technologies, whereas AAL encompasses these individual devices to environmental systems in which the assistance completely covers the living area and the person [21].

The Internet of Things (IoT) is the connection of physical things with the Internet. This connection makes it possible to access data from remote sensors and control the physical world from a distance [94]. These sensors can be environmental, such as cameras, RFID tags, microphones, motion sensors, contact, brightness, and temperature, or wearables, such as accelerators and vital parameter sensors [128]. These objects can be used to sense, analyse, control, and decide in collaboration with other objects or individually using high-speed, bidirectional digital communications in a distributed, autonomous, and ubiquitous way [156]. To enable greater security and well-being in a home, the home has to possess intelligence with the help of intelligent items, which is the vision of Ambient Intelligence.

IoT has the potential to assist in various aspects of everyday life and user behavior, especially at work and in the domestic environment. [14]. There is a strong relationship between IoT and Ambient assisted living. [56]. An AAL scenario is characterised by being connected, context-sensitive, personal, adaptive, and anticipatory. IoT should be able to provide all the features required for an AAL [56].

2.3 Agents and Multi-agents

Wooldridge [175] defines an agent as a computer system that sits in some environment and is able to perform actions autonomously in this environment to achieve its design goals. This agent senses the environment through sensors and has a repertoire of actions that can be performed to modify the environment [24]. Wooldridge and Jennings [176] cite the characteristics that intelligent agents should have:

- Autonomy: agents act without the direct intervention of humans or others, and have some control over their actions and the internal state.
- Proactivity: agents take the initiative to achieve their goals, not simply act in response to their environment.
- Reactivity: agents perceive their environment and respond in a timely manner to changes occurring in it.
- Social skills: agents interact with other agents (and possibly with human beings) through some agent-communication language.

There are architectures for modeling agents, being beliefs-desires-intentions (BDI) the widely used architecture [145]. The high-level idea of this architecture is to model the process of deciding which action to take to achieve certain objectives [145]. Thus, Beliefs represent the information the agent has about the world. This information is not always accurate or up to date. Desires are all possible states of affairs that the agent might like to accomplish. Intentions are the states of affairs that the agent has decided to work on. AgentSpeak(L) [144] is one of the agent-oriented languages that use the BDI architecture logic and provides a framework for programming BDI agents. Because this language is very abstract, Bordini et al. [24] create Jason, an interpreter for AgentSpeak, that provides several extensions that are necessary for the practical development of MAS. Jason was compared to other agent languages and achieved better performance [19].

The idea of MAS is multiple agents working in the same environment [175]. Each agent has a sphere of influence in this environment, that is, a part of the environment that they are able to control or partially control. The environment is controlled together. In order to make a decision, the agent must take into consideration how the other agents with some control will probably act [175]. There are some platforms to assist in the development of multi-agent systems, such as Jadex [25], Jade [20], Magentix2 [166], and JaCaMo [23]. JaCaMo is among the most used, and it incorporates the Jason language. Figure 2.1 shows an overview of JaCaMo, where it is possible to see its three dimensions and their relations/dependencies. This platform is composed by Jason - for programming autonomous agents; CArtAgO [148] - for programming environmental artifacts; and Moise [79] - for programming multi-agent organisations.

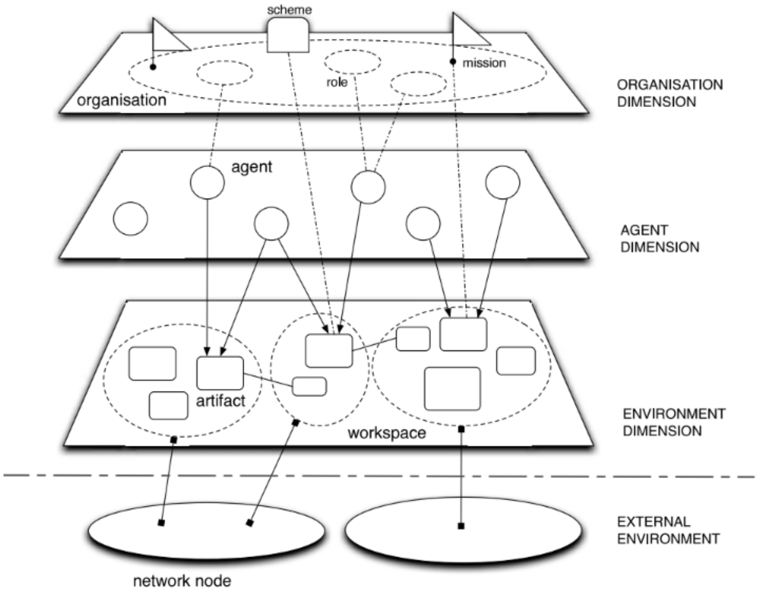


Figure 2.1: JaCaMo architecture overview [23].

In the **organisation dimension**, related to Moise, the organisational structure is defined in terms of group and role entities. In terms of the social scheme, mission, and goal entities - the social scheme decomposes the structure of the organisation's goals into sub-goals, which are grouped into missions. From a normative point of view, in terms of norms, which bind roles to missions, constraining an agent's behaviour, the concerns sets of goals that it will have to achieve when it chooses to enter a group and play a certain role in it [23]. Moise uses the XML programming language.

In the **agent dimension**, correlated to Jason, an agent is an entity composed of a set of beliefs, representing the current state of the agent and the knowledge about the environment in which it is situated, a set of objectives that correspond to tasks that the agent must accomplish/achieve and a set of plans which are either internal or external, triggered by events and that agents can compose, instantiate and execute dynamically to achieve the goals. Events may be related to changes in the agent's belief base or goals [23].

Finally, the **environment dimension**, related to CArtAgO, is composed of one or more workspaces, used to define the topology of the environment. Each workspace is a logical place containing a dynamic set of artefacts, which are the basic computational bricks defining the environment structure and behaviour, representing those resources and tools that agents can create, discover, perceive, and use at runtime [23]. CArtAgO uses Java programming language.

There are several applications for MAS, such as air traffic control, learning environments, entertainment, human-computer interaction, ambient intelligence, among others [78]. Because multi-agent systems are flexible and interoperable in nature, it becomes a good approach for systems with multiple devices and sensors such as Ambient intelligence.

2.4 Human-Computer Interaction

Ambient intelligence is intended for people living in “intelligent” electronic environments that have claims of being sensitive and responsive to their needs. This environment involves users, and the system modulates and filters information according to the context to meet users’ needs and their activities [34]. This environment differs from the traditional form of interaction that is centred on a device, system, and human-ability [182]. Currently, the critical issue that researchers in Ambient Intelligence have to address is designing tools that allow end-users to easily control and manage their smart homes [35]. It happens because it is not straightforward to understand which are the requirements that must be satisfied to effectively support end-users [35]. Therefore, it is essential to study ways of interacting with these environments and people’s needs.

Human-Computer Interaction is a discipline that is based on the design, implementation, and evaluation of interactive computer systems for human use, and the aspects related to such use [77]. This discipline has a multidisciplinary nature, using knowledge of psychology, design, computing, and linguistics, for example [18]. Hewett et al. [77] define some topics of study in HCI as the nature of human-computer interaction; the use of interactive systems in context; human characteristics; the architecture of computer systems and the interface with users, and development processes concerned with the use. The interaction design has a broader view than HCI. This vision addresses practice in designing user experiences for all types of technologies, systems, and products [152]. Designing usable interactive systems requires taking into account who will use them and where they will be used [152]. Butz [30] suggested the use of interactive design for designing user interfaces for ambient intelligence. The process of interaction design involves some basic activities [152]: establishing requirements; creating design alternatives; prototyping; and evaluating them. These activities complement each other and repeat themselves.

- The activity of **establishing requirements** has the purpose of understanding users, their activities, and the context of these activities so that the system of support for users to achieve their goals. From this, define a set of stable requirements to begin the design. Such requirements include everything from the features that users need to HCI quality criteria that must be satisfied in order for the design to be considered successful [18]. These requirements can be collected through interviews, questionnaires, and use observation, for example.

- The activity of **creating design alternatives** occurs after the requirements definition. In this stage, design ideas are proposed to meet the requirements.

- The activity of **creating prototypes** has the purpose of creating prototypes of the system. A prototype is a design manifestation that allows stakeholders to interact with it and explore its suitability. A prototype is usually more limited because it emphasises only some characteristics of the product. There are low fidelity and high fidelity prototypes.

- The activity of **evaluation** focuses on system usability and user experience when interacting with the system/prototype. Interface evaluation is guided by two methods: inspection and observation of use. In the inspection method, specialists inspect the interface to find possible errors that could detract from the user experience. Some examples of inspection methods are Heuristic evaluation and Cognitive walkthrough. In the observation method, users (potential or domain experts) use the system and usability problems are identified by the system designers. The main examples of the observation method are the Usability Test and Communicability Test [18].

There are some criteria and guidelines to guide the design of interactive systems. Basically, aspects of usability and accessibility are considered. Accessibility is related to the removal of barriers that prevent more users from being able to access and interact with the system interface [18]. Due to the importance of the topic, there is an international community designed to develop standards for the World Wide Web (WWW), the World Wide Web Consortium (W3C)[9]. This community have recommendations for making web content more accessible, such as WCAG[10] and WAI[11].

Usability, according to Nielsen [120], is related to the ease of learning and use of the interface, as well as user satisfaction as a result of such use. Nielsen [120] presents five principles of usability:

- Learnability: refers to the time and effort of the user to learn to perform some task of the system.

- Memorability: it is related to the cognitive effort to interact with the system and also to the number of errors committed during this interaction.

- Efficiency: refers to the time required to complete an activity with computational support. It evaluates whether the system does well what it proposes to do.

- Satisfaction: emphasises the emotions of users while using the system. The usage experience is something personal, but it is possible to create systems that promote a good user experience, which contains features that stimulate good emotions and avoid unpleasant feelings.

[9]http://www.w3c.br/Home/WebHome
[10]https://www.w3.org/Translations/WCAG20-pt-PT/
[11]https://www.w3.org/WAI/

- Errors: mainly linked to the ability of the system to help the user recover and avoid errors.

Therefore, to ensure the acceptance of Ambient Intelligence is necessary to take into account these topics.

2.5 Conversational Agent

A conversational agent, also known as chatterbot or chatbot, are computer programs that interact with users through natural language. The use of this technology began in the 1960s, intending to verify if chatbots could deceive users who were real humans [161]. Over time, it was noticed that these systems could not only imitate human talk but also be useful in areas such as education, commerce, health, business, among others [89]. Over the years, it appears that the virtual assistants that can be seen as an evolution of the chatbots, as besides being an interface for conversation, they also became executors of actions. Besides, they use inputs such as the user's voice, vision (images), and contextual information to assist, answering questions in natural language [76].

Conversational agents have been used in a variety of contexts, such as: health care to help physicians identify symptoms and improve assessment skills, diagnosis, interview techniques, and interpersonal communication [150]; helping elderly people with cognitive disabilities by providing proactive functions by sending messages to help them in situations where they are distracted [174]; in education to facilitate the teaching and learning process [163] and inclusive education [112]; in hospitality to provide information to guests about hotel services and to accompany them through the hotel spaces [183], among others.

Companies such as Google and IBM, for example, are providing tools such as Watson[12] and DialogFlow[13] for creating chatbots projects. These systems provide APIs for development, providing natural language processing capabilities for applications, services, and devices [55]. The behavior of the bot is mapped by intents. Intents represent the mapping between what the user says and what action or response is performed by the software. In Dialogflow, for example, each intent is composed by:

Training phrases: which represents possibilities of text entries made by the system user.

Action: an action that the system can perform so that it can give the user a better response to what was requested.

[12] https://www.ibm.com/watson/br-pt/
[13] https://dialogflow.com/

Parameters: values that can be extracted from an end-user expression.

Context: It is the relationship between the text and the situation in which it takes place.

Response: a textual response that the system shows the user depending on the text input made.

Intents can contain all of these elements but do not necessarily have to contain all. For a conversation to exist between the system and a person, it is mandatory the different text input that the user can say to the system (training phrases), as well as the responses that the system can deliver to these inputs (responses) [69].

Figure 2.2 presents the working architecture of Dialogflow. Through this architecture, it is possible to verify that the user can enter the conversation using the keyboard or voice. Afterward, within Dialogflow, a query is executed that seeks the registered intents for the input performed by the user. It is possible according to the intent have an external service named Fulfillment, which brings some results to the user. For example, if the user asks “How is the weather today?”, there is a web service that searches Google for the current weather according to the user’s region. The system processes the output to the user and writes or speaks it through audio.

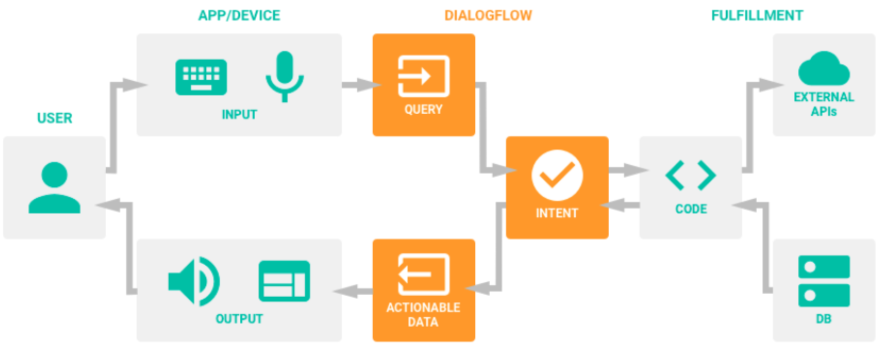


Figure 2.2: Dialogflow architecture [69].

The APIs for chatbots development allow integration with websites, mobile apps, Google Assistant, Amazon Alexa, Facebook Messenger, and other popular platforms and devices. Inserting virtual assistants into home-based devices such as Amazon Alexa and Google Assistant, which are voice-controlled, allows interaction between users and devices in a more humane and familiar way [71]. Especially, the use of voice input becomes beneficial for PVI [101], focus of this project. According to Pérez-Soler et al. [131], choosing a platform for chatbots development is difficult and particular to each project. They created a comparison between the main existing platforms to help developers to make this choice.

FINAL REMARKS

In this chapter, we present the theoretical basis that supports this thesis. We show the characteristics of the AmI domain. Then we present multi-agent that will be used in our approach, as well as the HCI interactive design process. In addition, we show ways to interact with the voice, using conversational agents, which are also important for this thesis.

3. INVESTIGATION OF END-USERS' NEEDS

In this chapter, we present our investigations towards the end-user needs. We used an HCI strategy named the triangulation technique. This strategy uses more than one collection technique to obtain different perspectives and confirm the discovery, thus allowing for more rigorous and valid results [18]. To do so, we performed a survey to identify the needs of PVI and we interviewed domain experts. Lastly, we conducted an interview to deepen the data collected in the first survey.

3.1 Survey with end-users

We investigated the needs and barriers of PVI. We created an online questionnaire to be answered by end-users. The questionnaire had qualitative and quantitative answers and was published in [124]. We chose this approach to reach more people, and also because it is an affordable and effective method to collect data [137, 18]. The questionnaire was made available from March to September 2018.

We split the questionnaire into three parts: first, we had the **consent form** to participate in the survey with information about the project and questionnaire; then we asked questions about **demographic aspects** such as age, gender, visual acuity, the state of Brazil where they live, and whether living alone; and finally, we presented **9 questions** about prior experience with technology, the level of knowledge about robot companion and virtual assistants, receptivity to the idea of a virtual assistant, technologies to help with daily activities at home, difficulties and easiness faced in daily activities while alone at home, and essential tasks a virtual assistant could potentially carry out (Table 3.1). We presented detailed explanations about each question to improve the understanding (e.g., what is a virtual assistant, companion robot, home automation, among others).

Table 3.1: The content of the questionnaire

Questions	**Response type**
Which of these technologies have you heard about? (virtual assistant, computer, companion robot, smartphone, tablet, smart tv, home automation, robot)	multiple choice
Which of these technologies have you had contact with? (virtual assistant, computer, companion robot, smartphone, tablet, smart tv, home automation, robot)	multiple choice

Table 3.1 continued from previous page

What is your level of knowledge about companion robots?	5-point likert scale
What is your level of knowledge about virtual assistants?	5-point likert scale
Do you like the idea of having a virtual assistant at home?	5-point likert scale
What technologies would you like for helping with daily activities at home?	open question
What difficulties do you face in daily activities while being alone at home?	open question
What are the technologies that most help you (when alone) in your daily activities at home?	open question
What tasks would you like a virtual assistant to be able to carry out? The tasks are listed in Table 3.2.	5-point likert scale

Table 3.2: Tasks for a virtual assistant

Id	Tasks
1	Find objects
2	Detect obstacles
3	Identify whether the light is on or off
4	Identify whether the window is open or closed
5	Identify whether the door is open or closed
6	Inform the time of the day
7	Inform the weather
8	Warn about appointments as a virtual calendar
9	Reminders to take medicine
10	Turn devices on and off
11	Notify when objects are out of the usual places
12	Warn how many meters away objects are
13	Warn if there is another person in the environment
14	Notify location (e.g., in degrees) of objects
15	Request help from any registered contact

We conducted an initial research with a participant who is blind and lives alone to assemble the questionnaire. We sent an e-mail to the participant asking, “what would be your greatest difficulties living alone?”. Based on the participants’ responses, we elaborated some questions. We also performed a pilot with this participant, where he helped us to assess and improve the questions.

Table 3.3: Demographic aspects of the sample

Sample Demographics (*n* = 27)	
Gender	**%**
Male	55,6 (15)
Female	44,4 (12)
Age	**%**
18-28	48.15 (13)
29-39	18.52 (5)
40-50	11.11 (3)
51-61	11.11 (3)
62-72	11.11 (3)
>73	0
Visual acuity	**%**
Blindness	81.48 (22)
Low vision	18.52 (5)
Living alone	**%**
Living with other people	81.48 (22)
Living alone	18.52 (5)

We released this questionnaire among our end-users using Facebook, Google groups, and people know to the Ph.D. candidate. Among the groups the questionnaire reached, we highlight the following: Associação De Pessoas Com Deficiência Visual de Santa Catarina - Apdvisc (≈170 members), AEE - Deficiência Visual (≈1.171 members), Deficiência visual - eu existo (≈8.745 members), Pessoas com deficiência (≈5.015 members), PSICOTEC-EPEDV (Educação Especial para Pessoas com Deficiência Visual) (≈170 members), Deficiência Visual (≈1.896 members), O Ensino de Música a Pessoas com Deficiência Visual (≈424 members), Minuto inclusão - deficiência visual (≈75 members), Psicólogas e Psicólogos com deficiência visual (≈469 members), and Google group acesso digital[1].

In addition, we also applied the questionnaire in person, as an interview, at the Associação de pessoas cegas do Rio grande do sul (ACERGS)[2]. This strategy was used to obtain more respondents. We read the consent form to the participants, and we left a copy of the form with them.

[1]https://groups.google.com/forum/#!forum/acessodigital
[2]http://acergs.org.br/

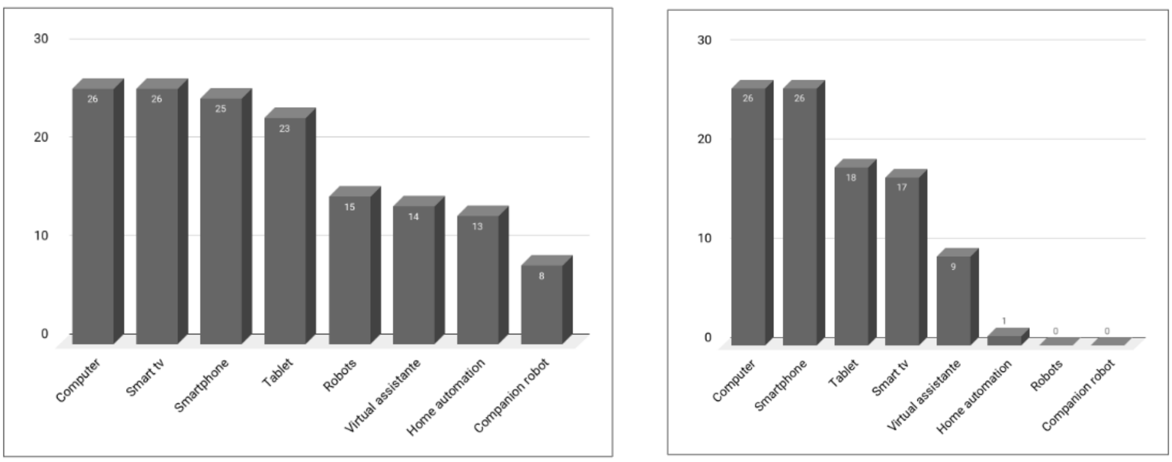
3.1.1 Participants profile

We obtained 27 answers to the questionnaire. The online instrument was filled by 16 people, while in person, we interviewed 11 participants. Table 3.3 provides the characteristics of the sample. Data analysis showed that the majority of the participants were male (55.6%). Among them, 81.5% are blind, and 18.5% have low vision, being 59.3% congenital (from birth). Participants were between 18 and 73 years old, and the most common age group is from 18 to 28 (48,15%). Most of the participants live in Rio Grande do Sul (68.18%), and the remaining in Santa Catarina (13.64%), Paraná (13.64%), and Minas Gerais (4.54%).

Most participants reported never have lived alone. Currently, 81.5% do not live alone. Among the ones who do not live alone, 11 participants reported that they live with people who are also blind.

3.1.2 Results

Prior experience with technology: when asked “What technologies have you heard about?”, smart TV was the most cited (96,3%), followed by computer (96,2%), smartphone (92,5%), tablet (85,1%), robot (55,5%), virtual assistant (51,8%), home automation (48,1%), and companion robot (29,6%) - see Figure 3.1. When asked about the technologies that they already had contact with, we had similar answers, with smartphone being the most common (96,3%), followed by computer (96,2%), tablet (66,6%), smart TV (62,9%), virtual assistant (33,3%), home automation (3,7%), robot (0%), and companion robot (0%) - see Figure 3.1(b).



((a)) ((b))

Figure 3.1: (a) Technologies they heard about, (b) Technologies they already had contact with.

Level of knowledge about companion robots and virtual assistants: when asked "What is your level of knowledge about companion robots?", most of the participants answered having no knowledge (66,7%). When asked the same question about the virtual assistant, less than half the participants (40,7%) had any knowledge. 11,1% of participants have knowledge about companion robots, and 33,3% have knowledge about the virtual assistant. We present the levels of knowledge the participants pointed out in Figure 3.2.

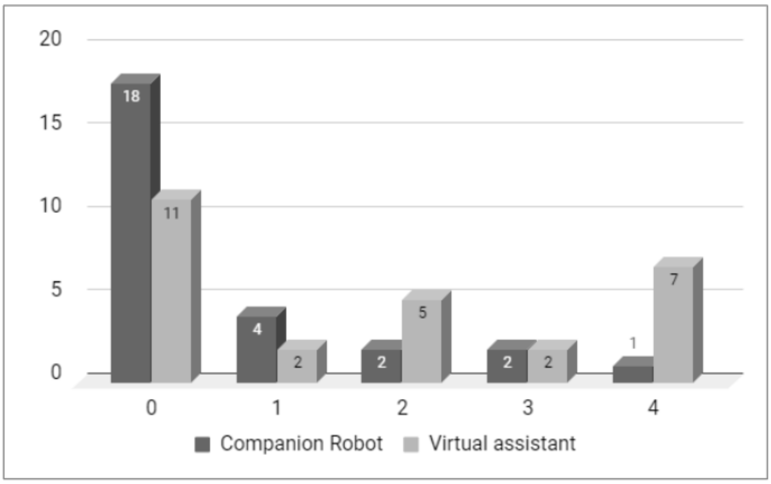


Figure 3.2: Level of knowledge about company robots and virtual assistant.

Receptivity to the idea of having a virtual assistant at home: 81,5% of participants liked or liked very much the idea of having a virtual assistant at home (Figure 3.3). The reasons for not liking the idea were: "Because it does the same things I did before, but in a different way, with more care" and "Because I learned by myself how to do things, so it is not needed."

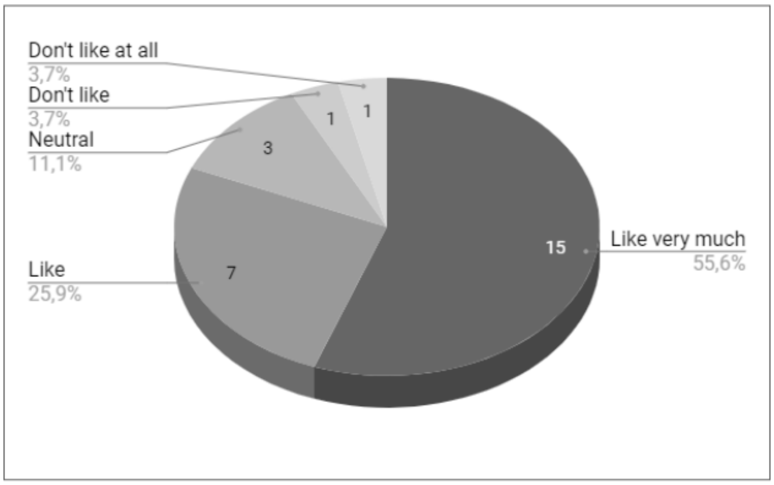


Figure 3.3: Participants receptivity to a virtual assistant at home.

Technologies to help: when asked "What technologies would you like for helping with daily activities at home?" most commonly cited technologies were: mobile apps

(48,1%), robots (25,9%), virtual assistants (18,5%), and sensors (14,8%). We present as follows some of the responses we obtained with the participants.

- "(I would like to have) a virtual assistant, to inform things that are relevant for me, such as the weather. Or a mobile application to send me messages every hour with the information I need. (I also would like to have) a robot with sensors to check and inform me about changes in the environment. Anything to give me more independence."
- "I often need to use different applications on my cell phone and computer to perform simple tasks, such as checking the color of something or reading a correspondence. If I had a robot to do it for me, I would feel like as if I used the robot's eyes. And of course, it would be nice if the robot could sweep the floors. It is an annoying task because I have to keep passing my hand on the floor to see if it is clean."
- "(I would like to have) robots that facilitate cleaning the house, sensors to identify, for example, whether they have open faucets, lights on, windows unlocked, and so on."
- "(It would be good to have) all these things to help in solitude, and to help know if there is an open door or chairs out of place."

Barriers in daily activities: when asked "What difficulties do you face in daily activities while being alone at home?" the participants answered: house cleaning in general (22,2%), reading (e.g., correspondences, newspapers, and medicines) (22,2%), non-accessible household appliances (18,5%), identify clothing colours (11,1%), finding items (e.g., clothes, medicines, and food) (11,1%), check if lights are on/off (7,4%), and identify obstacles (7,4%). Below we present some responses we obtained with the participants.

- "Some difficulties are to know if the light is on or off, to check the colors of the clothes and if it is dirty or smudged, to find things (such as a remote control), to recharge a phone, identify the bills. Find specific clothes, like the ones of my favorite color, find some medicine or a specific food. To be warned about some danger."
- "My only difficulty is solitude."
- "Knowing the color of clothes, product names, among other things. I can talk to people with accessible mobile apps, other applications help identify products and colors, but they still need to be improved."

Technology facilities: when asked "What are the technologies that most help you (when alone) in your daily activities at home?" the participants answered: mobile apps (33,3%), cellphone (25,9%), smart TV (18,5%), computer (18,5%) and screen readers (14,8%). Some responses from the participants are given below:

- “Mobile apps help identify the colours and some products. But they still need improvements. There are a number of accessible, leisurely, and helpful applications that help you keep in touch with others.”
- “The screen reader is a technology that helps me, and I use it on my computer and on the cell phone.”
- “Money reader. Navigation Application fails, but it helps. Packaging Readers, Whatsapp, Mobility applications, identification of colors and objects.”
- “Mobile apps help you identify colors and some products, but there’s still a need to improve. There are a number of apps that are accessible for leisure and that help keep in touch with others.”

Tasks for a virtual assistant: we asked “What tasks would you like a virtual assistant to be able to carry out?” and we presented a range to indicate the level of importance (0: not important - 4: very important). Table 3.2 presents the tasks we introduced to the respondents. Among the tasks the respondents consider important and very important, more than half wanted the virtual assistant to find objects (85.2%), notify if objects are out of place (81.5%), warn if there is another person in the environment (77.8%), prevent obstacles (74.1%), identify whether the light is on/off (70.4%), turn on/off devices (70.4%), reminders to take medicine (59.2%), warn how many meters away objects are (59.2%), warn about appointments as a virtual calendar (55.5%), request help from any registered contact (55.5%), inform the weather (51.9%), and notify location (e.g., degrees and hours) of the objects (51.80%). Less than half of participants wanted it to identify whether the door is open or closed (40.7%), inform the time (40.7%), and identify whether the window is open or closed (29.6%). Figure 3.4 shows the tasks ordered by the total of votes in the important and very important scale.

The participants also indicated the following tasks:

- “To be able to show something and to speak briefly about what it is, for example, what is the color or describe the object. Give me urgent warnings, such as storms. Sensor that map of my environment, thus giving me basic and/or more advanced information.”
- “Some of the above would be more useful if the scope were extended beyond the residence, such as preview obstacles, open doors, identify people or warn when people are coming closer. Since their residence is the most known place, blind people have a mental map of this place that has an almost exact correspondence with reality.”

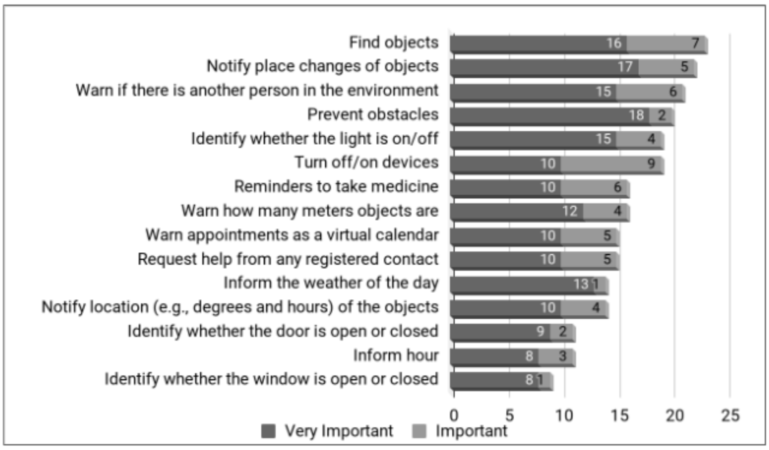


Figure 3.4: Top tasks for a virtual assistant.

- “Read newspapers and magazines, locate clothes.”
- “To identify colors and blemishes in clothes.”
- “To identify brands on the wall, like mold, and facilitate the cleaning.”
- “Mobile apps and news on the home appliances themselves, such as the audio in the dishwasher, whether the machine is open, how much water has been put in, and audio to tell when the phone is running low.”
- “Describing colors and objects, as some applications already do, would be an interesting and useful feature.”

We asked the participants if they would like to participate in next phases of our study, and 70% agreed, indicating their contact email.

3.2 Interview with domain experts

Based on the survey, we developed and applied an interview protocol with domain experts. The questionnaire has 9 questions, 5 on the expert’s profile and 4 on the needs of the end-users.The questionnaire was applied in person, in the form of an interview, in the *Associação de pessoas cegas do Rio grande do sul (ACERGS)*. The consent form was read to the participants who agreed to participate. A copy of this term remained with the participants.

3.2.1 Domain experts profile

We interviewed 5 participants who teach or have given classes to PVI. Table 3.4 shows the sample demographics. Most of the participants are Female (60%), having

Table 3.4: Domain experts sample

Id	**Gender**	**Age**	**Visual acuity**	**Time experience**	**Class type**
S1	Male	51-61	Sighted	4-6 years	Orientation and mobility
S2	Female	40-50	Blindness	4-6 years	Activity of daily living (ADL)
S3	Female	29-39	Blindness	1-3 years	Braille
S4	Male	40-50	Sighted	>10 years	Informatics, smartphone use, tablets, braille printers, any devices.
S5	Female	29-39	Sighted	>10 years	Informatics, Bioinformatics, and Biology

between 29 and 61 years old. Two participants are blind, and the remaining are sighted. Two have more than 10 years of experience working with PVI.

3.2.2 Results

Barriers in daily activities: when asked “What difficulties are you aware of that people who are visually impaired face in daily activities when they are alone in their homes?” the specialists answered:

- “If they are not aware of orientation and mobility they have all the difficulty. In this case, they can not do almost anything, they are alienated from everything.” (S1)
- “It is not that they face difficulties, the family who prunes the disabled, they are afraid and do not let them perform some activities like cooking.” (S2)
- “With all the features we have nowadays I do not see much difficulty, but it depends on the level of user experience. We have mobile apps, and screen readers on the computer. Using the cane I have the autonomy to come and go. For my college studies, I use Braille. At my home, I do normal household chores.” (S3)
- “It is difficult to access the TV menu, they can turn on the tv but do not access the tv guides. Computers do not have accessibility, 95% of sites are inaccessible.” (S4)
- “I believe activities related to cleaning your residence. Choice of clothes, with regard to color combination, for example. Lack of accessibility features in home appliances. For example, there are devices that have operational information in text format and do not have text equivalence in braille or audio, such as remote TV menus, cable TV, washing machines etc. Also, accessible interactive menus are lacking as in the case of microwaves. For example, there is no way to control the temperature of an air conditioner without seeing it in the control.” (S5)

Technologies to help: when asked “What kind of technologies do you think would be interesting for a person who is visually impaired to assist in the daily activities in their homes?” the specialists answered: Sensors (3:60%), Robot (3:60%), Home automation (2:40%), Mobile apps (3:60%), and Accessibility in equipment (2:40%). The responses from the specialists are given below:

- “Automation would be very interesting as well as mobile apps.” (S1)
- “Robots, sensors and cell phones. For example, if I had a machine with sensors that could talk to me about some information, it would be interesting. All the equipment should be able to communicate by audio.” (S2)
- “Identify colors for clothes or something you want to wear. Read correspondences, check product validity.” (S3)
- “Sensors, mobile applications that warn if there is light on, sensors for devices that are connected. Microwaves have no identification, so the equipment should have accessibility.” (S4)
- “Sensors, robots, virtual assistants, mobile applications, home automation.” (S5)

Tasks for a virtual assistant: we asked “What tasks can facilitate the daily home activities of a person who is visually impaired using a virtual assistant?” and we listed options to indicate the level of importance (0: not important - 4: very important). We presented to the domain experts the same tasks we presented earlier to the end-users - see Table 3.2. Figure 3.5 shows the tasks ordered by the total of votes in the important and very important scale. Considering the combination of responses important and very important, majority of specialists wanted the virtual assistant to prevent obstacles (5:100%), find objects (5:100%), turn on/off devices (5:100%), warn about appointments as a virtual calendar (5:100%), inform the weather (5:100%), notify if objects are out of place (5:100%), request help from any registered contact (5:100%), warn if there is another person in the environment (4:80%), reminders to take medicine (4:80%), identify whether the light is on/off (4:80%), warn how many meters away objects are (3:60%), and inform the hour (3:60%). Less than half of participants wanted it to identify whether the door is open or closed (2:40%), identify whether the window is open or closed (2:40%), and notify location (e.g., degrees and hours) of the objects (1:20%).

In addition to the items listed, specialists indicated:

- “The list you presented has a good size.” (S1)
- “Everything that communicates by sound is interesting, such as microwaves, or electric bean casserole with beep” (S2)

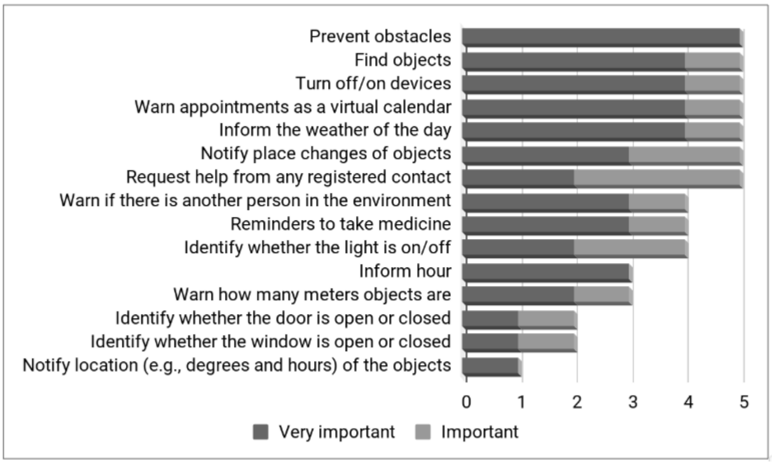


Figure 3.5: Top tasks for a virtual assistant - specialists.

- “It could be something that would identify if something is neat enough, or identify stained clothes such as coffee.” (S3)
- “In my view it was all quoted, mainly to find objects and changes of their location.” (S4)
- “Helping the visually impaired in choosing clothes. Warning certain food needs replenishment as a shopping list (smart refrigerator). Affordable menu for microwave and washing machine. TV remote control and affordable air conditioning and accessible cable TV menus (browsing and reading). For me, the main thing is to automate electronic devices with accessible resources, to facilitate and improve the quality of life of people with visual impaired. A robot that can aid in daily cleaning is also interesting (there are already those who sweep the house, for example). It could detect and report other types of dirt like water, scratches on walls). A robot or application with conversational interface could also be friendly to the point of being able to “talk” to the person who is visual impaired, informing clothes colors and how is the time, reading labels or texts to the user and being playful to the point to serve as entertainment (e.g., quizzes about facts or subjects that are interesting to the user, executed by voice commands or by an application accessible by the screen reader of a Smartphone).” (S5)

3.3 Interview with end-users

For this phase, we invited participants from the survey that agreed to keep contributing with our study. 3 participants accepted (Table 3.5). We asked them to participate in a structured interview. We conducted the interviews using Skype because the participants did not live in the same city as the PhD candidate. The interview had two parts: reading of the consent form for participation in the research; and 5 questions deepening the survey and interview.

Table 3.5: PVI profile

Id	**Age**	**Gender**	**Visual acuity**
P1	18-28	Male	Blindness
P2	18-28	Male	Blindness
P3	18-28	Female	Blindness

3.3.1 Results

In the first question we asked, “How do you prefer to interact with a virtual assistant? The options were: by voice, by text, by touch, by gestures.”. All participants responded that they prefer to interact with the virtual assistant by voice. After we asked what the second preferred option was, 2 participants responded by using text and 1 by touch.

In the second question, we asked “In which devices would it be interesting to put a virtual assistant to assist in the daily activities in your home? The options were: computer, smartphone, robot, TV”. All participants answered they prefer to insert the virtual assistant into a computer and smartphone. The second option was robot, having 2 votes. P3 suggested that it would also be interesting to add the virtual assistant on appliances like Washing Machine (saying washing options), in the freezer (saying what is inside).

In the third question we asked “What kinds of activities could be performed by a virtual assistant to assist in the loneliness of a person? It was an open question.”

- “Play music, bring news, read poems, read small informative text, talk about events and talk.” (P1)
- The response of P2 happened in two moments, the first during the interview and another after the interview. He/she reported that he had not been satisfied with his answer to this question during the interview, so after thinking about the issue he sent a new reply by email.
  - First answer: “It’s not very healthy to have a robot to entertain, but you could ask to chat, play music, joke (such as Google assistance). But I would not use this function. It would be better to have a more functional robot with something more practical.”

- Second answer: “Well, based on the assumption that a robot will hardly replace the presence of and the connection that can be had with a similar human (which was what limited my response at that moment), nothing prevents a robot from being a robot and even then I can have some kind of meaningful connection with him/her, that will lessen my loneliness. Just as I can relate to beings different from me, like other animals for example. A robot like that, in my opinion, will have to have 3 things, before the utilitarian ones: personality, sensibility, and spontaneity/unpredictability.

  Personality: think it would be good if it had/developed tastes, habits, maybe even its own phrases (even if strange) and that he was not simply a slave. He may refuse to do something I asked for, because I did not say the magic word, for example. Of course, keeping the good census, if I ask him to call the police because someone is entering my house without permission, it would not be good for him to refuse. He can go on to like objects with a certain format, and ask to own/use some object.

  Sensitivity: It would be interesting if it were possible to detect feelings, by facial expression or tone of voice. It is important for you to feel that there is really someone with you (who understands you at this level), not necessarily a human ability because my dog seems to know when I am sad, angry or happy.

  Spontaneity: Sometimes the robot could take initiatives alone. Silly example of dialogue: “Hey, you look sad”, and starts playing an animated song out of nothing. “I’m not sad about it.” “Okay, since you prefer to suppress your feelings.” I believe this generates a connection, even though I know it was programmed, in the last case I can think that in a way I am communicating with who created it, just like when I read a book I feel a connection with the author. Another thing is that it does not need to communicate only by speech, it can have alternative forms. And he also does not have to do only things his owner likes.

  Utilitarian skills: It would be cool if he could describe to me some things, say, for example if the can I am showing you contains beer or Coke. To warn me, in subtle ways, of some dangers: the person who came to visit me seems to be armed, there are shards of glass on the floor or some dirt (for those who have a dog). I remember you had questions about utilitarian things.

  That’s what I discovered when I best worked out my thinking. The robot does not need to interact at the level of the bicentennial man, or the operating system in the movie Her. Even with weak AI, I believe it is possible to generate a connection. My idea would not be to simulate a human being, but to have a robot with which it is possible to have a relation beyond the utilitarian one and that does not seem fake (relation between human with the limitations of

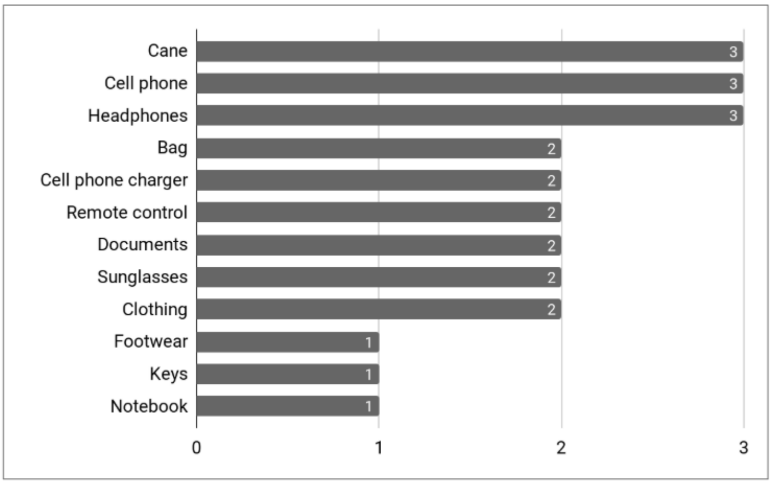


Figure 3.6: Objects to be found.

human, and robot with the limitations of robot) . In the Game of Thrones series, at least in the books, there is the Hodor character, which is intellectually limited, so that the only word he can speak is his name (although he can modulate pronunciation to express feelings). Still, this does not stop him from being loved and valued by the character Bran, who had been paralyzed and who received constant help from Hodor to go from place to place."

- "I do not know, because it will never replace the human being." (P3)

In the fourth question, we asked "If there was a virtual assistant's option to find something that you missed at home, what items would be interesting to find? We list some options and the participant could mark several. The options were: cane, bag, cell phone charger, footwear, cell phone, remote control, keys, documents, headphones, notebook, sunglasses, clothing.". Figure 3.6 shows the responses of the participants. The most voted items were cane, cell phone, and headphones.

The last question was "If you had a virtual assistant, what level of autonomy should the assistant have?". This question had some options, and several could be marked.

- No autonomy - the assistant should only carry out activities requested by the user.
- Average autonomy - the assistant must carry out the activities requested by the user and also perform activities alone when perceiving the environment.
- High autonomy - the virtual assistant must perceive the environment and perform activities alone, without the user request.
- Adjustable autonomy - the virtual assistant has proactivity to verify the activities to be performed, but confirms with the user before performing any activity (or just

some activities that have been configured as more sensitive that need authorisation).

All participants preferred Adjustable Autonomy. P1 reported that it prefers the option "average autonomy" in second place.

FINAL REMARKS

Through the survey with end-users, we found that the respondents accept the idea of having a virtual assistant in their home. The results clearly indicate that much help can be provided to such users through ambient assisted living and a custom-made virtual assistant for blind users. The majority of barriers/difficulties faced by participants in their home are related to house cleaning in general, reading (e.g., correspondences, newspapers, and medicines), non-accessible household appliances, identifying clothing colours, finding items (e.g., clothes, medicines, and food), checking if light is on/off, and avoiding obstacles. Most of the participants would like some technologies such as mobile apps, robots, virtual assistants, and sensors in order to support their daily activities at home. It was a much encouraging finding for our ongoing work. We confirmed these results when we interviewed domain experts.

In terms of specific tasks for a virtual assistant, most of the respondents wanted to find objects, to be notified of objects being out of place, begin warned if there is another person in the environment, avoiding obstacles, checking whether the light is on/off, turn devices on/off, reminders to take medicine, information about how far away objects are, reminders about appointments as a virtual calendar, and request help from any registered contact. Some of these tasks are also related to the needs of the elderly, for instance, reminders to take medicine, reminders of appointments as a virtual calendar, and requesting help from any registered contact, while others are very specific to blind users, such as for example colours. These results were also confirmed when we interviewed domain experts.

When we interviewed some of the participants who are visually impaired, we identified the type of interaction they preferred; which devices would be more interesting to place the virtual assistant; how the virtual assistant could assist in solitude; which objects would be important to find; and what the virtual assistant's level of autonomy is. The findings in sequence:

- type of interaction: voice.
- devices: computer and smartphone; and robot.

- solitude: some characteristics were emphasised for a virtual assistant as personality, spontaneity, sensibility, and utilitarian functions. Some utility functions reported were: play music, joke, read a poem, read informative text, and events.
- objects to find: the main objects are a cane, cell phone, and headphones.
- autonomy level: adjustable.

4. DESIGNING AMBIENT INTELLIGENCE SYSTEMS

This chapter presents the work we published in [125] and [126]. In Chapter 3 we understand the user needs and set the requirements. The next step according to the interaction design method [152] is to create design alternatives. At this stage, we have to propose design ideas to meet the requirements. Keeping that in mind, in this chapter, we present our two investigations conducted in the literature to identify the resources and guidelines that are used in ambient intelligence design. We also describe our first design idea that was evaluated with a user who is visually impaired.

4.1 Ambient Intelligence Technologies for Visually Impaired: A Mapping Study

We conducted a Mapping Study (MS) that is a type of systematic literature review [28] used to provide an overview of a research area [132]. We classify existing solutions according to the techniques, technologies, architectures, methodologies, features, and evaluations they used or conducted. We use the protocol proposed by Petersen et al. [132]. The main goal of this study is to identify and understand the technologies used in intelligent environments to assist PVI. The MS was divided into two main parts. The first part is the Planning, where we defined the research questions, search strategy, and selection criteria. The second part is execution and results, where we presented the execution of the planned activities and the results.

4.1.1 Planning

Research questions

Based on the purpose of this MS, we defined 7 research questions:

RQ1 - What is the type of users?

RQ2 - Where (geographically) and when (year) did the research take place?

RQ3 - What technologies were used?

RQ4 - What architectures were used?

RQ5 - What techniques were used?

RQ6 - What methodologies are adopted to design the systems?

Table 4.1: Search expression

Keyword	Alternative term and Synonym
Visual impairment	(blind OR visually impaired OR visual impairment OR visual disability OR blindness OR unsighted OR low vision OR disabled people) **AND**
Ambient intelligence	(ambient assisted living OR ambient intelligence OR smart home OR smart Care OR smart service OR smart homecare OR ambient-intelligence environment OR smart environments OR home environment OR smart spaces OR home care)

RQ7 - Which features are provided?

RQ8 - How were these environments/technologies evaluated?

RQ9 - What are the challenges and limitations of these environments/technologies?

Search strategy

We selected 5 relevant digital libraries in computing science and healthcare: ACM Digital Library[1], ScienceDirect[2], IEEExplore[3], Scopus[4], and Pubmed[5]. Afterwards, we identified the keywords related to the research topic, such as "visual impairment" and "ambient intelligence", as well as their alternative terms and synonyms. Although this MS is addressed to find results focused on visual impairment, we added "disabled people" in the string because this is a general term that includes several disabilities including visual impairment. We combined these terms using logical operators to create the search expressions shown in Table 4.6. We adapted the search expressions according to the mechanism of each digital library, so as not to alter its intended meaning.

We defined a control article for validation of search expression. This article was previously identified in non-systematic searches. The article title is "RUDO: A Home Ambient Intelligence System for Blind People" [80]. If these articles were in the digital libraries they had to come in the search with the search expression that we created. If the control papers are not returned during the search, the string needs to be adjusted until they do so.

Selection criteria

We created some criteria for selecting the publications, which are shown in Table 4.2. We use the selection criteria in two parts:

[1]https://dl.acm.org/
[2]https://www.sciencedirect.com/
[3]https://ieeexplore.ieee.org/Xplore/home.jsp
[4]https://www.scopus.com/
[5]https://www.ncbi.nlm.nih.gov/pubmed/

Table 4.2: Selection criteria

Inclusion	Exclusion
(I1) Result containing in the title, in the keywords, or in the abstract some relation with the theme of this review (Intelligent Environments and Visual Impairment).	(E1) Not published in English. (E2) Similar or duplicate results, only the most recent will be considered. (E3) Results that are not related to the theme of this work (Intelligent environments or visual impairment). (E4) Books and abstracts from conference presentations. (E5) Narrative reviews, comparative studies, surveys, and other systematic reviews. (E6) Studies set in other environments not in home environment. (E7) Studies other than computer science or engineering. (E8) Results prior to 2009.

- first, one of the Ph.D. candidates read only the abstract, title, and keywords of the selected papers. We assigned the status of "accepted" to the papers that met the inclusion criteria. These papers were selected to be fully read later.

- in the second phase, the Ph.D. candidate and another researcher reviewed these results, individually. Afterwards, we compared the results from the two researchers, and when it was different, they discussed until reach a consensus. In this phase, some studies were initially considered appropriate for inclusion, but after being fully read they were excluded. Also, we used the Kappa method for measurement of interrater reliability [110]. We used Start[6] to help classify the papers, which is a tool that supports the organisation of systematic reviews.

4.1.2 Execution and Results

The application of the search expression in each digital library brought a total of 807 papers, of which 129 were duplicates. After applying the selection criteria, in the first phase, we selected 127 papers. Afterwards, in the second phase, we selected 65 papers, applied again to the selection criteria by reading the entire paper. Table 4.3 shows the final result of the selection in each base. We applied the Kappa method and obtained an agreement of 92.85%. According to Cohen's Kappa interpretation, this is an "Almost Perfect" result [110].

We identified that 84.61% of the results actually implemented solutions for AAL, while 15.38% of the results contained non-functional prototypes [100, 105, 67, 46, 119, 133], frameworks [67, 186, 168], design methodologies [133], case studies [49], and techniques analysis [17].

Referring to question **RQ1**, 60% of results combined some types of users, for example, elderly and disabled people, or elderly and blind users. In this case, we consider each type individually for analysis. The majority of the results are directed towards elderly people (35.92%) [108, 177]. A considerable part of the publications deal with visual impairment in general, focusing on "disabled people" (33.98%) [12, 29]. Only 15.53% of

[6] http://lapes.dc.ufscar.br/tools/start_tool

Table 4.3: Results per digital library

Digital library	**N**	**Duplicated**	**Accepted**
ACM Digital Library	196	14	6
ScienceDirect	15	8	0
IEEExplore	84	9	21
Scopus	348	96	36
Pubmed	164	2	2
Total	**807**	**129**	**65**

the publications explicitly cite the focus on PVI [179, 37]. 14.56 % of publications show approaches to other types of users, such as people who are physically disabled (e.g., have paralysed limbs or hearing impairment) and families of the elderly and disabled people [143, 149].

In the next questions we will present the answers as follows:

- generic papers: papers with generic focus, for example, for disabled people.
- specific papers: paper that contain a specific study to PVI.

Addressing question **RQ2** in general papers, Figure 4.1 shows the distribution of papers per year, being 2015 and 2017 the years with the most papers. Figure 4.2 shows that Spain (8), Italy (7), Brazil, and France (5) are the countries that most published on ambient intelligence. We found 40 publications from the European continent, followed by Asia (13 papers) and America (9 papers). The number of papers per country/continent was collected according to the country of the institutional affiliation of the first author.

Considering specific papers, 2015 (31,25%) and 2018 (25%) were the years with the highest concentration of papers. The countries that most published were Brazil (3) and Italy (3). The European continent (9 papers) has the most publications for this type of user as well.

Referring to question **RQ3**, we identified 94 different technologies in general papers, and the most used are presented in Table 4.4. We considered each technology individually in analysis. There are a variety of technologies and most of the publications used a combination of technologies. Some results had a combination of RFID + Sensors [22, 181, 173, 64, 102], or Motion sensors + Cameras [65, 98, 66], or Devices + Sensors [97, 61, 64], for example.

Considering specific papers, most used technologies were: Computer/laptop (7.84%), Accelerometer (3,92%), Arduino (3,92%), Cameras (3,92%), Microphone (3,92%), Motion sensor (3,92%), Raspberry Pi (3,92%), and Smart device (3,92%). These publications also used a combination of technologies.

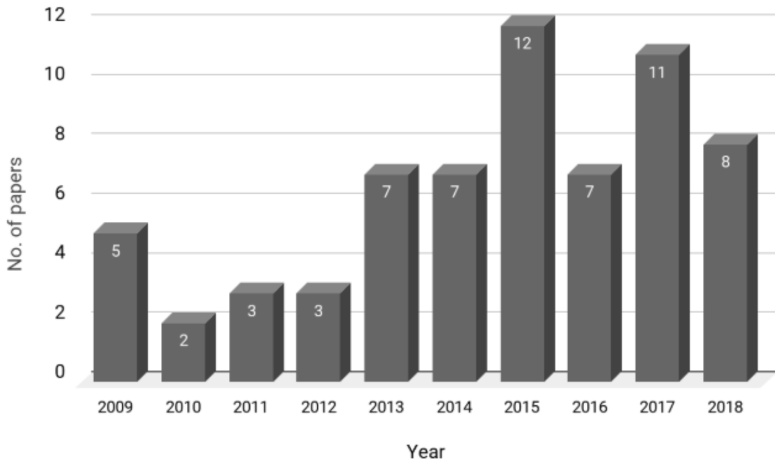


Figure 4.1: Number of papers per year

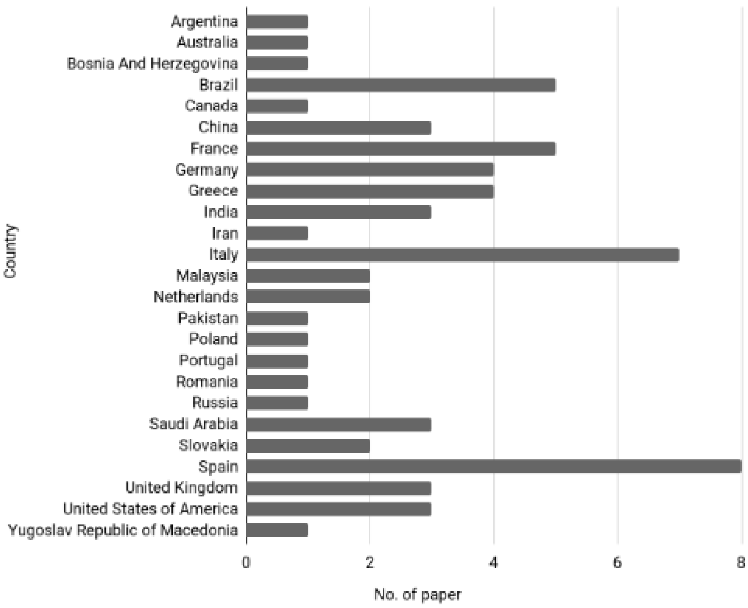


Figure 4.2: Number of papers per country.

Referring to question **RQ4** in general papers, most architectures used were the authors' own architectures (39.28%) [143, 117, 75, 38], Service-Oriented Architecture (SOA) (10.71%) [65, 141, 66, 22, 43, 13], Multi-agent systems (MAS) (7.14%) [160, 64, 54, 59], and Others (e.g., ROS, multi-robot, OSGi, KNX, etc) (7.14%) [177, 41, 102]; 35.73% of results did not declare the architecture they used.

Considering specific papers, they also used its own architectures (56.25%), SOA (12.5%), and MAS (6.25%); 25% did not declare which architecture was used.

Addressing to question **RQ5**, we found results that make use of a large number of techniques, so we group these techniques as follows:

Table 4.4: Type of technologies

Technology	Percent of Paper	Ref
Sensor	6.89%	[72, 53, 108, 2, 22, 81, 43, 82, 11, 115, 160] [59, 173, 64, 61, 38]
Computer/Laptop	4.31%	[66, 111, 75, 136, 43, 111, 82]
Arduino	3.44%	[149, 91, 117, 2, 181, 136, 111, 82]
Camera	3.44%	[65, 82, 98, 66, 179, 87, 140, 102]
Environmental sensor	3.44%	[91, 181, 140, 102, 80, 136, 98, 173]
RFID	3.44%	[173, 64, 102, 22, 181, 9, 85, 95]
Smart device	3.44%	[141, 160, 97, 64, 61, 143, 117, 51]
Robot	3.01%	[158, 87, 184, 102, 181, 177]
Kinect	2.58%	[177, 178, 74, 13, 59, 53]
Microphone	2.58%	[177, 38, 172, 9, 171, 88]
Bluetooth	2.15%	[149, 53, 117, 2, 97]
Motion sensor	1.72%	[88, 102, 66, 98]
Smart object	1.72%	[72, 22, 13, 169]
Home automation	1.72%	[169, 97, 171, 61]

- Artificial intelligence: encompasses computational vision, decision tree, machine learning, deep learning, reasoning engines, neural network, agents, and Bayesian network.

- Detection and recognition: includes algorithms for recognition and detection of voice, gesture, activity, movement, face, finger, pose, eye blink, motion, human, and speech.

- Networking: encompasses the internet of things, communication paradigms and protocols, synchronisation, web services, and data sharing.

- Others: includes a navigation system, object recognition, Robot Operation System, Visual-Range Odometry, among others.

Several results used combined techniques, and we considered each one separately for analysis. The most used techniques in general papers are: Detection and recognition (34.95%), Artificial Intelligence (22.33%), Others (24.27%), Networking (14.56%), and not declared (3.88%). Some of the results use Detection and recognition [87, 108, 75, 81], Artificial Intelligence [136, 160, 82], and NetWorking [51, 178, 72], for example.

Considering specific papers, the most used techniques were: Others (36%), Detection and recognition (28%), Artificial Intelligence (24%), Networking (8%), and not declared (4%).

Referring to question **RQ6** in general papers, most results (68.42%) did not adopt a particular methodology for the design of AAL solutions. Some results have mixed some methodologies. The most used methodologies they reported are: Service oriented (10.52%) [66, 22, 141, 13, 97], User oriented (8.77%) [80, 81, 32], Agent oriented (8.77%) [54, 160, 59, 64, 61], and Design science research (DSR) (3.50%) [80, 81].

Considering specific papers, most publications do not state which methodologies they used (61.11%). The most used methodologies they reported were: User oriented (16.66%), DSR (11.11%), Agent oriented (5.55%), and Service oriented (5.55%).

Addressing question **RQ7** in general papers, details regarding the features most cited by authors to help users are provided in Table 4.5. Several papers propose more than one feature. For example, in [82] there are control and monitoring of devices, and turning on/off the devices.

Among the specific papers, the most cited features are: Warning whenever it detects a potential hazard (6.66%), detection and recognising objects (6.66%), turning on/off the devices/sensors (6.66%), and avoiding obstacles (6.66%).

Table 4.5: Type of features provided

Feature	**Percent of paper**	**Ref**
Environmental/appliance/device control	5,36%	[51, 141, 82, 13, 160, 41, 97, 61]
Environmental/device/people monitor	5,36%	[82, 43, 65, 54, 173, 64, 66, 2]
Health monitoring	4,02%	[160, 64, 95, 181, 61, 53]
Turning on/off the devices/sensors	4,02%	[171, 82, 91, 117, 32, 29]
Fall detection	2,68%	[106, 115, 98, 173]
Detection of dangerous situations	2,01%	[54, 178, 64]
Prevention of medical emergencies	2,01%	[53, 43, 66]

Referring to question **RQ8**, we categorised the solutions evaluations as follows:

- type of environment: when evaluation of the proposed solution was performed in a:
  - controlled environment: experiments that occurred in research laboratories, controlled by the researchers.
  - virtual environment: experiments in which they tested algorithms, dataset, simulations of real environments in virtual environments.
  - real environment: when the proposed solution was installed and evaluated in real environments such as homes for the elderly, homes for the PVI, etc.
- type of users: when the evaluation of the proposed solution was performed by:
  - end-user: the proposed solution was evaluated by users who are the focus of the solution, such as the elderly, PVI.
  - user: the proposed solution was evaluated by general users who are not the focus of the solution.
  - not evaluated by user: the proposed solution was not evaluated by end-users and other general users. This type usually occurs when the solution was evaluated in a virtual environment.

Among the general papers, 36.36% did not declare the type of environment used, 27.27% did not declare the type of user, and 3.64% of the results did not evaluate the solution yet. Most of the results (29.09%) were not evaluated by any user, 25.45% were evaluated by end-users and 14.55% were evaluated by other users. Regarding the type of environment used in the evaluation of solutions, they used: virtual environment (25.45%), controlled environment (18.18%), and real environment (12.73%). Some results performed evaluation in two types of environment: controlled environment and real environment (1.82%), and virtual environment and controlled environment (1.82%).

About the specific papers, the most common types of environment are: controlled environment (18.75%), real environment (18.75%), virtual environment (6.25%), and controlled environment and real environment (6.25%). 50% did not declare the environment. Most of the evaluations (37.5%) were performed with end-users, 18.75% with users, and 6.25% without users. Additionally, 37.5% did not declare the type of users that performed the evaluation.

Referring to question **RQ9** in general papers, 66.66% did not declare challenges and limitations. The rest of the results could not be quantified, hence, it is not possible to provide any table or chart form of the results. There are some limitations on use of Kinect such as software and hardware [178] and maintaining a certain level of hand steadiness to control [13]. Some papers reported solution implementation just in a single user context [80, 81]. Moreover, problems related to real-time were also identified as to track 5 persons simultaneously [74] and perform some analysis and exploitations [98]. Also, some limitations of Occlusion [178], Recognition [2, 177], and Performance [136]. The limitations and challenges of specific papers were related to implementation because they were implemented just in a single user context [80, 81]. 75% of results did not declare limitations and challenges.

4.2 Guidelines to improve user interaction with ambient intelligence systems

The involvement of HCI aspects in user interface design has an increasingly significant impact on building useful and intuitive AmI systems [8]. Seeking to add to this research theme, we performed a systematic literature review in order to identify HCI guidelines for the design of ambient intelligence systems. We believe that these guidelines significantly contribute to designing more intuitive AmI systems for users, including those with disabilities. We follow the protocol developed by [92], which involves three phases: Plan, Conduct, and Report the review. Our primary objective is to identify “how to make user interaction with ambient intelligence systems more natural”.

Keeping that in mind, we investigate criteria/guidelines for human-computer interaction, including usability, accessibility, and user experience, among others.

4.2.1 Plan

In this phase, we developed the research questions, search protocol, and selection criteria. Based on our main objective, we developed a research question: *What HCI guidelines have been created, used, or evaluated to improve user interaction with ambient intelligence systems?* To answer these question, we chose five digital libraries that store research studies in the field of Computer Science: IEEExplore[7], ACM Digital Library[8], Scopus[9], PubMed[10], and Web of Science[11].

Furthermore, we specified the following keywords "Ambient intelligence", "Human-Computer Interaction", and "Guidelines". Then, we combined these main concepts and related concepts using logical operators to create a search string (see Table 4.6). We adapted the search string to follow the pattern of each digital library, keeping the intended meaning. We searched for the terms in the abstract, title, and keywords. We do not add constraints on the publication year.

Before starting the search on the digital libraries, we selected a primary control study to validate our search string. The validation took place as follows. Using the search string we created, the chosen paper had to appear in the results provided by the digital library; if the paper did not show up, we improved the search string until it did. The paper selected as the control study is "New ITG Guideline for the Usability Evaluation of Smart Home Environments" [113]. This paper was chosen because it answered our research question.

We created one selection criteria for paper inclusion and six selection criteria for paper exclusion:

- *Inclusion*
  - The paper must contain, in the title, keywords, or abstract, some relation to the keywords and related concepts (see Table 4.6).
- *Exclusion*
  - Published in a language other than English.
  - Similar or duplicated paper, only the most recent is considered.

[7]https://ieeexplore.ieee.org/Xplore/home.jsp
[8]https://dl.acm.org
[9]https://www.scopus.com
[10]https://www.ncbi.nlm.nih.gov/pubmed
[11]https://www.webofknowledge.com

Table 4.6: Search String

Keywords	Related concepts
Ambient intelligence	(“ambient assisted living” OR “ambient intelligence” OR “smart home” OR “smart care” OR “smart service” OR “smart homecare” OR “ambient-intelligence environment” OR “smart environment” OR “home environment” OR “smart space” OR “home automation”) **AND**
Human-computer interaction	(“usability” OR “accessibility” OR “human-computer interface” OR “user interface” OR “user interaction” OR “human-computer interaction” OR “user experience”) **AND**
Guidelines	(“principles design” OR “guidelines” OR “heuristics” OR “rules”)

- Results that are not related to the keywords and related concepts.
- Abstracts from conference presentations.
- Narrative reviews, comparative studies, surveys, and other systematic reviews.
- Papers unrelated to Computer Science or Engineering.

To ensure the quality of the results, we use the Kappa Method for Measurement of Interrater reliability [110]. This method allows alignment between researchers and reduces bias. Also, we use the PRISMA Flow Diagram to report the results [103].

4.2.2 Conduct

We started this phase by applying the protocol defined in the previous section. First, in February 2020, we applied the search string to each digital library and extracted the results in a text format (e.g., BibTex, Medline). We imported the results on StArt[12], a tool to support literature review processes.

The authors (JDO, JCC, and VSMPC) applied the Kappa method as follows. After removing duplicate papers, out of the remaining 335 papers, we selected 100 papers for an initial evaluation. Each author individually evaluated the same 100 papers, deciding which papers to include or exclude using our selection criteria. Then, the results of each author were compared. When there was disagreement, the authors discussed together to reach a consensus on the status of each paper. Before such discussions, we obtained a percentage of agreement of 90.82%. In the Kappa method, this is considered an “almost perfect” agreement. Finally, one of the authors (JDO) applied the selection criteria to make decisions on the 235 remaining papers.

[12]http://www2.dc.ufscar.br/~lapes/start/

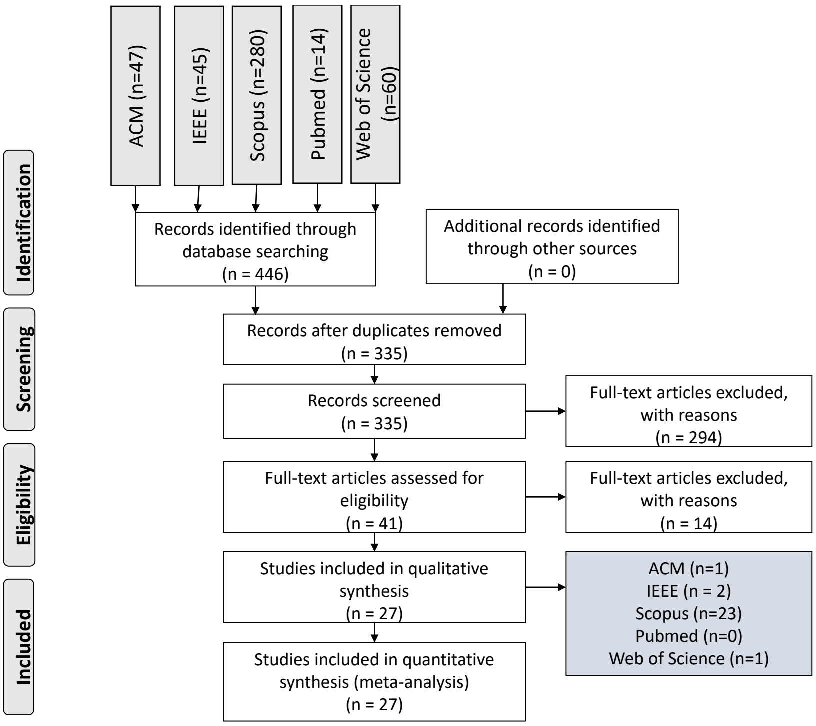


Figure 4.3: PRISMA Flow Diagram.

4.2.3 Report

We evaluated a total of 446 papers in the selection phase, from which 111 were duplicated. Then, we applied the selection criteria and accepted 41 papers. In the extraction phase, after fully reading the 41 papers, we excluded 14 and accepted 27 papers (see Figure 4.3). In this phase, most papers were excluded because the guidelines were too general, or they were for smart homes or AmI but not specifically concerned with user interaction, or because the paper did not present guidelines at all.

We also checked if and how those studies evaluated the results they present. From the 27 accepted papers, 17 (63%) carried out one or more types of evaluation on the guidelines, methodology, or the system/model they developed based on the guidelines. Some of the papers created guidelines from the lessons they learned in the development of AmI. Regarding the type of the evaluations, 11 papers carried out usability evaluation [70, 104, 62, 162, 73, 99, 134, 5, 153, 39, 180], 5 papers carried out end-users evaluations [70, 107, 33, 62, 73], 4 papers used surveys [83, 33, 104, 73], 2 papers reported using interviews [27, 40], and one paper mentioned a heuristic evaluation [104]. All reported evaluations were carried out with users, having on average 34 users evaluating each study – ranging from 3 users [153] to 136 users [26] involved in each evaluation.

We found results from 2002 to 2020, most of them in the range from 2017 to 2019 (see Figure 2). Fifteen countries published on this research topic. Among them,

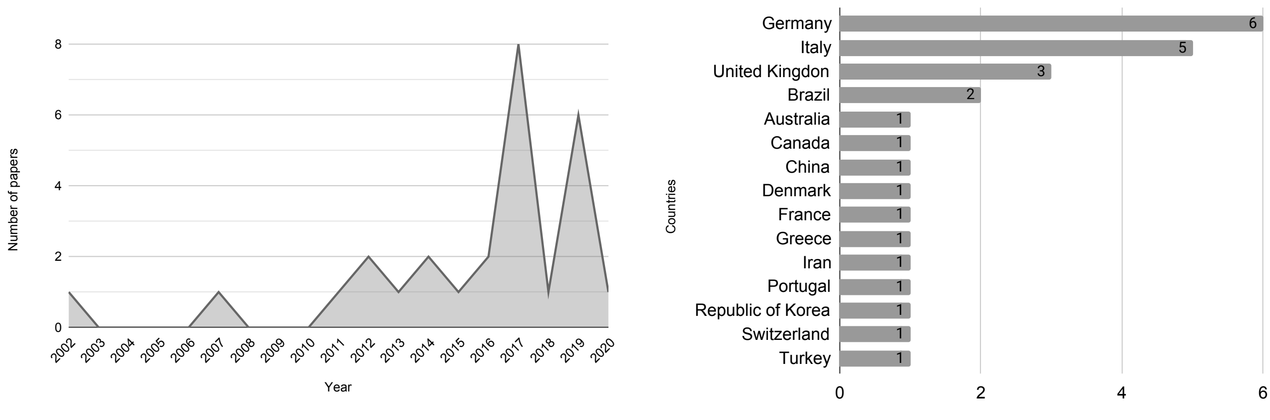


Figure 4.4: Number of Papers per Year and Country.

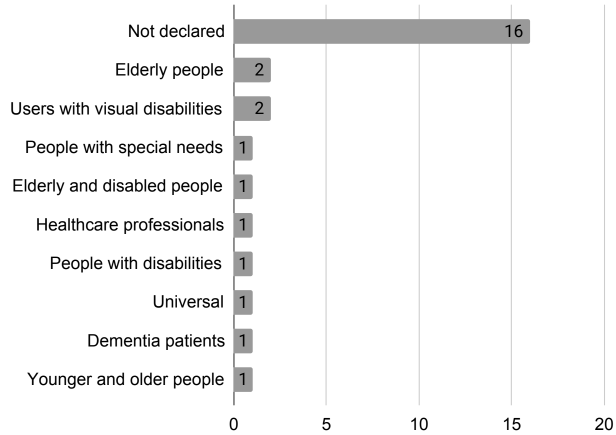


Figure 4.5: Number of Papers per Type of End users.

Germany (6 papers), Italy (5 papers), and the United Kingdom (3 papers) were the countries with more papers (see Figure 2). We collect this information by looking at the first author's institutional affiliation. Figure 4.5 shows the type of end-users that the authors addressed their research. Most papers (more precisely 16) did not declare the type of end-user. Most of the papers that declared the type of end-user were aimed at people who have special needs, such as elderly or disabled people.

4.2.4 Results

In this section, we answer our research question. We read each one of the papers and identified which guidelines referred to HCI and related concepts. We found a total of 120 guidelines. We then grouped similar guidelines and created some categories. These categories later became a unified guideline including the paper's author's ideas. We identify 10 categories and guidelines as shown in Figure 4.6.

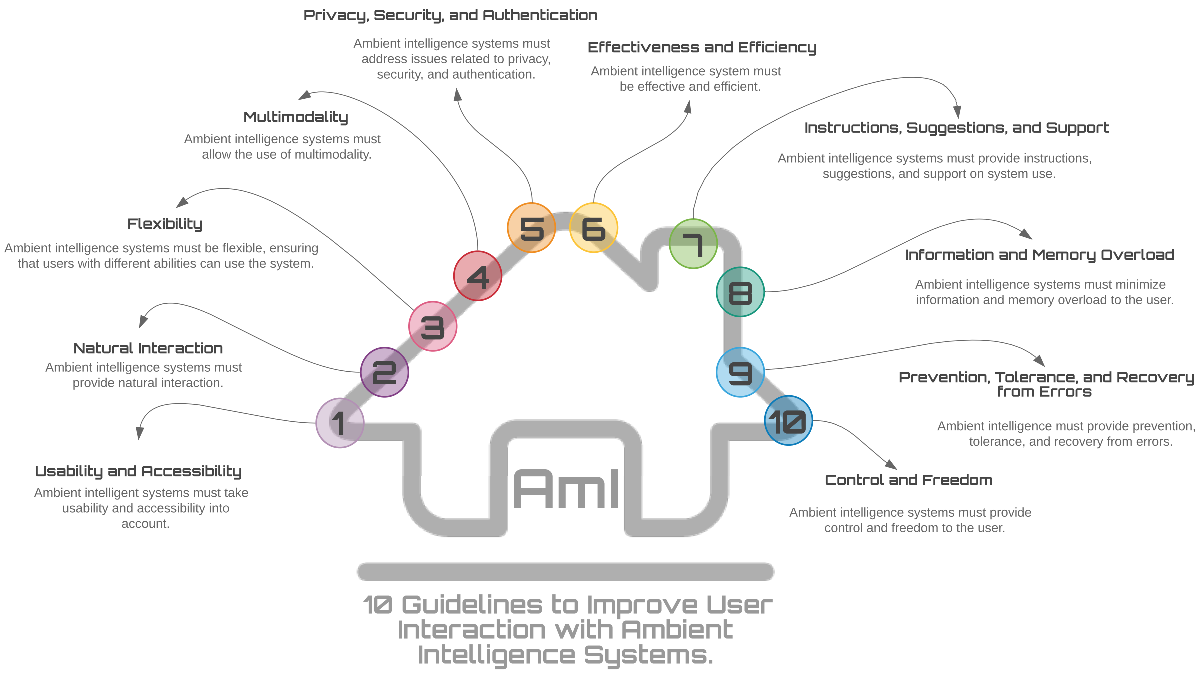


Figure 4.6: 10 Guidelines to Improve User Interaction with Ambient Intelligence Systems.

4.2.5 Usability and Accessibility

Guideline 1: Ambient intelligent systems must take usability and accessibility into account.

Definition: [122] states that usability is related to the ease of learning and use of the interface, as well as user satisfaction as a result of such use. Accessibility is related to the ease of access for the different types of users [18], taking into account user's disabilities, for example.

Fifteen papers reported the importance of creating and evaluating the ambient intelligence systems according to usability and accessibility criteria. Many of the papers employ the use of norms and guidelines already established by the scientific community, such as: Nielsen's heuristics [104, 114, 134, 153], ISO 9241/110 [26, 162], and Web Content Accessibility Guidelines (WCAG 2.0) [39, 52].

They also use known questionnaires such as the System Usability Scale (SUS) [62, 104], or similar questionnaires adapted using the norms and guidelines mentioned above. Some of the usability questions cited by the authors of those papers were: easy to learn [114], easy to use [73, 114, 134, 180], easy to understand [73], consistency and standards [39, 107, 113, 185], and visibility of system states [39, 60].

4.2.6 Natural Interaction

Guideline 2: Ambient intelligence systems must provide natural interaction.

Definition: According to [121], the system must use concepts and terms that are more familiar to the users, rather than technical and specific terms, and the interaction with the system must be logical and natural for the user.

Twelve papers included the guideline that ambient intelligence systems must provide natural interaction for the users. Some of the suggestions from those authors to make the interaction more natural include:

- Insert voice command and a conversational interface [40, 62, 83, 107].
  - Maintain a natural conversational flow [107] and the dialogue context [83];
  - Insert more natural and intuitive triggers/commands [83].
  - The system must use terms that the user understands [107];
  - When the information is transmitted to the user through soundtracks, these must be made available spaced in time and cover different parts of the sound spectrum [164].
- The user should not need technical help to use the interface [73].
- Involve the users in the design process [70, 113, 155]. For instance, in a home environment, consider the perspective from each user in the house to represent the space division, references, rooms, and names [155]. Also, the system should address the real-world needs of its users [113].
- Involve a multidisciplinary team in the development of the system [70].
- It is necessary to provide ways for the user to find smart devices automatically, for example, searching by name, type, or location in the environment and avoiding the use of acronyms or technical terms when passing the information to the user [62].
- Provide customisation according to the user's location, or translation of the elements to another language in order to enable the internationalisation of the environment [155].
- The users must enjoy using the system [39, 62, 114].
  - The system must be attractive and aesthetically enjoyable [39, 114];
  - Support engagement and motivation, whether in group or individually [39, 114];

- Ensure quality of use during the system use. The *quality of use* criteria is related to characteristics of the interaction and the interface that ensure the expected features during the system use, such as usability, user experience, accessibility, and communicability [18].

4.2.7 Flexibility

Guideline 3: Ambient intelligence systems must be flexible, ensuring that users with different abilities can use the system.

Definition: To be flexible, the system must allow the user to perform the same tasks by executing different steps, taking into account the different abilities of the different types of users [122].

Nine papers mentioned that Ambient intelligence systems must be flexible to support different types of users. To provide this capability, they suggest the system have:

- Both simple and complex options [155, 27].
- Capability for the user to control the different aspects and configurations of the system. For instance, the user should be able to alter the sound volume, change the font size, manage the color contrast, the zoom, and resize virtual objects [27, 39, 50].
- Allow the user to personalise scenarios, interface elements, and interaction with the system [33, 39, 60, 70, 113, 155].
- The system must be pre-configurable to execute a set of actions when an activity is determined [83].
- Provide an initial configuration of the software, adjusting the properties of smart objects in the design whenever they are beneficial to the user [70].

4.2.8 Multimodality

Guideline 4: Ambient intelligence systems must allow the use of multimodality.

Definition: According to [86], a system with multimodal interaction must allow users to connect with the system using multiple input and output interfaces, such as speaking, texting, or making gestures.

The authors of eight papers reported on the importance of inserting multimodal interaction [50, 83, 155, 164], feedback [50, 39, 40], and interface [70, 130] in ambient intelligence systems to improve the user interaction with the system. Some suggested modalities were: audio, text, voice, vibration, and visual.

4.2.9 Privacy, Security, and Authentication

Guideline 5: Ambient intelligence systems must address issues related to privacy, security, and authentication.

Definition: The system must assure the users that their data will not be accessed by people without consent, that their data is safely stored, and that only authorised users can access the system through authentication.

Seven papers mentioned that ambient intelligence must ensure user Privacy [3, 27, 60, 83, 113, 114, 155], Security [3, 60, 83, 113, 114], and Authentication [60, 83]. This is necessary for the user to trust the system. Some precautions mentioned by the authors:

- Privacy
  - Making sure that private information is sufficiently protected [27] and preventing strangers from accessing sensitive data [83].
- Security
  - The devices and the environment must be safe for the user to operate, providing a feeling of confidence and security during use [113].
  - Provide security that prevent unauthorised users from accessing and, at the same time, are comfortable for using their functionality in a smart home [60].
  - Provide control of smart elements only when their elements can be safely controlled, that is, without any risk to the user. For example, the system can only open the front door when the user is located within a radius of 200m [60].
- Authentication
  - The system should be able to check whether the person interacting with the system is authorised and also check the permissions before the user starts executing a command [83].
  - Whenever the system identifies unauthorised access, the system must immediately inform the user and guide him by a security mechanism that requests the authorisation of access and the identification of the user in the system [60].

- Also, the user needs to immediately know what they need to do, so as not to suffer information gaps or confusion [60].

4.2.10 Effectiveness and Efficiency

Guideline 6: Ambient intelligence system must be effective and efficient.

Definition: According to the Cambridge dictionary[13], effectiveness is related to achieving the result you want, and efficiency is not wasting time or energy when executing a task. Therefore, the system must help users to quickly achieve what they want to do with the system.

Six papers mentioned that ambient intelligence systems must maximise effectiveness and efficiency. For example, the authors suggested:

- Fewer steps in dialogues with the system to perform tasks [107].
- Do not disturb the user by asking for a password whenever they use the system, for instance, when the interaction is performed through a mobile application [60].
- Effective communication [114].
- The system must be useful in improving the user's quality of living, and the usefulness must be measurable [5].
- Arrange functionalities and commands effectively and efficiently [33].
- Provide a dynamic interface that clearly indicates changes in the environment. For instance, the user should be warned if there are new appliances in the environment, if there are obstacles in the paths where they usually go through, or if there are new alternative paths within the environment [155].
- Develop a single system able to interface itself with several applications for remotely handling various services and devices [33].
- The system must allow the user to input and update the available smart devices, and this process should be easy to do whenever needed [27].

[13] https://dictionary.cambridge.org/

4.2.11 Instructions, Suggestions, and Support

Guideline 7: Ambient intelligence systems must provide instructions, suggestions, and support on system use.

Definition: Although it would be better if the users did not have to use the system documentation [121], the system must have a minimal set of help and instructions for the user, suggest next steps, and support in case of doubt.

Seven papers point out that ambient intelligence systems must assist the users by giving instructions, suggestions, and support. The papers highlight:

- Provide simple instructions and brief messages [27, 164].
- Whenever the system does not understand what the user wants to execute, the system must provide command suggestions [83].
- Provide a manual with possible commands the user can use, with appropriate terminology for them [83].
- Provide accessibility support for different types of users. For instance, the system should make data available in accessible formats, providing the same information as text, audio, video, and others, in such a way that people with different disabilities can use it [3].
- Contextual cues should be incorporated to help users to remember actions [164].
- Provide clear examples of how the users can use the system [26].
- Provide pre-configured elements and support mechanisms in the intelligent environment for the discovery and use of resources and elements [70].
- Provide adequate feedback in a reasonable time about what is happening in the system. Always keep the user informed [107].

4.2.12 Information and Memory Overload

Guideline 8: Ambient intelligence systems must minimise information and memory overload for the user.

Definition: The system must avoid presenting more information than needed for the user in a particular moment, and the system should not ask the user to retain detailed information for being able to interact with the system. The user should recognise the next step when interacting with the system, rather than recalling the steps that have to be performed to achieve its aims [121].

Six papers indicated the relevance of not overloading users with information and mental effort [33, 70, 99, 107, 155, 164]. Some tips from the authors to solve this problem:

- Minimise or avoid irrelevant and distracting information [33, 155, 164].
- Allow the user to repeat some previous information [107, 164].
- Minimise short term memory load, for example, information that is listed should be kept short and concise [107] and visualisation of content related only to the current goal [33].
- Facilitate user's comprehension by using short sentences and pausing after each statement [164].
- Simplify as much as possible repetitive tasks [33].
- Hide programming complexities by using visual methods and metaphors in graphical user interfaces [70].
- Provide navigation support to reduce cognitive effort. Employ hierarchical concept categories to support the selection of resources [70].
- Do not confuse and distract users from their main task during the use of the system. For example, if the system has a graphical user interface (GUI), plan the graphic elements and icons' layout carefully, so avoid confusing the user [99].

4.2.13 Prevention, Tolerance, and Recovery from Errors

Guideline 9: Ambient intelligence systems must provide prevention, tolerance, and recovery from errors.

Definition: The system must avoid user errors, for instance, by enabling to the user only those options that are feasible given the particular context. In case of an unexpected error, the system must tolerate it, presenting to the user information that allows them to bring the system to a stable state quickly. According to [121], the system should help the users indicating an error in understandable language, indicating the problem clearly, and helping to construct a solution.

Six papers referred to the importance of ambient intelligence ensuring prevention, tolerance, and recovery from errors. The papers suggested:

- The system must provide compatible error response and context to error that may occur [107].
- Correct actions must be reinforced by redundant sensory cues, such as a blip or visual information [164].
- Make presentation formats (auditory, textual, or pictorial) intuitive and straightforward to reduce misinterpretation [164].
- The behaviour of the system must be understandable to the user, who must be able to identify and correct errors. Thus, ultimately, control over the system must remain with the user [113].
- Design and implement ways to minimise and avoid accidental dangerous actions and provide reliability and safety features [39].
  - Restrict the user's possible actions to prevent errors [39].
  - Provide a clear indication of risks [39].
  - Avoid damages to humans and the environment by providing fail-safe features [39].
  - The system must be reliable [39].
- Whenever possible, the system must learn and predict the activities in advance [83].
- Provide realism in the system response to enable measuring the delay between a user's request and the correct system response [5].

4.2.14 Control and Freedom

Guideline 10: Ambient intelligence systems must provide control and freedom to the user.

Definition: According to [121], *user control and freedom* is related to support undo and redo steps of the system. It is a heuristic to help users get out of an unwanted situation when interacting with the system, without having to follow many steps.

Three papers found that ambient intelligence systems must provide the ability to control and freedom to the user. They suggested:

- During the interaction, the user must be able to interrupt its execution with a new interaction or with dialogue, such as saying "stop" [107].

- The user must act intentionally on the environment, regardless of their sensory abilities and ambient conditions [39].
  - Minimise physical effort to the user, making actions more feasible [39].
  - Enable alternative action modalities [39].
  - Do not impose time constraints [39].
  - Do not impose disabling barriers [39].
- Users must be able to share and exchange their actions and messages. In other words, allow the transition from individual to collective activities through an environment where people are interconnected. [39].
  - Provide mechanisms to enable actions and messages exchange [39].
  - Ease cooperation and participation [39].
  - Consider the impact of messages or actions on the social context. For instance, if the system emits a sound, it should not disturb other people while warning the main user [39].
- The system should provide an easily accessible way for controlling the environment, such as through an application or a web browser [60].

4.3 Initial design

From the needs identified in Chapter 3, we carry out a proof of concept with the main features pointed out by the users, that is, "Find object" and "Notify location (e.g., in degrees) of objects". In addition, the users have indicated their preference for mobile apps. For that purpose, we create an Android app[14] that use a deep learning algorithm with a fully-convolutional model called YOLOv3 [147]. YOLO allows the identification of objects in real time if these objects are in the training base. We chose YOLOv3 because it runs significantly faster than other detection methods with comparable performance [147]. We made some changes in YOLOv3 to make it possible to work with the data it provides. On normal execution, YOLOv3 only presents the name of each object found in the image. So we modified its code, presenting not only the names, but the objects coordinates, to better guide the user later on the application. The application works as follows (Figure 4.7):

[14]This application was developed jointly with the students of scientific initiation João A. L. de Moraes Junior and Davi Kniest, in the project "Seleção de técnicas de machine learning, visão computacional e internet das coisas para assistência de pessoas com deficiência visual em suas residências", PIBIT-CNPq 2018-2019.

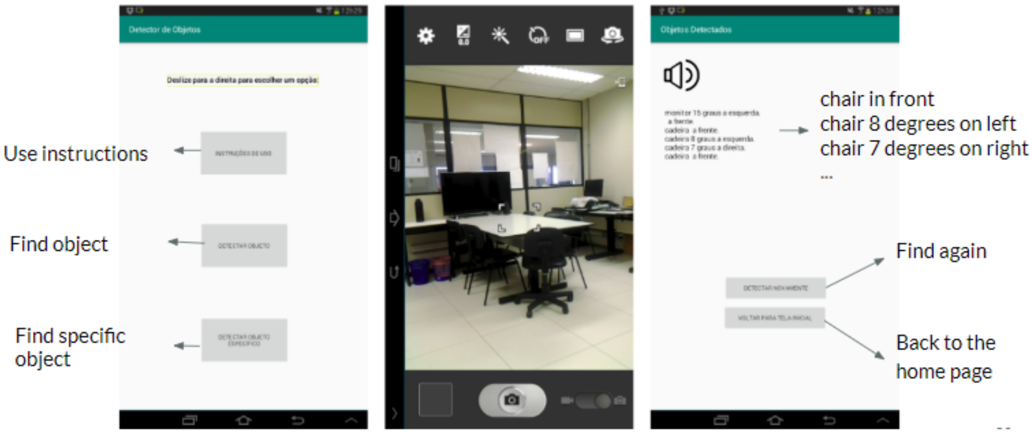


Figure 4.7: Android Application

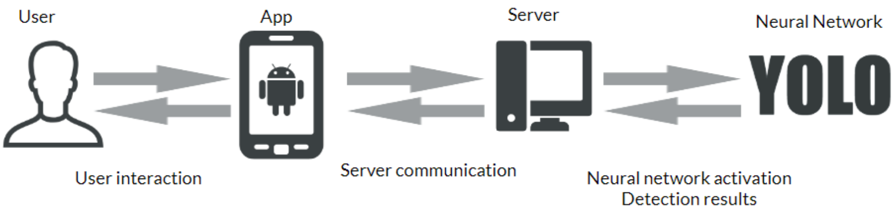


Figure 4.8: Architecture application

- The application has 3 buttons[15]: use instructions, find objects, and find a specific object. The **use instruction** button has information on how the user should use the application, and what they will find in each application option. Pressing the **find objects** button, the user can identify multiple objects at the same time. Finally, pressing **find a specific object** button the user types the name of a specific object to be found.

- When the user selects one of the options to find objects, the application opens the camera of the smartphone so the user can take a picture.

- The application connects to the server which is running the YOLOv3, then returns to the user the feedback about the objects (Figure 4.8). The audio feedback was provided by Talkback informing the objects in each photo and how many degrees to the right or left they are located, for instance, “Chair 8 degrees on left”.

We evaluated the application with a 25 years old male user, who is congenital blind. The user had already used a text-detection application on objects. The participant is an Android user so he already knew about Talkback, which is an Android native accessibility service that helps visually impaired people to interact with their devices. We conducted the evaluation procedure as follows:

[15]The application was developed in Portuguese, and for this proposal, we translated the instructions and buttons name.

- We tested the application in a controlled environment, having three objects (a notebook, a bottle, and a remote controller) distributed on a table.
- We positioned the participant at a one-meter distance from the table.
- We state the following to the participant: "The application you will test aims to detect objects in a given scenario. As for the scenario, we put 3 objects to be recognised in a table which is 3 steps ahead of you. Now, we would like you to freely use the application, going through its three features: use instructions, find objects, and find a specific object. If in doubt, ask the researchers."
- When the application provided the location of the objects, we asked the user to go to the table and pick up the objects according to the instructions provided by the application. After using one of the find objects options, we switch the objects' place to avoid user bias.
- After using the application, we asked the participant to fill in a questionnaire about his user experience during the evaluation. This questionnaire had 14 questions about usability including topics related to *ease of use*, *understand*, *learn to use*, *usage instructions*, and *user satisfaction*. The questionnaire had 3 discursive questions, plus 11 having a 5-point Likert scale (strongly agree, agree, neutral, disagree, strongly disagree). For each Likert question, we also asked the participant to textually explain his opinion.

The user was able to find the objects using both the "find object" option and the "find a specific object". The participant strongly agrees the application was easy to use, to learn, and to understand. The instructions were adequate. The user highlighted the positive points of the application: *to have autonomy in finding the objects and to have a sense of its location and orientation with the information presented; and the application camera is appropriate and simple to use*. However some suggestions were provided by the user: *to provide real-time feedback of detected objects; cover more objects; bring more information about the position of objects; save the position of objects to remember later; and better differentiate the application options*.

We are aware of the bias introduced by an evaluation made by only one user. Although this phase represents just the first step into our evaluation journey, it already provided us with insights to guide our next steps.

FINAL REMARKS

We started this chapter by presenting our mapping study to identify studies for visually impaired people in the field of Ambient intelligence. During the research, we found that most studies focus on disabled people or combine the types of users. Only 15.53% specifically mentioned people who are visually impaired. These findings demonstrate that more studies need to be carried out for these users.

Answering our research question “to identify how AmI technologies are used to assist people who are visually impaired”, the literature has shown that the authors have combined technologies to implement interesting features such as warning whenever it detects a potential hazard, detection and recognising objects, turning on/off the devices/sensors, and avoid obstacles. They also preferred to use their own architectures or SOA. In many studies, there was no participation of end-users during the system development and evaluation. Many human-computer interaction methods demonstrate the importance of involving the system end-user in the design phases, such as interaction design method [152].

We believe that systems have to be developed for and by the end-user. In this sense, we agree with [42]; if the end-user is not involved in the system design, likely, the technology will not be accepted by them. Thus, researchers should consider the specific interests, demands, and needs of the end-users, especially when it comes to disabled people. Despite this, we demonstrate an advance in this topic by showing the features, technologies, techniques, architectures, and methodologies that are being used by the systems developed for AmI, both for the general public and people who are visually impaired.

In this chapter, we also present a systematic literature review to identify HCI guidelines for the design of ambient intelligence systems. Our main interest was to find the guidelines created, used, and/or evaluated to improve the interaction of users with AmI systems. The digital libraries and selection criteria used here guided us to accept 27 papers out of 447. From the 27 papers, we identified a total of 120 HCI guidelines.

Inspired by the paper’s guidelines, we grouped the authors’ findings into ten categories. Then, each category led to one overall guideline highlighting the authors’ specific ideas related to that category (see Figure 4.6). Our categories have more specific guidelines and also more general ones. Researchers must select the ones that suit their system; it is not necessary to apply all the guidelines, applying most of them often suffices. We believe that our summarised guidelines can be very useful for other researchers and practitioners to create and evaluate their ambient intelligence systems.

Throughout this systematic literature review, we found that the researchers have a marked interest in how to make ambient intelligence systems more natural for users. About 55.55% of the papers states that including usability and accessibility in this type of system is of paramount importance to provide more interesting and usable systems to users. Another relevant issue for researchers is the natural interaction, with 44.44% of the papers pointing that out; we can highlight the use of voice and conversational interfaces, in this regard. Also, the creation of systems more familiar to user experiences and the flexibility of use for people with different skills.

Our study made it possible to identify the need for AmI to minimise the information available to the user, avoiding memory overload. In this paradigm, it is necessary to prioritise understandable and easy to recognise information, with no need for repetition to the user. Also, we observed some consensus among the researchers regarding the customisation of scenarios, interface elements, and interaction with the system, as well as the guarantee of privacy and security.

Regarding the limitations of our work, as it is a qualitative study, we may have missed some important results due to researchers' bias. However, we tried to reduce this limitation by searching the five most relevant and largest digital libraries and applying the Kappa method to avoid bias. Despite the limitations of the protocol we used, positive results have emerged, in particular the condensed but comprehensive set of guidelines for designing AmI systems. We aim to take into account these HCI guidelines in the design and evaluation of our own systems.

Lastly, we developed a first design idea based on user needs and the key features and technologies identified in the mapping study. As mentioned earlier, the involvement of end-users in system design is essential, thus we conduct a user study to identify improvements for our design idea.

5. AN APPROACH TO AMBIENT ASSISTED LIVING

In this chapter, we introduce our approach of a MAS to assist people who are visually impaired at home. We chose to create a multi-agent system because, in general, it is designed to handle environments containing distributed and dynamic resources [44, 109]. In addition, using this system, it is possible to add more features by only adding more capabilities to the agents, more agents, and artefacts.

In Chapter 3, we identify the main features that visually impaired people need at their homes. We grouped these features into some categories, depicted in Figure 5.1, and included the highlighted features in our approach. The categories are as follows:

Environmental control: this category has the features related to the environment, such as identifying whether the light is on or off; identify whether the window is open or closed; identify whether the door is open or closed; and turn devices on and off.

Location: this category shows the features related to objects' location, such as: find objects; identify when objects are out of the usual places; identify location (e.g., in degrees) of objects; and warn the user of how many meters away the objects are.

Security and health: this category brings the features related to the safety and health of the person assisted, such as: warning the user if there is another person in the same environment; request help from any registered contact; detect obstacles; and reminders to take medicine.

Entertainment: this category encompasses features related to the entertainment for the assisted person, such as: inform the current time of the day; inform about the weather; warn about appointments as a virtual calendar; entertainment for solitude (e.g., jokes, conversation); and read labels and colors.

Also, during the design of the system, we selected some guidelines introduced in Section 4.2, as described below:

- 1. Usability and Accessibility: We primarily consider the ease of use, ease of understanding, and ease of learning.
- 2. Natural Interaction: We use a conversational interface providing a natural interaction for users. We are also concerned with inserting natural and intuitive commands to perform tasks, including terms and intuitive feedback.
- 3. Multimodality: the user can exchange information with the system via voice or text.

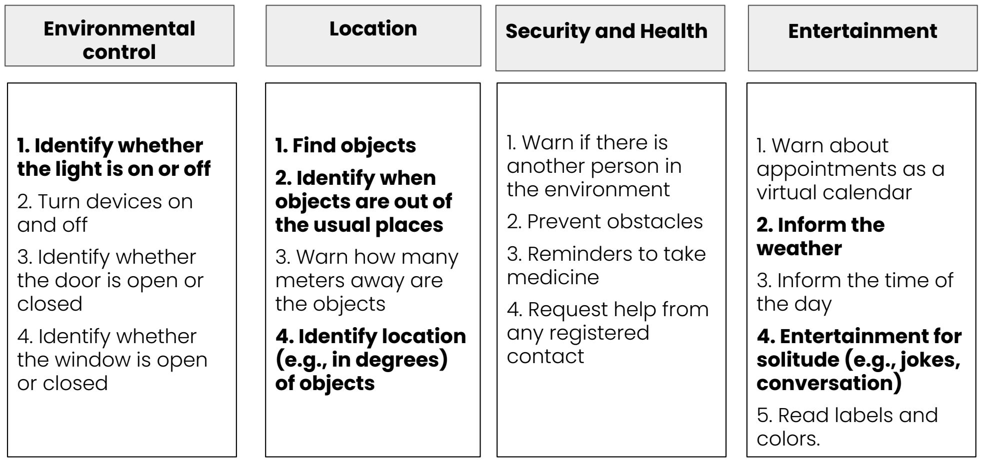


Figure 5.1: Features categories - the ones that are highlighted we implement.

- 6. Effectiveness and efficiency: the user needs a few steps during a dialogue with the system to perform a task. The user does not need to log into the system for each use. While this can be a threat to the user's security, it is an enabler for the user. Furthermore, considering that the user needs to log in to their smartphone, this risk is minimised. The system has effective communication.
- 7. Instructions, suggestions, and Support: We have inserted a help command in the system with the system's main features that can be requested at any time. When the user requests "Help", the system informs which features the user can request.

5.1 Approach Overview

Figure 5.2 shows a high-level view of how our approach works, we name our approach of Homer. First, the user interacts with the system through voice commands (according to user preference - see Chapter 3), using the Google assistant. The Google assistant is integrated with Dialogflow platform, where we created our conversational agent. Our agent talks in Portuguese. We chose DialogFlow because it offers several integrations and for being available for free. DialogFlow sends action requests to our multi-agent system, which performs the requested actions on it based on the current state of the environment. Our multi-agent system also integrates with Google cloud vision API[1], Open Weather API[2], and through Arduino[3] we have communication with peripheral, sensors and actuators such as light and humidity sensors. Thus, depending

[1]https://cloud.google.com/vision
[2]https://openweathermap.org/api
[3]https://www.arduino.cc/en/software

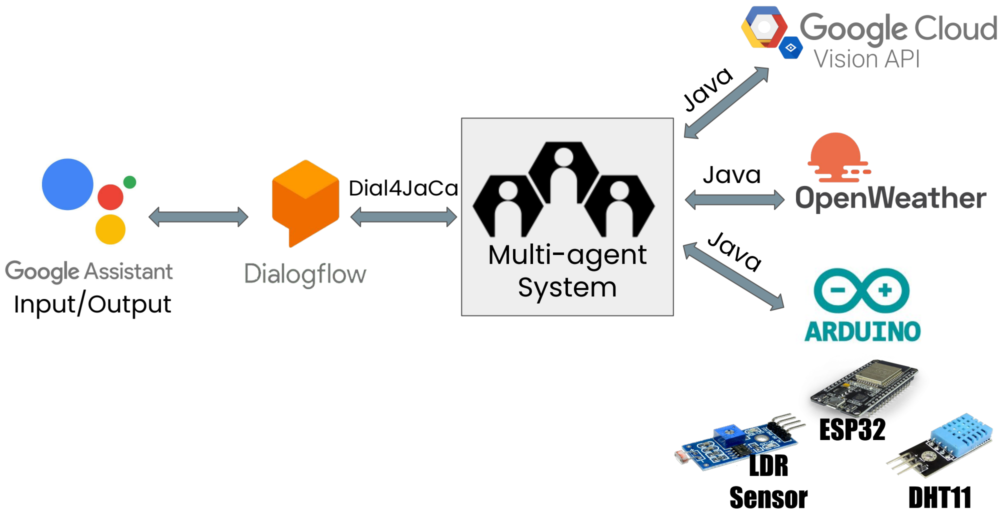


Figure 5.2: High-level view of our approach.

on the user's request, Homer calls one of the available integrations and then updates the user about the system's current state using voice feedback.

In our initial prototype, presented on Chapter 4, we used YOLOv3 [147] for object recognition using an internal server in our lab. However, we chose to move to Google's Cloud Vision API because it has an entire cloud architecture that is easy to implement and has no cost for testing. Also, we decided to work with Dialogflow because it is easy to integrate with Google Cloud.

The multi-agent system was developed using the JaCaMo platform, that, as seen in Chapter 2, it includes Jason, which is an interpreter that performs better than other agent programming languages [19]. In addition, using an organisation of agents (Moise) and environment (CArtAgO) is interesting in this scenario because Moise enables agents to perceive the roles available in the organisation, and with CArtAgO enable us to model the devices in the environment.

5.2 The Multi-agent system: Homer

The main elements of our multi-agent system[4] are presented in Figure 5.3. It consists of four layers. The `Organisation` layer contains the main role of the Caregiver system. All agents extend this role, as we can see in the `Agents` layer. Figure 5.4 shows the roles and groups using Moise[5] notation [79]. Also, in the `Agents` layer, we can see that a specific agent was created according to the categories of features. The `Artefacts` layer has all the artefacts in the system. The `Integration` layer has all the Java codes

[4]We make the implementation available on Github https://github.com/smart-pucrs/Homer
[5]In this proposal we simplified Moise specifications to keep the focus on the main aspects.

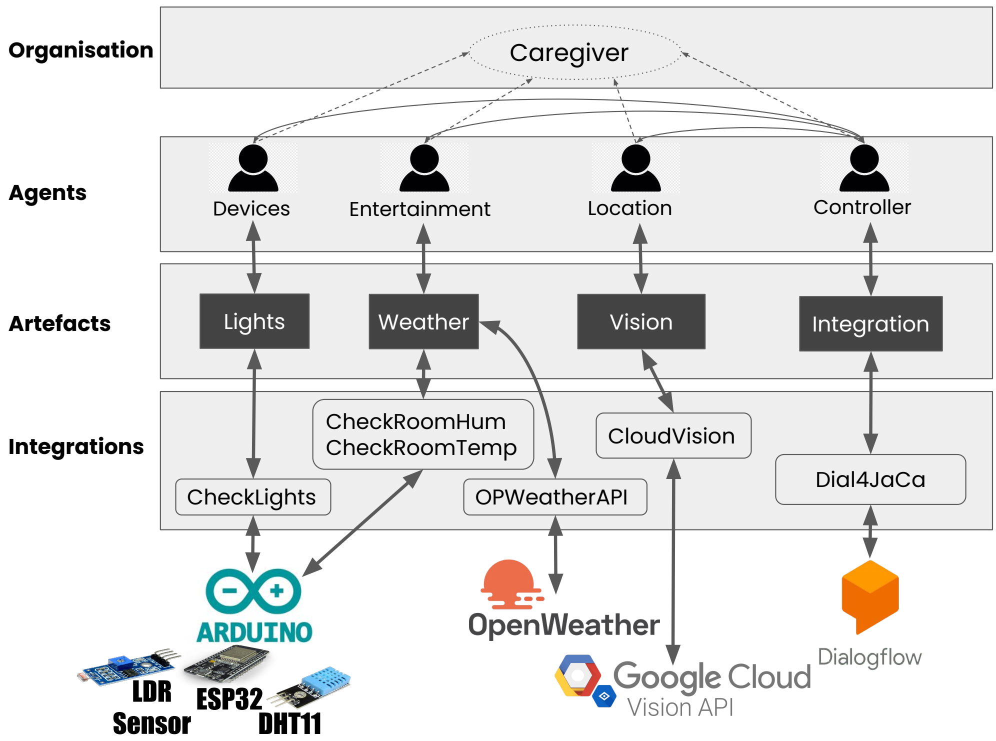


Figure 5.3: Multi-agent system structure.

to access the APIs, which are then accessed by the `Artefacts` to communicate with the agents. This `Integration` layer allows us to easily change the technologies our multi-agent system communicates with, such as replacing Cloud Vision with YOLO or Dialogflow with another natural language understanding platform.

The information flow, that is, the user's request, occurs as follows. Dialogflow sends the user's request to our multi-agent system. To receive those requests, our system uses an integration between JaCaMo and Dialogflow called Dial4JaCa [6] [57], which extends the open-source JaCaMo Rest project [7] [10]. It is represented by the `Integration artefact`, in Figure 5.3. Then, our `Controller agent` is responsible for forwarding the request depending on what it is about. For instance, when it is a request about an object location, a plan is triggered that forwards the request to our `Location agent`. Likewise, when the request is about the weather, another plan that forwards the request to the `Entertainment agent` is triggered. Similarly, when it comes to the status of a light or the temperature, the triggered plan forwards the request to the `Device agent`.

Each specific agent reacts according to the perceptions sent by the artefacts in our system. For instance, the `Location agent` consults the `Vision Artefact`, which then consults CloudVision, and the response is delivered to the `Controller agent`, which notifies the user.

[6]https://github.com/smart-pucrs/Dial4JaCa
[7]https://github.com/jacamo-lang/jacamo-rest

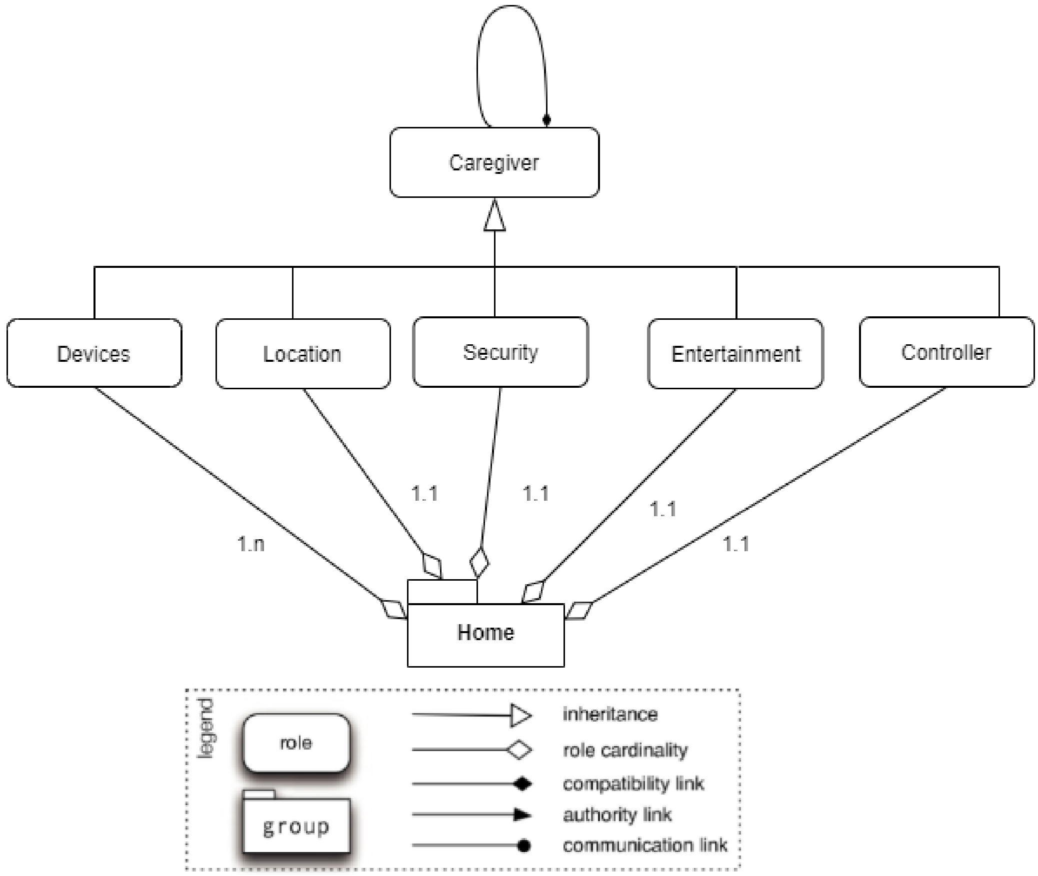


Figure 5.4: Multi-Agent Organisation.

We believe that with the structure we created, it is possible to be expanded by adding new features, and in addition, it is also possible to change the integrations used in the system. For this, it would be enough to respect the data requested by the artifacts.

5.3 Implementation

In this section, we will detail each agent's responsibilities in our system. A Homer demo video is available on YouTube[8].

5.3.1 Controller Agent

The `controller agent` is responsible for all communication between DialogFlow and the specific agents; that is, it receives requests from the users and forwards them to the specific agents. Afterward, it receives the agents' conclusions and delivers them to Dialogflow.

[8]https://youtu.be/t8ZyKnPU32A

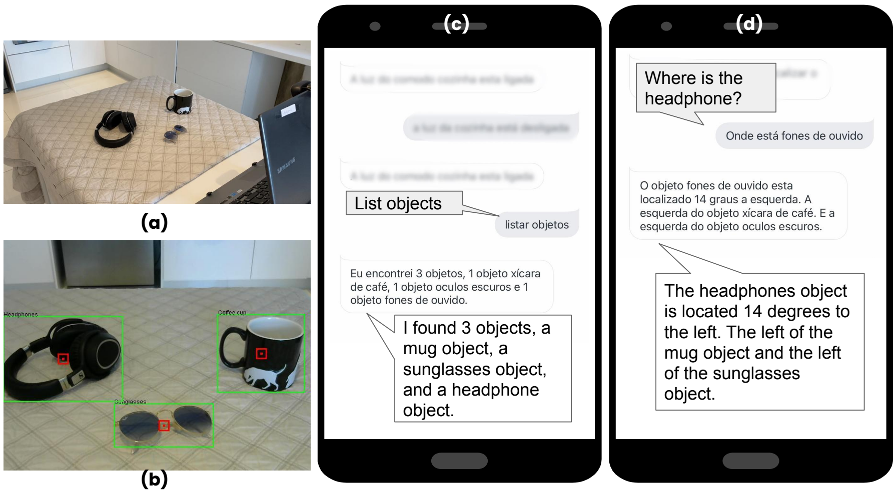


Figure 5.5: Homer execution (a) scenario, (b) scenario recognised by the camera, (c) find objects, and (d) find specific objects.

5.3.2 Location Agent

All *location features* were implemented using the Cloud vision API. The Cloud vision API needs images for object recognition. To provide those, we have implemented a Java class that identifies and access the user's webcam and takes pictures of the environment. This data is then processed by Cloud vision. It is important to mention that for each object, the Cloud vision API returns the name of the object in English and the `X` and `Y` coordinates followed by a confidence degree. We translate the names of the objects to Portuguese using a service provided by Google cloud [9]. Also, we created a class named `ObjectRepresentation` in which Java methods calculate the degree position that each object is, and whether it is on the right, left, or in front of the camera. All these calculations using the user's webcam position as a reference. These information is accessed by `Vision artefact`.

We implemented two ways to use the *find objects*. In the first one, the user can list all the objects in the image. This feature lists the number of objects and their respective names. In this feature, we chose not to present the locations of every object in the environment because the message could get too long and tedious for the user. In the second one, the user can search for a specific object and obtain its location, such as the degrees and whether it is on the right/left or in front of them.

Moreover, to search for a *specific object*, we provide additional information regarding the two closest objects related to the requested one. This is important in case the user cannot determine the precise location of the object given only the degrees and

[9]https://cloud.google.com/translate

directions coordinates. We believe two objects provides a good balance in order to avoid overwhelming the user with information.

To determine those objects, the `Location agent` searches for the closest object in the X axis of the image. The second object is searched in the Y axis of the image. Given a list containing all objects identified in an image, the agent iterates over it and selects the object that minimises the following equation:

$$diff = (x_r + x_1)/2$$

, where x_r is the x-coordinate of the requested object and x_1, similarly, is the x-coordinate of another object in the given list. The resulting object is then removed from the list. This process is repeated in the Y axis to select the second object.

Next, we inform the relative position (right or left) of the requested object regarding the selected objects. To this end, the `Location agent` compares the objects' x-coordinates. If x_1 is greater than x_r, the requested object is on the left of the other one. Conversely, if x_1 is less than x_r, the requested object is on the right.

In some cases, there may be more than one object with the same name in the image (e.g., two books). In these cases, the system uses the first object it finds to return information. If there is only one closest object, the system lists in relation to that object only. If there is only the requested object and two more objects in the scene, the list of those objects is returned. Figure 5.5 shows the execution of the features of *find objects* and *find specific objects* with Homer.

We created a feature to *Identify when objects are out of the usual places*. This feature allows the user to identify when an object has been moved away from its usual location or when new objects have appeared in the environment. We compare the image that was taken previously with a new picture. The `Location agent` is responsible for this task. The `Location agent` receives the string that comes from `Vision Artefact` that contains each object's location in the last image, such as degrees and its relative direction. It has a plan to compare these information. If the new image contains the same data as the last image, then it means everything is in the same place; if it is different, it means it has moved. If the object is not in the list of the old image, then it is added as a new object. Also, if there is any object in the old image that was not found in the new one, then the `Location agent` informs that one object was not found. Figure 5.6 shows the execution of the *identify when objects are out of the usual places* feature. In that demonstration, we took the sunglasses object out of the scene.

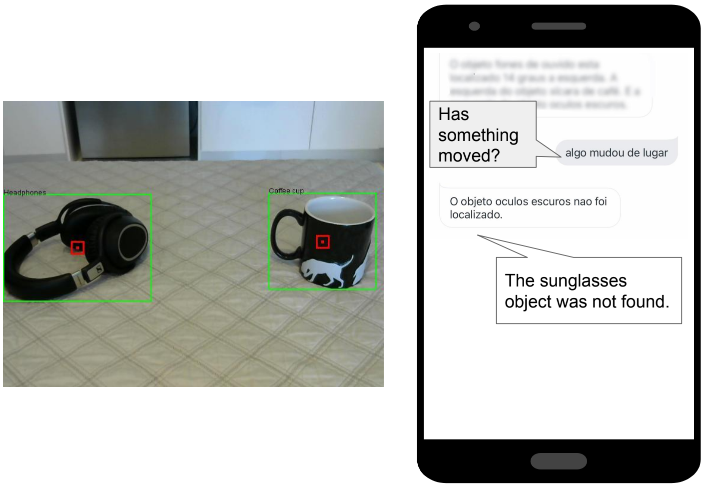


Figure 5.6: Homer execution - Identify when objects are out of the usual places.

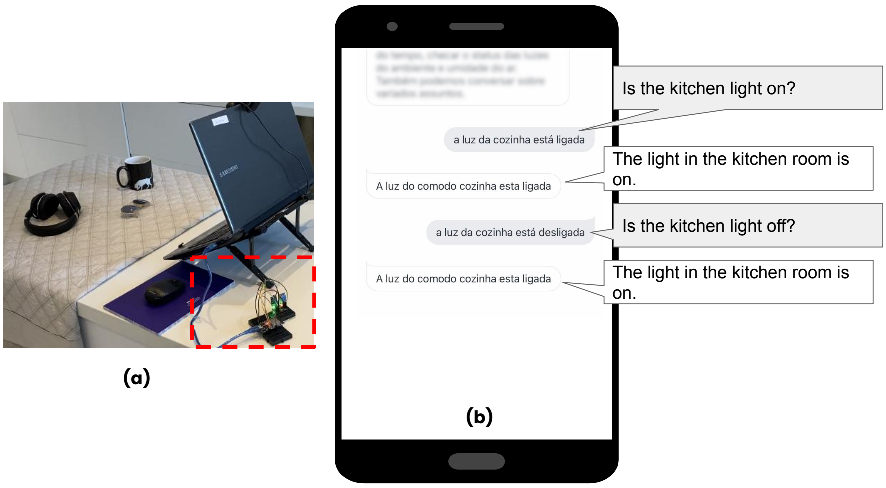


Figure 5.7: Homer execution (a) micro-controller board with sensors, and (b) identify whether the light is on or off.

5.3.3 Devices Agent

We created a `Devices Agent` to control the environment; at the moment, it is responsible for *identifying whether the light is on or off* feature (see Figure 5.7). To do so, we used a micro-controller board to send data from a light sensor via Wifi, making it possible to check the status of the light (on/off). We access the board using the HTTP method. We describe in Appendix A the components we used, how the assembly was carried out and how the installation and communication with the multi-agent system are done.

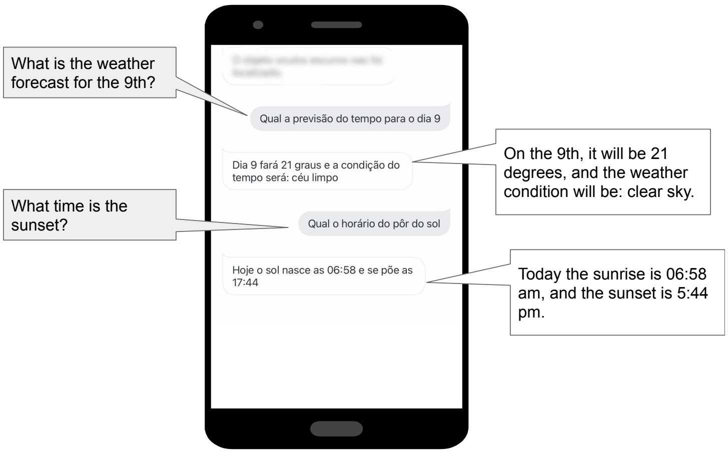


Figure 5.8: Homer execution - Inform the weather.

Figure 5.9: Homer execution - Entertainment for solitude.

5.3.4 Entertainment Agent

Our `Entertainment agent` is responsible for free conversation, telling jokes, and reporting the weather forecast. In the *Entertainment for solitude* feature. Dialogflow uses the concept of intent. Each intent has questions, e.g.,"what the user says" and possible responses to the request. When the response is not fetched from an external service, they are registered directly in Dialogflow. A huge number of intents registered in Dialogflow makes the communication with the user more natural and diversified. With that in mind, we have entered 100 intents with the appropriate user-assignable questions and answers. It has intents that allow small talk and that tell jokes to the user (See Figure 5.9). Also, we added default fallback intent for when the agent does not recognise the user's request. So, in this case, the user is informed that "Sorry, but I do not understand."

The *Inform the weather* feature allows the user to know the weather forecast for a specific day of the next seven days to come or the current day (See Figure 5.8). The user can also check the sunset time and the humidity conditions for a particular day. Our `Weather Artefact` accesses the `OPWeatherAPI class` that uses the Open Weather API and makes those properties observable to the `Entertainment agent`.

6. EVALUATION

In this chapter, we present two evaluations we performed to evaluate our approach. We performed the first evaluation with HCI specialists and the second with end-users, people who are visually impaired.

6.1 Evaluation with specialists

We performed an evaluation with seven HCI specialists. Our goal was to identify usability issues and suggestions for improvement. These specialists were intentionally selected, according to their expertise's in the HCI area. We asked specialists to watch a Homer demo video made available on YouTube[1]. Then, we asked them to answer an online questionnaire. In that demo, there was a brief explanation about the whole system, about our persona, and some scenarios for using the system. Afterwards, we run the scenarios using Homer. We performed the following features in the video: list objects, find a specific object, inform the weather, check if any object was out of place, help, and check lights.

Table 6.1: HCI specialists profile - Homer evaluation

Id*	Age	Gender	Last degree	Academic Formation	HCI experience (years)	Work with PVI	Experience with virtual assistant
S1v	29-39	F	PhD	Computer science	6 +	Yes	Yes
S2v	29-39	M	MsC	Computer science	1-3	Yes	Yes
S3	40-50	M	PhD	Computer science	1-3	No	Yes
S4v	40-50	F	PhD	Design and Technology	6+	Yes	Yes
S5	29-39	F	MsC	Computer engineering	6+	No	No
S6v	29-39	F	PhD	Computer science	6+	Yes	Yes
S7v	40-50	M	MsC	Systems Analysis	3-6	Yes	No

(*) specialists who have worked with PVI received an id with the letter v at the end.

In the online questionnaire, the main questions evaluated were: if each of the features are adequate and easy to understand, and if reviewers would have suggestions for improvements to them. There was also an overall evaluation of the system with questions to identify whether the system is easy to use, easy to act on instructions, easy to understand what actions are available and whether the information is useful. Also, if the specialists believed that the features are useful for people who have visual impairment. Furthermore, the positive and negative points of the system were asked. In this section, we analyse and discuss their answers.

Table 6.1 summarises the HCI specialists profile. As for the profile of the specialist, they are between 29 and 50 years old, being 4 females and 3 males. All have either a PhD or a master's degree, 4 being in Computer science. Most of them have

[1] https://youtu.be/t8ZyKnPU32A

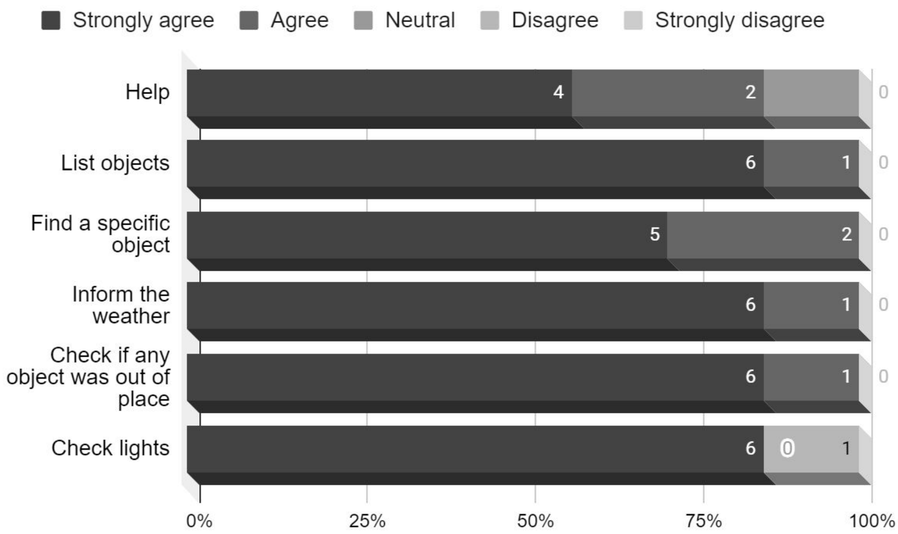


Figure 6.1: Features evaluation - adequacy - by specialists.

more than 6 years of experience in HCI. Excepted 2 specialists, all of them work or have worked in projects to people who are visually impaired. As for experience with virtual assistants, only two never used it. Some virtual assistants cited were: Siri, Google home, Google assistant, and Alexa.

6.1.1 Results

The results indicated that most specialists strongly agree or agree that the features contained in Homer are adequate (Figure 6.1) and easy to understand (Figure 6.2). About the *Help feature* being adequate, S2v was neutral, stating that it would be interesting to “Know which rooms have a camera”. S5 disagreed that *Check lights feature* is adequate and easy to understand, and she/he suggested that the user should only be informed “Yes or No”. Nowadays Homer inform “The light in the kitchen room is off/on”. S5 also disagreed that the *find a specific object feature* is easy to understand, and she/he suggesting that “The degree information can be confusing. Maybe just the relationship would be enough”.

Figure 6.3 shows that most specialists believe that the system is generally easy to use, easy to act on instructions, easy to understand what actions are available and whether the information is useful.

We analysed the suggestions provided by the specialists and grouped them into two categories: items to confirm the need with end users and new features.

- **items to confirm the need with end users**:

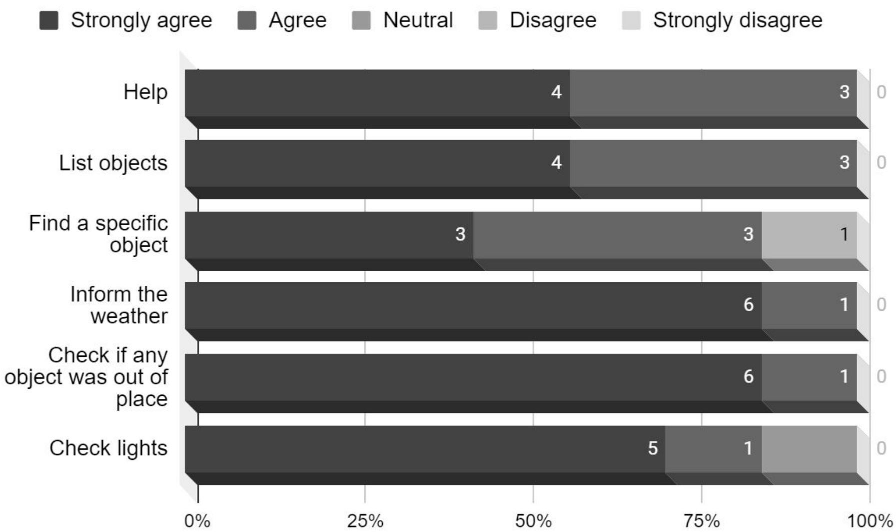


Figure 6.2: Features evaluation - easy to understand criterion - by specialists.

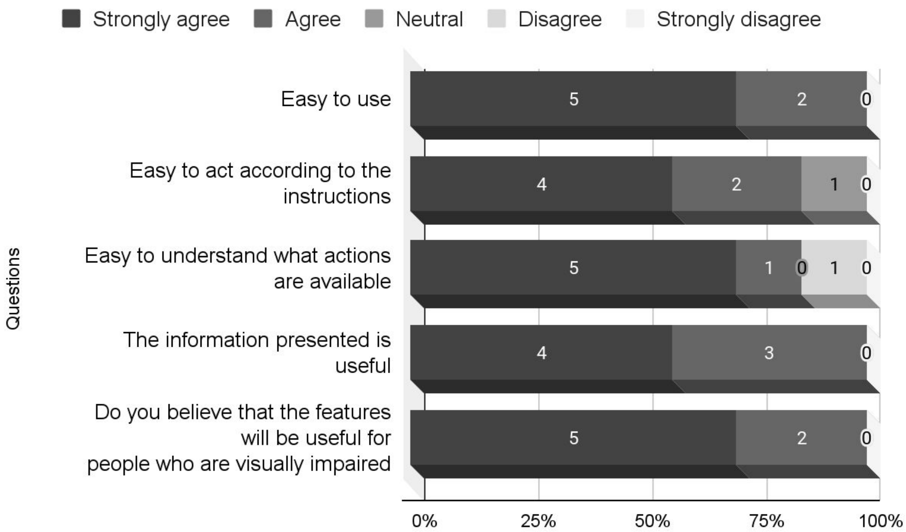


Figure 6.3: General questions homer evaluation- by specialists.

- S1v, S3, and S5 suggested some changes to the help feature. S1v said that it would be interesting "the *help feature* to present what functions it can perform in detail too". Also "Test with a screen reader. My suggestion is to provide the user with help or guidance on how to use it for the first time with the screen reader. " While S3 and S5 suggested adding "examples of how to call the features".
- S5 suggested that the *list objects feature* present more information about the position, such as side, down, right, and left. Since the *list objects feature* presents all the objects in the environment, we thought it would be tiring for the user to have more information about each object. In this way, we decided to show only the number of objects and the objects' names. So the user could

choose which object wants more information when finding a specific object. However, taking into account the specialist opinion, we will ask the user about this.

– S1v finds it interesting to "provide information about the surface, for example, whether it is smooth and its color."

– S4v suggested to "inform the user at what distance Homer is (Homer), e.g., Listing objects at a distance of..." We will confirm it in the user evaluation. We believe the user will know the camera's position at home, then this information may be unnecessary.

– S7v suggested "find two objects at the same time." Again, we will check with the end-user.

- **New features**:

  – S2v, S6v, and S3 suggested the use of multi-cameras and other types of cameras such as smart cams or from smartphones. S6v questioned the need to use a fixed camera in the environment, and asking "Could not the user use the camera from their own smartphone?".

  – All specialists suggested adding more information on the environment and location of objects. S2v recommends listing objects by room, e.g., "List Room Objects". S3 and S6v asked to add more location information, for example, if the object is on the table or center of the room. S4v suggested to inform the camera distance. S1v proposes Homer to tell the camera position. S7v asked to fetch more than one object at the same time. S2v suggested basing the location of objects on the smartphone location and not only on the camera location.

  – S1v and S2v suggested adding alarms and notifications. S1v proposes that Homer could schedule an automatic check, for example, if it is night the light must be kept on. S2v suggested configuring notifications for when the user is not in the room to warn that some object is no longer in the environment. Also, to create an alarm for sunset and temperature sensor to bring the temperature difference inside the user's house and on the street.

  – S6v recommends that Homer tell which lights are on/off. S7v to add more sensors. S2V suggested adding a motion sensor to let the user know if something passed in front of the camera.

  – S3 and S4v thinks Homer's voice is a little mechanised. Unfortunately, the Google assistant only provides two types of voice for testing, a male and a female. However, we will ask the end-users' opinions.

  – S1v and S2v suggested that Homer should keep the microphone always on.

  - S2v and S3 suggested that Homer should have a calibrate or configuration feature. S2v commented about Homer being able to “configure fixed furniture as references for object identification” and gave as an example “the camera is on top of the sink because that is where the camera gets more information from the room, but I want to configure it that the right/left instructions and degrees are always based on the kitchen entrance door.” S3 suggested to “create a feature to calibrate the system”. In this way, Homer remembers the position of objects as they are in the environment at the moment. If changes are made, we can recalibrate.”
  - S2v suggested a new command “where the user can send feedback about the application, such as suggestions for new features, for example. (...)”

The specialists also pointed out the following advantages of using Homer.

- “(...) As the prototype implements several features, we can verify that this study can be used in different contexts and according to the users’ needs. I believe that Homer will be very helpful in helping home automation for people who are blind.” (S1v)
- “I think the system will be very useful for people who have visual impairments to be able to build, more clearly, their mental map with greater accuracy. The possibility of finding specific objects I also consider to be of great importance.” (S2v)
- “I thought it was amazing what was achieved with this prototype. I think if I could, I would use it even if I have no visual impairment.” (S3)
- “Fast location of objects, assistance in daily activities.” (S4v)
- “Assists the visually impaired in basic tasks that they would need help with.” (S5)
- “The system is simple in its form of voice interaction. And it presents extremely useful information for the daily life of a person who is visually impaired. In my opinion, the prototype delivers everything that is proposed in an excellent way.” (S6v)
- “Practical application of technology. I think check lights are amazing, very useful and practical, I think it’s the highlight of the research. You took a luminosity sensor and gave it a service that you never thought would be supported by an intelligence. (...)” (S7v)

Table 6.2: Users profile - Homer evaluation

Id	Age	Gender	Visual Acuity	Living alone	Experience with virtual assistants
U1	18-28	M	Congenital Blindness	No	Yes (Google assistant, Google Home)
U2	40-50	M	Acquired Blindness	No	Yes (Google assistant)
U3	18-28	F	Congenital Low vision	Yes - 4-6 years	Yes (Siri, Google assistant, Google Home)
U4	18-28	F	Congenital Blindness	No	Yes (Google assistant, Siri)
U5	18-28	F	Congenital Blindness	No	Yes (Google assistant, Google Home)
U6	18-28	M	Acquired Blindness	No	Yes (Google assistant)
U7	18-28	M	Acquired Blindness	No	Yes (Google assistant)

6.2 Evaluation with end-users

We invited users who participated in the initial phase of the research (Chapter 3) to evaluate Homer. In addition, the participants themselves nominated other participants. In total, seven users who have visual impairment agreed to participate in the evaluation. Our only restriction on participation was that users had already used the Google assistant and that they had access to the Google assistant on their own smartphone for the tests. Our objective in this evaluation was to verify if the our approach meets the users' needs and the HCI guidelines.

Table 6.2 summarises the profile of the participants. Data analysis showed that participants are between 18 and 50 years old, and the most common age group is from 18 to 28 (85,7% - 6 users). Regarding visual acuity (85,7% - 6 users) are blind, 3 of them have congenital blindness and 3 of them acquired the blindness during the life. All participants are virtual assistant users, among the most used are Google assistant and Google home. Most participants are male (57,1% - 4 users). Except for one participant, they all live with other people.

Due to the pandemics situation, we created an evaluation that could be performed online, so that users could use Homer and make their usage considerations. As we had no way to use the users' computer webcam to take real-time images, we asked users to send a photo of some environment in their home. That way, it would be possible to analyse how Homer behaves using real data. Also, as the user knows their home, they could check if the information presented makes sense. To use Homer, the users downloaded the trial version onto their smartphones. Before testing, we added the users as testers in the system. Also, during the use of Homer, we were available to resolve questions and we follow the execution logs generated by the application. After using Homer, we asked the users to complete an online questionnaire.

Before the test, we sent an e-mail to the users with an explanation of Homer, a description of the user-submitted image that was selected for the test, and instructions about the test. We sent the following instructions to the user:

1. Access the link on your mobile device.

Table 6.3: Evaluated criteria and questions from the online questionnaire

Criteria	Questions
Usability, Accessibility, and Natural Interaction	Is the system easy to use? Is the system easy to learn to use? Is it easy to act on the instructions? Is it easy to understand what actions are available? Is the information presented useful? Does the system maintain a natural conversation? Is the system easily accessible? Did you like Homer's voice?
Features	Did the system help you find specific objects? Did the system help listing objects in the environment? Did the system help with the weather forecast?
Satisfaction	Would you use the system in your daily activities? Would you recommend the system to others users? What are the positive points of the system? What are the negative points of the system? Do you have any suggestions for improving the system?

2. Click on accept to be a tester.
3. You will be given a message saying "ok, let's download the trial version of Doctor Homer."
4. When the Homer Assistant says "Hi, I am Homer Assistant. Can I help you?" it means it is ready to use.
5. Start by asking "Help".
6. Test each of the features mentioned.
7. At the end of the test, complete the online questionnaire.

The online questionnaire contained a consent form for participation, six questions to identify users' profiles, and 16 open questions about the system. Table 6.3 presents the questions we asked to the users.

6.2.1 Results

Following we describe the results we obtained from the online questionnaire[2]. Figure 6.4 and Figure 6.5 show the photos taken and send by users, the green markings show what Homer recognised.

Concerning the "Is the system easy to use?" question, all users answered yes. Thus, the users U1 and U2 inform that "Yes, of course at the beginning it is a bit complicated, as you still don't know how it works, but once you do, it's pretty easy to deal with it" (U1) and "Yes, the system is very easy to use, very intuitive." (U2).

[2]We carry out an English translation of user responses.

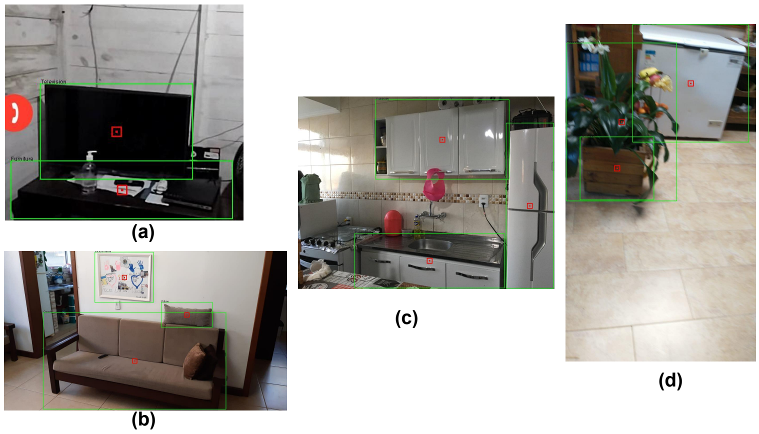


Figure 6.4: Photos from users' home (a) U1, (b) U2, (c) U3, and (d) U4.

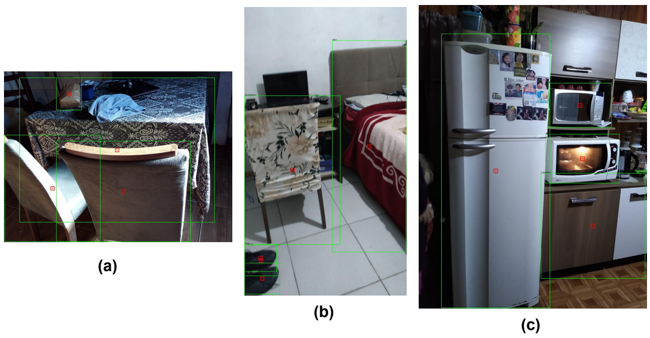


Figure 6.5: Photos from users' home (a) U5, (b) U6, and (c) U7.

Referring the "Is the system easy to learn to use?" question, all the users answered yes. The U1 and U2 observed that "yes, the application is very clear on this issue, if you learn how to deal with it right away, it was observed that you have to learn to speak as well as it understands" (U1) and "Yes, the system is very easy to learn to use, it doesn't require learning, you just have to memorise the keywords." (U2).

When we asked "Is it easy to act on the instructions?" question, all the users answered yes. U1 and U2 inform that "Yes, the app gives feedback on how to handle it while using it, and it warns you when you don't understand what was said" (U1) and "Certainly, once the instructions are assimilated, it is very easy to operate and act with the system." (U2).

Relating the "Is it easy to understand what actions are available?" question, all the users answered yes. Some comments were made "Yes, but I think he should be more objective to understand"(U1), "Yes, it's very easy to understand the available actions for sure" (U2), and "even when asked to Homer, it is easily informed what features are available." (U7).

Concerning the "Is the information presented useful?" question, all the users answered yes. Users U2, U4, and U7 described some points they liked the most such as "Yes, they are useful because they give the real size of the system and where we can explore.” (U2), “Yes, especially when it comes to the ease of use light (identify whether the environment light is on or off).” (U4), and “They are useful and I believe that in the real world if it suits each reality it gets even better.”(U7). However, U3, despite stating that the information is useful and highlighting the features of listing objects and finding a specific object, informed that it would be necessary “(...) to recognise a greater number of objects, especially small objects, (...) ” (U3).

About the “Does the system maintain a natural conversation?” question, except U7, all users answered yes. The users also made some comments, such as:

- “Yes, the system maintains a very natural conversation, while within the intentions where it was programmed, if you go a little outside, let’s say, that cycle of intentions that was designed, it already responds with standard evasions as if it didn’t understand the command and such, as well as the default Google Assistant. However, I believe that as the artificial intelligence registers new situations, it will respond according to this new directive. But at first yes.” (U2)
- “It could be more natural, but I think it is good enough.” (U3)
- “Yes, but could have an option to choose female or male system voice. Note: just a suggestion.” U5
- “In parts. It cannot interpret much information, often because the words I used. Certainly, if we catalogue the environment based on more angles, the information would be more accurate.” (U7)

Referring the “Is the system easily accessible?” question, all the users answered yes. U1 and U2 stated that “yes, for those who use it directly and not too.” (U1) and “Yes, easy to access. I believe that when the system is in production, it will be even better.” (U2)

Concerning the “Did you like Homer’s voice?” question, five users answered yes and two answered no. Users who did not like it commented that “This was the part I liked least, it was a bit weird voice, but if I had the option to change it, it would be better.” (U2) and “I found it very robotic, but I believe that having the difference between the one I use and the Homer is a good point.” (U7). Users who liked the voice also made suggestions “The voice is OK, but if it could be the voice of the Google Assistant, it would be nicer and more understandable for some people.” (U3) and “Yes, but it could have more options for the voice (female or male)” (U5).

Five users answered yes and two answered no about the “Did the system help you find specific objects?” question. It is important to mention that an error occurred in using U3 and U4, who pointed out “no” in this question. We have fixed the error for the subsequent users’ evaluation (e.g., U5, U6, and U7).

Concerning the "Did the system help listing objects in the environment?" question, all the users answered yes. However, U3 again suggested that "[...] It would be important to recognise more objects and, in particular, small objects. It would also be nice to detail better large objects, such as colors and other visual features." (U3). Meanwhile, U2 commented that "Yes, in this case, it was also extremely satisfying. I think it listed 3-4 objects from the environment and can check the positional characteristics of the object." (U2).

Addressing the "Did the system help the weather forecast?" question, all the users answered yes. U1 and U2 commented that "yes, it is one of the most important functions in the blind person's daily life" (U1) and "Yes, that question was asked and it answered calmly."(U2)

About the"Would you use the system in your daily?" question, except U3, all users answered yes. U3 reported that it would only use it if "it could provide much greater detail in the description of the environment than currently presented. If you could, for example, help me find small objects in an environment." (U3). Some of the users who answered yes to the question commented that "yes, for sure, of course it will still improve in some aspects for the best use." (U1) and "Yes, no major issues. I believe it would help a lot in locating objects as well as the more trivial tasks of weather forecasting or something beyond that to be programmed, they are very interesting tasks. Color identification would be nice too." (U2)

Concerning the "Would you recommend the use of the system to other users?" question, except for user U3, all users answered yes. U3, as in the previous question, reaffirmed that "Only if he could offer a much greater detail of the description of the environment than what was presented at the moment. If you could, for example, help me find small objects in an environment."

Considering the "What are the positive points of the system?" question, the users commented:

- "Is the way that the app to always respond by speaking verbally, it will not show results for clicking only verbally." (U1)
- "As a positive point that I had not seen in any assistant like this, it was this directional thing that was inserted in it that I believe is of great value for localization even more for those who cannot see, it is very interesting and this intelligent interface that talks to us . This is very interesting." (U2)
- "System is very accessible and easy to understand, and I believe it has great potential to develop." (U3)
- "Everything is very important." (U4)
- "I really liked it." (U5)

- “in my opinion it is a very good assistant, with a very good voice and that he does his duties well and helps a person with a disability very well.” (U6)
- “Easy access. It makes it possible to know the environment in which I live through a database that I can build.” (U7)

About the “What are the negative points of the system?” question, the users answered:

- “Is that sometimes he doesn’t understand, he has to say the same question several times or he changes, and the little information so far is little, he could have more access to the internet or even bring more information as a whole. ” (U1)
- “I didn’t like the voice intonation. And at that time, I think my internet was a little slow, it took a while to reach the function, he didn’t answer the weather forecast question satisfactorily, answering with standard answers, right because the response time was extinct. But other than that, OK. ” (U2)
- “The ability to identify and locate objects is still very low and restricted.” (U3)
- “There are no negative points all are good.” (U4)
- “As I’ve always said since the beginning of the questionnaire to have more than one system voice option.” (U5)
- “I found no negative points. It would add more daily features, but this depends on the possibilities and development of the assistant.” (U7)

Referring the “Do you have any suggestions for improving the system?” question, the users commented that:

- “[Homer] should have internet access, talking in the feature help more suggestions on how to talk. [it should] have more options for verbal feedback, and it presents much information beyond what you already have. Also, he could describe the place and speak some colors not all objectively and give more information in real-time.” (U1)
- “One cool thing would be the identification of colors, I don’t know if it is outside the scope of the work, but it would be very interesting, for example, to look for a shirt in a drawer or look for blue clothes, or click on the clothes and identify that the first on the stack is green. Another normal thing like that besides testing would be to increase the scope of intentions and interactions it recognises. However, I think that if you go into production and everyone starts asking him, he kind of starts to learn, I think that would be machine learning, right. But it’s excellent in general terms.” (U2)

- “Improve the ability to identify objects in the environment and improve the ability to find objects.” (U3)
- “No” (U4)
- “Have more system voice options.” (U5)
- “Although the assistant is good and I liked it, it could also have a function to identify clothes colors so that a blind person can know what clothes they are wearing.” (U6)
- “Make a general mapping of the house. Putting the banknote reader feature. If it was possible to find phone numbers or be linked with a friend’s number in case you need some extra support. Read colors.” (U7)

6.3 Discussion

Our evaluations show that the system meets the criteria of usability, accessibility and natural interaction, features, and satisfaction. However, the participants suggested some improvements and new features, which we discuss as follows.

- Catalogue the environment from more angles for more accurate information (U7). This suggestion was also pointed out by HCI specialists (i.e., S2v, S6v, and S3) when they indicated the need for the system to have multi-cameras.
- Detail more information about objects such as colors and more visual characteristics (U1, U2, U6, and U7). This new feature was also observed in the evaluation with the HCI specialists (S1v). This feature has also been identified in Chapter 3 and Chapter 5. However, we had to prioritise some of the features indicated by users.
- Recognise more objects and smaller objects (U3). This improvement is related to the Cloud Vision API, we used in this first version of Homer the trained basis provided by the API. In future work, it is necessary to train the base to recognise more objects.
- Find phone number or register a friend’s number, if the user needs help (U7). This need is associated with the “Request help from any registered contact” feature that was identified in Chapter 3 and Chapter 5.
- Have the option to configure the assistant’s voice (U2, U5, U3, and U7), for instance, female or male voice. This suggestion was also identified by two HCI specialists, S3 and S4v.

- Increase the phrases recognised by the system (U2, U4, and U7). This suggestion is related to the intents registered in Dialogflow and the number of training phrases added to each intent. During the evaluation, the users requested some features in different ways than the ones that was registered in the system. Thus in the free conversation, they requested intents that the system was not prepared. We have identified these requests in the training section of Dialogflow and added them to the corresponding intents. Then, for the new requests that did not exist corresponding intents, we created the new intents. For example, the user requested “How far is the earth from the moon”, we created the new intent.

During the HCI specialists evaluation, Sv1 raised concerns that Homer would be screen reader tested. In the evaluation with users, it was identified that Homer behaves well with the screen reader; the voices do not overlap and have the same behavior as the Google assistant.

Another suggestion identified by specialists was that the user could use the smartphone’s own camera (S2v and S6v). During the evaluation with end-users, we found that this would not be a good option as most of them had difficulty taking pictures of their home and had to have someone to check the pictures first.

FINAL REMARKS

In this chapter, we present the evaluations performed to evaluate our approach (Chapter 5). First, we evaluated with seven HCI specialists and then with seven PVI.

7. RELATED WORK

In this chapter, we present a literature review about multi-agents for ambient intelligence, ambient intelligence for people who are visually impaired, and human-computer interaction in ambient intelligence.

7.1 Multi-agents in Ambient intelligence

In this section, we detail the specific publications that use multi-agent systems for Ambient intelligence that we found during the Mapping Study (Section 4.1). Most of the publications are for elderly and disabled people [159, 64, 64, 61, 157], only one publication [59] focused specifically on people who are visually impaired.

Fernandes et al. [59] presented the design of an architecture capable of processing information from the environment and propose actions to the user who are visually impaired, to predict a possible obstacle at home. For information processing, the proposed architecture use Agents, and in the future, they will be inserted into multi-agents. The authors present the architecture design, but they did not perform an evaluation.

Sernani et al. [159] proposed a multi-agent system called “Virtual Care”, with the aim of helping an elderly or disabled patient to monitor health conditions and control the environment. Virtual Care is a system for managing a network of distributed sensors composed of environmental and biometric sensors while being an interface layer between the network, the person assisted, their relatives and the medical team. In addition, it includes an objective-oriented reasoning module, i.e., the Virtual Carer Agent (VCA), based on the BDI architecture. Sensors and actuators are implemented using the JADE framework, while the BDI agent representing the VCA and the Registration Agent is implemented using JASON language. This architecture provides for user interaction through audio and gestures but is not currently used. They evaluated the system using simulations.

Fraile et al. [63, 64] create HoCaMa [63] and AMADE [64] a hybrid multi-agent architecture that facilitates remote monitoring and care services for disabled patients, for example, alerts and warnings, like remembering to take medications, control, and supervision home care environment. The architecture combines deliberative and reactive agents, and incorporated Java card, RFID, and SMS. In the implementation was used FIPA ACL, and SOAP protocol. HoCaMa/AMADE were reasoning and planning mechanisms: case-based reasoning (CBR) and case-based planning (CBP) actions and plans are selected according to their respective utility functions. The architecture was implemented in one home of five patients and was tested during 30 days. They compared HoCaMa/AMADE with ALZ-MAS (another architecture created by the same authors).

The case study consisted of analysing the functioning of both architectures in a test environment. The system sends alerts to the cell phone, but the user can not interact directly with the system for make requests. This architecture is no longer available for download because the authors have sold it to a private company.

Fiol-Roig et al. [61] developed a virtual agent for disabled and elderly people assistance, called Intelligent Butler. The agent performed health care, and control devices, house security; informs about the goods available and those exhausted in the house, such as food or medication; and preferences and schedule. The system incorporated sensors and domotic devices. The agent use perception-action vector (PAV) and object attribute tables (OAT). This system was evaluated with a virtual simulation of a home domotics environment. The person assisted does not interact with the system.

7.2 Ambient intelligence for people who are visually impaired

In this section, we detail the specific publications for people who are visually impaired that we found during the Mapping Study (Section 4.1).

Rizvi et al. [149] designed system to users turn the home appliances on and off just sending command by using an Android application. The system enables old aged, handicapped, and people who are blind to operate their home appliances remotely by using SMS services, the global system for mobile (GSM), voice application, and Bluetooth. This work did not carry out an evaluation; it only presented the design.

Freitas et al. [66, 65] proposed a Health Smart Home system for disabled people that can anticipates them about accidents that can occur in some location of their house. Thus, through sensors the system performs environmental monitoring, and if an event is detected, the user is informed through sounds, vibrations, and alert images that appear on his/her smartphone. They implemented a prototype that warning whenever it detects a potential hazard and monitors rooms. The prototype was created with low-cost technology and includes the following: Raspberry Pi boards, motion sensors, cameras, and a central server. The server will manipulate the data captured by the sensors and send alerts via smartphones. This paper just presents the design, so it has no evaluation.

Buzzi et al. [32] focused on the design of the interface for home automation systems for blind people, mainly the functions and layout of the interface, in order to improve interaction via screen reader. The system provides verification of which devices/sensors are on/off; turn on/off the devices/sensors; get an overview of the information about the status of the house/room/device. Three visually impaired people participated in the testing of the proposed web interfaces. They asked users to interact with the system, assigning them three tasks: check (if any) what devices are in the living room; turn off all the lights, and detect the internal temperature. Users performed all tasks in a natural environment, using the work area to navigate the prototype, one at a time.

Rajan et al. [143] proposed HuMorse, a universal home automation system for the elderly and people who are visually impaired, speech, or paralysed limbs. The system has input with a smartphone that captures and performs facial processing or tilting gestures, which is mapped to the Morse code - points and dashes. The user operates the system with eye blinks and tilts gestures to manipulate electrical and electronic devices, such as television and light. They test the proposed system initially using two types of inputs - eye blinks and smartphone-based. Then, in an experiment in a domestic environment, with the presence and absence of light. The assessment did not include end-users.

Ye et al. [179] presented a 6-DOF pose estimation method for a robotic navigation aid (RNA) for the people who are visually impaired. The RNA uses a single 3D camera for pose estimation and object detection. The system perceives its environment and provides navigational information to its users. Also, the system provides 3D object detection and wayfinding. They evaluated the prototype in a controlled environment and real environment with users, but not with people who are visually impaired.

Vacher et al. [172] presented an approach to provide voice commands in a smart home for seniors and people who are visually impaired. The system can recognise the home automation command (e.g., on/off devices), identify the speaker, and provides an emergency call. They conducted evaluations using a corpus recorded by real users in a smart home.

Hudec and Smutny [80] introduced RUDO, an ambient intelligence system for people who are blind. RUDO assists the user in tasks and various situations at home. RUDO has several modules that mainly support: alerting to other household members' movement in the flat, recognition of approaching people, the user work on a computer, supervision of (sighted) children, the cooperation of a blind and sighted person, zonal regulation and control of heating by a blind person. The system used a neural network and was design using design science research. RUDO was installed in the home of the researcher who designed the system, which is blind, for evaluating the artifact. This assessment lasted 2 years.

Hudec and Smutny [81] added new features to the RUDO system. The new features system enables a new way of perceiving not only the surroundings, but also the social context of situations so that the person who is blind can better respond and engage in communication and social life. For example, alerts the PVI about movement outside and inside the house; recognizes a scene of the hallway door being left open; speech synthesis to inform them about current temperature and uses local and short term meteorological data available online; and recognizes an outdoor scene of increased canine activity, which it announces with the respective notification sound. To identify these scenes, RUDO uses motion detectors installed at various places inside and outside the house. The paper did not report evaluations.

Campos et al. [37] presented a solution that combines YOLO for object recognition in the video, and audio description in order to produce a narrative of the detected information. The solution they proposed provides context information for people who are blind who would like to use surveillance cameras to monitor environments. The system uses a database, which consists of 44 video clips of collective activity. They performed experiments with demos to verify and validate such a system. The prototype did not evaluate with PVI.

Ando et al. [11] proposed a haptic device to help people who are blind with information about obstacles inside a house. The haptic interface aims to reproduce the same stimuli provided by a traditional cane, without any contact with the environment. They present a prototype of the system, implemented using a short cane with a smart sensing strategy and an active handle. They performed tests of the solution with users in blindfolded users.

Mengoni et al. [111] proposed an interactive user interface to control a multisensory shower accessible by both sighted and blind users and able to adapt its control knob to reproduce Braille texts. To do so, they integrated an electro-tactile feedback device and adopted soft-touch finishing to stimulate touch sensations better. They explored haptic technologies to create a virtual high-fidelity prototype to assess individual end-users' response during the user interface design process. They used Arduino to implement the firmware to carry out data elaboration. They conducted a rough task analysis to preliminary verify the efficacy of the prototyping technique and the usability of the proposed interface. This analysis involved 12 sample users: about which six women and six men, four being PVI, all aged between 60 and 65. They highlight the prototype they developed does not affect task success, and the end-users perceive it as familiar and barrier-free.

Vacher et al. [171] presented an approach to improve voice command recognition. They propose the use of verbal orders to turn the light on or off, open or close blinds, ask about temperature and ask to call your relative. To do so, the system uses Markov logic network and automatic speech recognition. They tested the approach with 11 visually impaired and elderly participants in a real smart home. They provided the participant with a list of voice commands to be spoken and actions to be taken. Each participant had to use vocal orders to perform each of the tasks that we mentioned earlier.

Jafri and Ali [85] developed an application for detecting and recognising objects in the home environment for visually impaired people. The application uses an RFID-based, visual-tag computer vision-based, and non-visual tag computer vision-based approach. This approach is just a functional prototype; they did not evaluate.

Kyriazanos et al. [95] proposed a novel ambient assisted living platform, aiming to support the functional capabilities of the elderly and visually impaired, thus better their lifestyle. The features provided are health monitoring; finding the user medication and other personal objects in indoor environments; and medication and medicine related information and services. The proposal uses RFID, SQL, Ontology, object tracking information, and location determination Algorithms. Their application was installed and tested inside Tecnalia's Homelab. Besides on-site evaluation and following the release of the prototype, they also evaluated the proposal through interviews with end-users using paper prototyping. The people who participate in the interviews are from Finland, Greece, and Spain, including caregivers, health professionals as well as care center residents.

7.3 Human-computer interaction in ambient intelligence

In the HCI scenario, some authors focused on the development of guidelines for ambient intelligence [113, 8, 101], other authors tested some environment control tools in terms of usability and accessibility [31, 139]. Other papers were explored forms of interaction using speech recognition [170, 58].

Moeller et al. [113] created guidelines for the evaluation of smart home environments. These guidelines address aspects of the usability in smart home environments. In doing so, it takes a user-centered viewpoint and does not consider purely functional testing of software or hardware components. Although smart home systems are used in AAL, their guidelines presented only usability aspects, but they do not cover criteria, such as user safety, ethical aspects of care-taking by a machine. Also has no guidelines for users who have disabilities. These guidelines have not been evaluated.

Alshammari et al. [8] presented a mobile app principles design for the smart home in terms of usability and attracting more users. The authors present 19 usability principles and an evaluation checklist. For future work, they want to incorporate these principles with machine learning. They did not evaluate their proposal and it do not address the specific needs of people with disabilities.

Leporini and Buzzi [101] created 5 general recommendations for designers and developers of home automation and remote control systems in order to enhance accessibility and usability for the blind user. They mapped these recommendations during an online survey and face-to-face interviews they performed with blind Italian users to collect its expectations and habits regarding home automation technology.

Buzzi et al. [31] tested Fibaro[1], a popular residential remote control system, as a case study using screen reader interaction. They configures Fibaro to remotely control

[1] https://www.fibaro.com/pt/

sensors and devices installed in the house of one of the authors. The results indicate that accessibility and especially usability need to be improved to make interaction easier and more satisfying for blind people. They present some suggestions to help developers design more accessible remote control systems user interfaces.

Pyae and Joelsson [139] conducted a web-based survey to investigate usability, user experiences, and usefulness of the Google Home smart speaker. Although participants think Google home is a usable and user-friendly device, the participants also reported a number of usability challenges. This study did not include PVI.

Vacher et al. [170] presented an experiment with seniors and PVI in a voice-controlled smart home using the SWEET-HOME system. The system uses Automatic Speech Recognition and Markov Logic Network. The system was tested in a controlled environment with 6 seniors, and 5 PVI. When a vocal command is detected and, according to the context (e.g., user's location), the system generates a home automation command to turn the light on, close the curtains, or emit a warning message through a voice synthesizer (e.g., "be careful, the input door has remained open"). To assess the system they performed semi-directed interviews and sessions in which each participant was alone in an apartment and had to interact with the system following predefined scenarios. This way, they evaluated the user's interest in their proposal, and the accessibility, usefulness, and usability of the system. The rigid grammar used for generating voice commands was among the main complaints. Some people simply wanted a different pattern for efficiency, while some others were looking for more natural speech. Another commonly reported problem was the fact that the system never indicated whether it understood a command or whether the command was completed.

Ennis et al. [58] described a solution to assist older people to live independently within their home or care home. The solution consists of a custom-built cabinet containing a smart mirror and medication tracking shelves. They connected an Amazon Echo to allow the user to vocally interact with the solution. To evaluate the developed solution, they performed an usability test with a group of 8 people consisting of care home staff and family members from people resident at a care home, to determine how elderly people would feel using a solution like this. They asked each participant to fill in complete a usability questionnaire. They have highlighted several limitations in using the commercial off the shelf voice assistants. In particular, the most apparent limitation is that Amazon's Alexa cannot proactively speak, in other words, the user must initiate the conversation.

Stephanidis et al. [165] identified seven HCI grand challenges in development of AmI. The challenges identified were: (1) Human-Technology Symbiosis; (2) Human-Environment Interactions; (3) Ethics, Privacy, and Security; (4) Well-being, Health, and Eudaimonia; (5) Accessibility and Universal Access; (6) Learning and Creativity; and (7) Social Organisation and Democracy.

Table 7.1: Related work summary of Multi-agent in ambient intelligence

Ref.	Technologies	Features	Evaluation with end-users
Fernandes et al. [59]	Sensors Kinect Agent	Avoid a possible obstacle at home	No
Sernani et al. [159]	Jason Jade Fipa ACL Database	Monitor health conditions and control the environment	No
Fraile et al. [64, 63]	Fipa ACL SOAP protocol	Alerts and warnings, such as Remembering to take medications, location and movement control	Yes(*)
Fiol-Roig et al. [61]	Intelligent Agent Sensors Domotic devices	Health care, control devices, needs of accommodation of the user (light level, temperature, blinds, windows, etc.), house security, informs about the goods available and those exhausted in the house, such as food or medication, and preferences and scheduling.	No
Our approach	JaCaMo Dialogflow Cloud vision Sensors	Environmental control, Location, Entertainment	Yes

Legend: (*) Elderly and disabled people.

7.4 RELATED WORK SUMMARY

In this section, we present a summary of the related work previously presented. Table 7.1 shows a related work summary about multi-agent in ambient intelligence. We have compared the technologies used, the implemented features, and if there was an evaluation with the end-users. Some of the features brought by the authors are similar to what this thesis addresses. However, none of the publications have all the features of this thesis. Mainly, in the presented architectures, they did not add forms of interaction in which the users could make requests to the system. In addition, a significant differential of our work is the use of chatbots and the use of the Portuguese language. Furthermore, the publications did not evaluate solutions for the visually impaired.

Table 7.2 presents a related work summary focusing on Ambient intelligence for people who are visually impaired. These publications show approaches that use general techniques. However, the publications [149, 65, 66, 32] presents only tool design without implementation. These publications also have features similar to this thesis proposes. However, none of the publications have all the features we propose. In addition, they present different technologies, and most have not been evaluated by people who are visually impaired.

The papers related to HCI and ambient intelligence, have presented guidelines for ambient intelligence [113, 8, 101], and evaluation of usability and accessibility of some environment control tools [31, 139]. In addition, they explored forms of interaction using speech recognition [170, 58]. Varcher et al. [170] have similarities to our approach because they have vocal orders and some similar features, but the architecture they used differs from ours. Also, our approach is different because it is in Portuguese.

Table 7.2: Related work summary of Ambient intelligence for people who are visually impaired

Ref.	**Technologies**	**Features**	**Evaluation with end-users**
Rizvi et al. [149]	Android Application, Global System for Mobile (GSM), SMS services, Bluetooth, and voice application	Turning on/off the devices (TV, fan, light)	No
Freitas et al. [66, 65]	Raspberry Pi boards, motion sensors, cameras, smartphone, and a central server	Monitors rooms and issues a warning whenever it detects a potential hazard	No
Buzzi et al. [32]	Web interface	Checking which devices /sensors are on/off; Turning on/off the devices/ sensors; Getting an overview of information about the home/room/device status	Yes
Rajan et al. [143]	Smartphones, Accelerometer, Eye blink detection, Voice Recognition, Smartphone Gesture Detection	Control television, light, and sensor-controlled sliding doors	No
Ye et al. [179]	Single 3D camera for pose estimation and object detection	Perceive its surroundings and provides navigational information to its user	No
Vacher et al. [172]	Speech Recognition	Turning on/off devices; identify the speaker; and Provides emergency call.	Yes (*)
Hudec and Smutny [80]	Neural network	Recognition of approaching people, alerting to other household members' movement in the flat, work on a computer, supervision of (sighted) children, cooperation of a sighted and a blind person (e.g., when studying), control of heating and zonal regulation by a blind person	Yes
Hudec and Smutny [81]	Neural network	Alerts the person with blindness to movement inside and outside the house; Sounds are activated by movement in the individual parts of the flat where the sensors are placed (e.g. hallway, kitchen); Recognises a scene of the hallway door being left open; Speech synthesis to inform them about current temperature and uses local and short term meteorological data available online; and recognises an outdoor scene of increased canine activity, which it announces with the respective notification sound	No
Campos et al. [37]	Deep learning techniques (YOLO)	Object recognition in the video	No
Ando et al. [11]	Haptic Cane; Distance measurement by ultrasound sensors.	Provide the user with information on the presenceof obstacles inside the environment (hapic cane)	No
Mengoni et al. [111]	Multisensory shower, Open-Source object-oriented programming language; Arduino	Control a multi-sensory shower	Yes
Vacher et al. [171]	Automatic Speech Recognition and Markov Logic Network	Vocal orders to turn the light on or off, open or close blinds, ask about temperature and ask to call his or her relative.	Yes
Jafri et al. [85]	RFID-based, visual-tag, and computer vision	Detecting and recognising objects in their home environment	No
Kyriazanos et al. [95]	RFID, ontology, SQL, Object Tracking Information, and Location Determination Algorithms	Medication and medicine related information and services; health monitoring; finding their medication and other personal objects in indoor environments.	Yes
Our approach	JaCaMo, Dialogflow, Cloud Vision, Arduino, sensor	Environmental control, Location, Entertainment	Yes

Legend: (*) use only dataset.

8. CONCLUSION

Throughout this thesis, we show that the theme of ambient intelligence has been gaining attention in recent years. This theme has been a challenge in the area of human-computer interaction, since currently interaction is no longer performed only through the graphical user interface, but through gestures or voice, for example. Furthermore, these environments require an advanced control system such as Homer, which is among the contributions of our work.

Our main objective in this thesis was to *determine how AmI interfaces can be made more suitable for the interaction with users who are visually impaired.* The thesis puts forward an approach based on multi-agent systems and its potential is demonstrated by a prototype. We responded to this objective through our specific objectives:

- Identify the needs of people who are visually impaired, which could be supported in an Ambient Assisted Living. In Chapter 3 we present our extensive research that featured a survey to identify the PVI needs, which was published in [124], and we interviewed domain experts. Also, we conducted an interview to deepen the data collected in the first survey. As a result, we identify 17 main features, the type of interaction, which devices to use, and the autonomy level necessary in the system.

- Identify the resources and guidelines used in ambient intelligence design. In Chapter 4 we present two investigations into the literature. In the first, we performed a mapping study to identify the techniques, technologies, architectures, methodologies, features, and evaluations used in AmI [126]. In the second, we performed an systematic literature review to identify guidelines to improve user interaction with AmI systems and identified 10 guidelines [125]. From these studies, we performed our first design alternative that was evaluated with a visually impaired user.

- Design a multi-agent system taking into account the needs of PVI and the guidelines to improve user interaction. In Chapter 5, we present our approach of a MAS to assist PVI at home, which the part of the integration between Dialogflow and JaCaMo was published in [57]. We included in this approach six main tasks that the users identified. Regarding the design, we consider the main features and guidelines studied. Homer, our approach, contains the following features: find objects, find a specific object, Identify when objects are out of the usual places, identify whether the environment light is on or off, and entertainment for solitude (i.e., free conversation, jokes, and inform the weather). Homer can be easily extended to include new features and technologies.

- Evaluate the interaction of people who are visually impaired with the multi-agent system. In chapter 6, we describe two evaluations of the approach performed. The first evaluation with 7 HCI specialists and the second one with 7 users who have visually impaired. We understand that Homer respects usability, accessibility, natural interaction, features, and satisfaction criteria with these evaluations. However, improvements and new features were identified. For example, most users think it is essential that the AmI system recognise smaller objects and object colors. Also, the voice system can be configured.

8.1 Challenges and Limitations

Regarding the limitations of this work, we used a single camera in the environment. Thus, the information obtained in the object location feature had no depth. This means that the information was not highly accurate, and we were not able to give information such as if one object was on top of another, or under another, for example. The use of Dialogflow, can also be considered a limitation, as it was only possible for the user to make requests; the system could not talk to the user without receiving a request. Thus, it was not possible for the system, for example, to remind the user of something or, upon identifying a change, inform the user.

Another limitation was the evaluations carried out in Chapter 6; we could not carry out the evaluations as planned, observing the user's use and allowing the specialists to used the application. Despite that, we believe that we could obtain good results in the evaluations, but further evaluations are needed. Still related to the evaluations, the online evaluation carried out with users who have visual impairment was a very challenging experience. For example, users having to send photos and the differences that exist in users' smartphones such hardware configuration and software versioning. To overcome these challenges, we are available to users on Whatsapp to support the installation and configuration of Homer on their smartphones.

8.2 Future Work

During the development of this thesis, we identified future directions arising from the results and their limitations, which may allow future work to increase knowledge on this theme. One of the directions to follow would be the integration of more sophisticated communication in the developed work, such as, for example, the use of argumentation. Thus, arguments could be built that support information offered to the user, or even arguments that support decision-making (and other mental attitudes of agents), providing them when requested. Argumentation is already a technique known for supporting explainable AI, with some advances in the area of multi-agent systems [129, 6].

An example of using argumentation would be, if the user requests for something like "are you sure this is this object?" (or position, etc), there could be reasoning patterns for instantiating arguments such as: "the object has <characteristic Y> and <characteristic X>, normally objects <characteristic Y> and <characteristic X> are <Object>, so I recognise it as <Object>".

Another interesting direction would be the use of ontologies. Today, Homer has a default message when the system does not understand what the user is asking for or there is no corresponding intent. In this sense, the knowledge requested by the user could be searched in ontologies, for example, Babelnet [118]. Sensor data can also be stored and searched in ontologies [7].

Also, in our future work, we intend to (i) implement all features identified during this work that has not yet been implemented; (ii) make improvements identified by users, such as the voice configuration and color identification module; (iii) also related to this, conduct training in cloud vision to identify more objects. We also intend to (iv) insert data privacy and security issues into Homer, (v) conduct more user evaluations, and (vi) extend Homer for use with other chatbots (e.g., Rasa, Watson, Luis), other image detection technologies (e.g., ROS, YOLOv3), and use more cameras and sensors. We also believe that the Homer could be evaluate with other types of users, such as elderly people.

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APPENDIX A – INTEGRATION OF MICRO-CONTROLLER BOARD AND SENSORS WITH HOMER

A.1 Components

- Essential:
  - EP32 (wifi microcontroller)[1]
  - Light Sensor Module[2]
  - Sensor DHT11 (temperature and humidity)[3]
- Connections:
  - 3 mini protoboards (for better organization)[4]
  - Jumpers to connect (wires)[5]
- Optional:
  - Micro USB Cable (Communication with computer to enter code on board)

A.2 Assembly

Fit components on protoboards and connect with jumpers (wires). Figure A.1 shows the connections and Figure A.2 shows the recommended protoboards organisation.

A.3 Installation

- Install Arduino IDE https://www.arduino.cc/en/software.
- Follow the Site Instructions to use ESP32 in IDE: https://www.fernandok.com/2018/09/instalando-esp32-no-arduino-ide-metodo.html
- Go to Tools > Manage Libraries (Figure A.3)

[1] https://www.eletrogate.com/modulo-wifi-esp32-bluetooth-30-pinos
[2] https://www.eletrogate.com/modulo-sensor-de-luminosidade-ldr
[3] https://www.eletrogate.com/modulo-sensor-de-umidade-e-temperatura-dht11
[4] https://www.eletrogate.com/mini-protoboard-170-pontos
[5] https://www.eletrogate.com/jumpers-macho-macho-40-unidades-de-20-cm

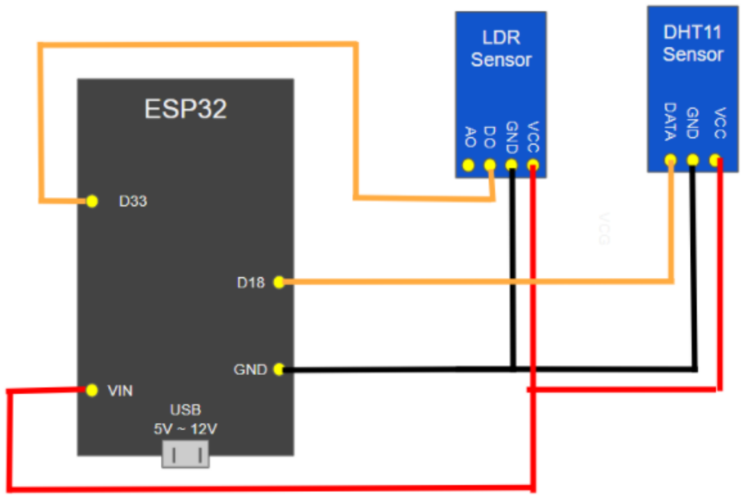

Figure A.1: Connections

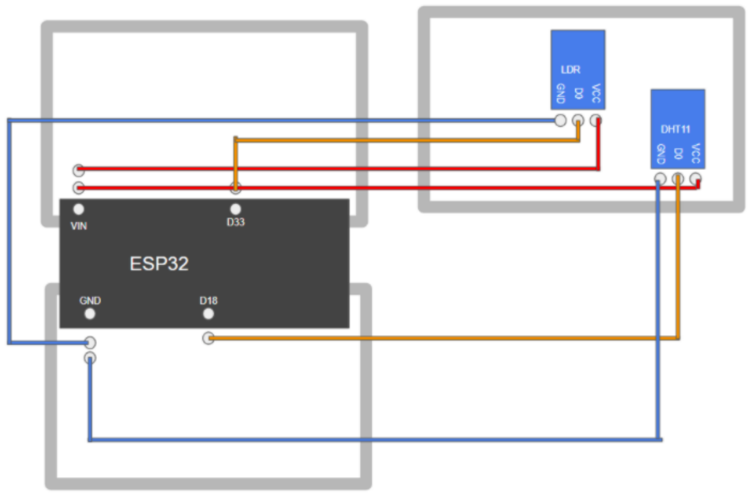

Figure A.2: Recommended organisation with protoboards

- Search and install the following libraries:
  - Adafruit Unified Sensor
  - aREST
  - DHT sensor library

A.4 Setting up the code and entering it into ESP32

- Go to Tools > Board and select ESP32 Dev Module (Figure A.4)

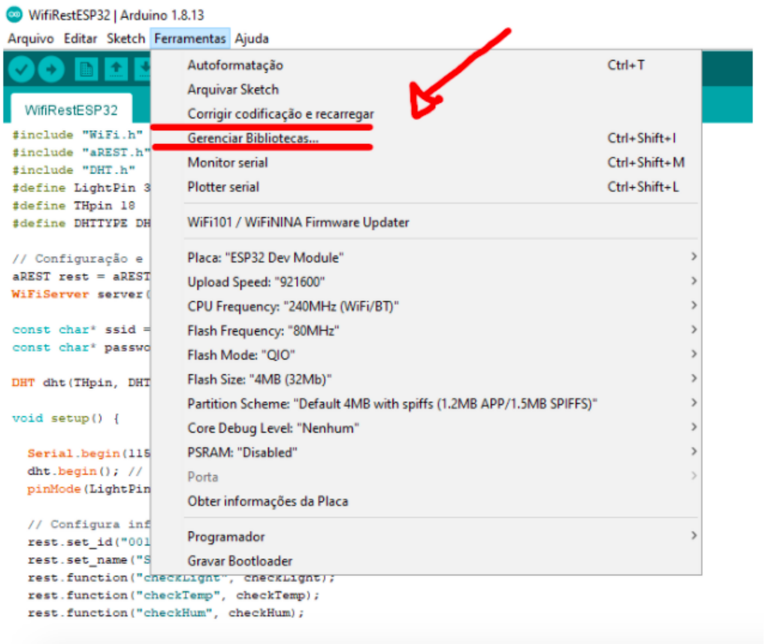

Figure A.3: Arduino - Manage Libraries

- Go to the SSID and password constants in the `WifiRestESP32.ino` file in Homer to replace their values with the name and password of the wifi network ESP32 should connect to (Figure A.5).
- With the ESP32 already connected to the computer, click on the arrow to load the code to the board (Figure A.6).
- If no errors occur, the output of the IDE should behave similarly to Figure A.7 or Figure A.8 (If you have any errors, see the last page of the document):

A.5 Making requests and integrating with Homer

- After the code is loaded onto the board, click on the magnifying glass icon (Figure A.9) in the upper right corner to open the board communication terminal.
- If the wifi connects correctly, the terminal should display a message indicating the local IP of ESP32 (Figure A.10).
- Requests can already be made; you can use your browser to test, for example: <IP_ESP32>/checkLight (Figure A.11).
- The terminal will print to confirm the requests (Figure A.12).
- Now just insert the ESP32 ip in the `CheckLights.java`, `CheckRoomTemp.java`, and `CheckRoomHum.java` classes to integrate with Homer (Figure A.13).

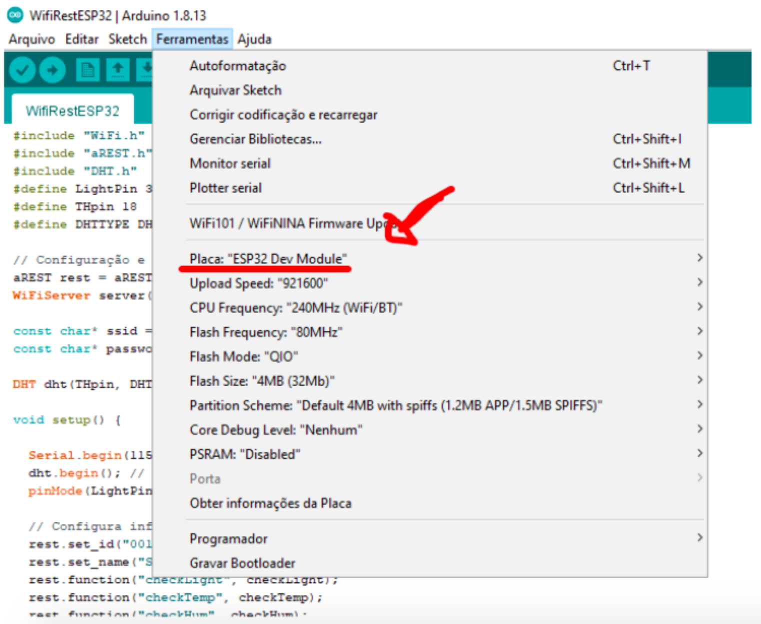

Figure A.4: Arduino - ESP32 Dev Module

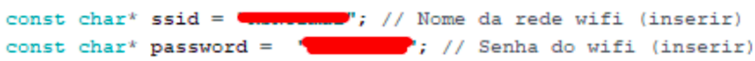

Figure A.5: User and Password

- You may encounter the following error (Figure A.14). To fix, when the “Connecting ...” appears, press the Boot button on the board and hold it until charging starts normally.

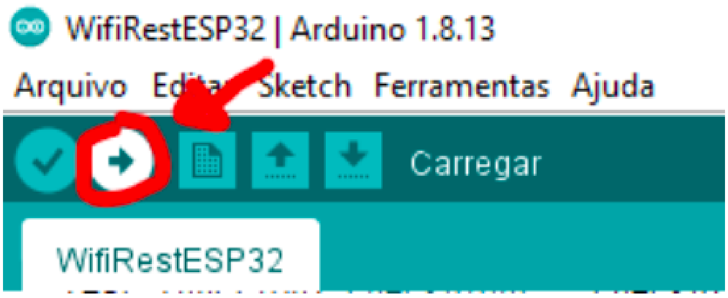

Figure A.6: Arduino - load the code to the board

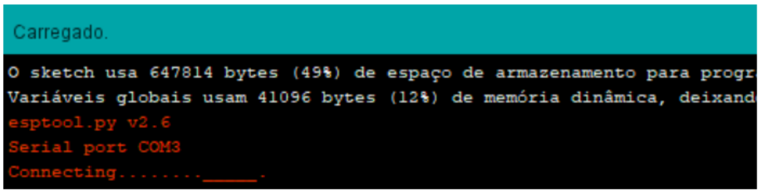

Figure A.7: Arduino - Error example 1

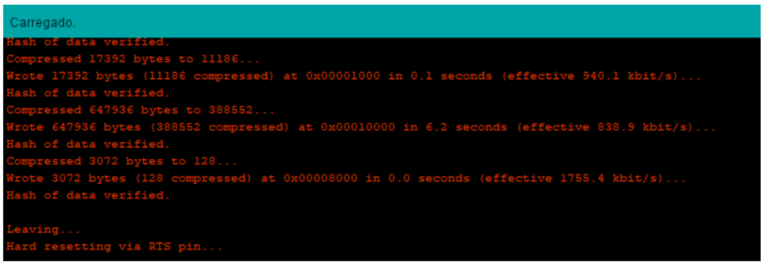

Figure A.8: Arduino - Error example 2

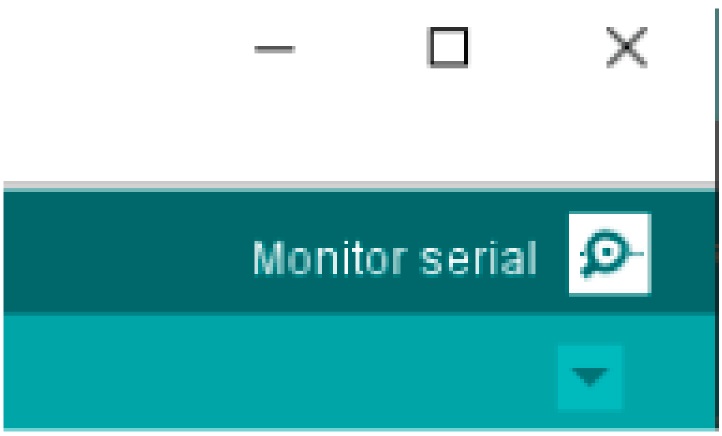

Figure A.9: Arduino - Magnifying Glass Icon

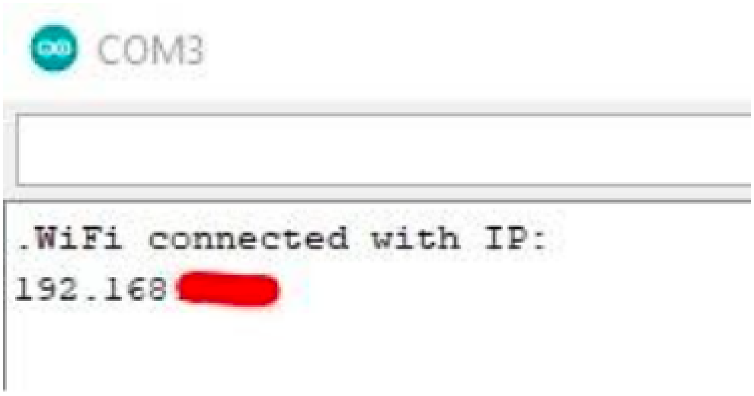

Figure A.10: Connection

Figure A.11: Request

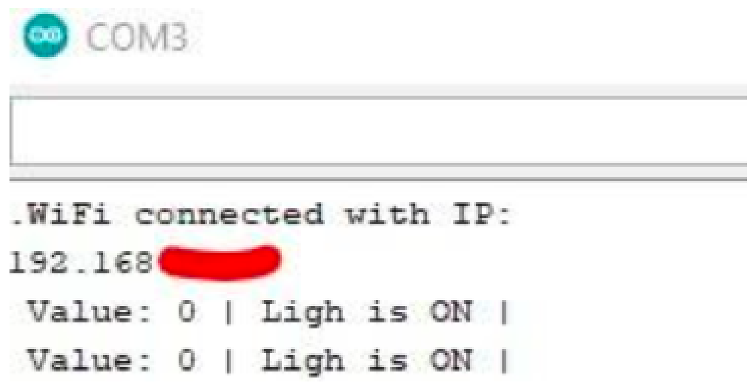

Figure A.12: Print requests

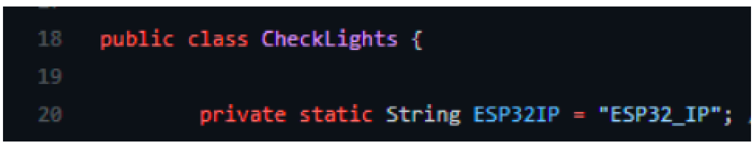

Figure A.13: Homer - Insert IP

Figure A.14: Common error

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