

# Solutions focused on High-Level Assistive Technology: Perceptions and Trends observed from a Systematic Literature Mapping

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## Resumo

### Abstract

This work presents the results achieved from the application of the Systematic Literature Mapping (SLM) methodology on the theme: Development of High-Level Assistive Technology (AT) Solutions. The article details the execution of this research technique to map the state-of-the-art on the proposed theme. Based on the obtained results, the paper proposes a taxonomy of the works, characterizing them according to the type of proposed solution and functionalities available in the applications. Additionally, the article highlights the architectural and technological aspects found in these studies. Finally, the paper discusses the main trends perceived throughout this analysis, as well as identifies potential gaps to be explored as a sequence of this research.

**Keywords:** *Assistive Technology; Human-Computer Interaction; Software Engineering; Frameworks; Prototypes; Systematic Literature Mapping*

## 1 Introduction

Technological advances in several knowledge areas enable the development of hardware and software solutions that aims to simplify people with specific needs' lives. Among the users' profiles that can benefit from this scenario, the one formed by people with physical disabilities compose a universe directly favored by these advances. According to the report by the World Health Organization, more than a billion people have some kind of disability worldwide (WHO, 2017). This number reveals the existence of a considerable part of the population who have difficulties in performing simple daily tasks properly, such as eating, communicating, cleaning, working or even moving.

Specifically in Brazil, according to the 2010 census by the Brazilian Institute of Geography and Statistics, 23.9% of the Brazilian population declared having at least one type of disability. Of these, 7% reported some type of motor impairment, ranging from mild restrictions such as tremors or lack of mobility of a limb, to more severe problems such as amyotrophic lateral sclerosis or tetraplegia, for example (IBGE, 2010). Assistive Technology (AT) is the research area concerned with the development of devices and applications that seek to improve the quality of life of people with physical or cognitive limitations (DRNP, 2012).

The AT term itself is relatively new, and its definition is still maturing. However, the use of AT resources is not recent, since it refers back to the beginnings of human history. At that time, the adoption of mechanisms to assist people's daily lives could be observed in the use of primitive artifacts, such as tree branches, used as walking sticks, for example. On the other hand, the emerging preoccupation with assistive issues must be credited to the more contemporary thoughts that focus on the inclusion of all individuals in a society where each individual should have the right to participate actively

in it.

Formally, the term originates in 1988, defined in the United States of America as a legal element within that country's Public Law 100-407, which makes up the American Disabilities Act (ADA). These laws regulate the rights of disabled citizens in the United States, providing a legal basis for public funds to purchase the resources they need. At the European level, AT is often replaced (or used as a synonym) for "Technical Aids" or "Assistive Technologies". Galvão Filho (2009) specifically highlights the EUSTAT (Empowering Users Through Assistive Technology) project, in which the term "Support Technologies" has the following definition:

*"The term Support Technologies encompasses all products and services capable of compensating for functional limitations, facilitating independence and enhancing the quality of life of people with disabilities and the elderly".*

In Brazil, the concept of AT is even more recent. In the Brazilian context, Bersch (2017) states that AT is a research area that aims to provide greater independence, quality of life and social inclusion for the physically disabled, increasing the possibilities of communication, mobility, interaction with the environment, learning and integration with family, friends, and society. Thus, analyzing AT definitions around the world, it is possible to perceive that they all converge to one essential goal: improving the people's life quality by investing in processes, devices, or services that enhance these users' preserved skills.

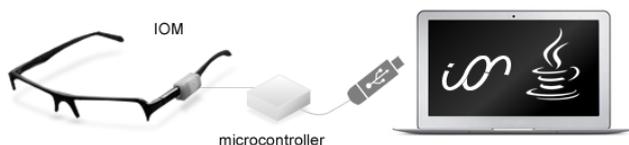
Researches related to AT have been producing solutions that aim to help or simplify people's lives. Prosthetics, wheelchairs, optical glasses, television legends, hygiene aids, assistant robots, computer access tools, among others, are examples of products with an assistive nature. According to

SEABRA and MENDES (2009), several classifications that can be used to categorize AT types. One of them considers the cost and the resources used, dividing them into three levels:

- Low-level AT - simple, non-electric and low-cost devices;
- Medium-level AT - devices that use electricity, but without computational resources; and
- High-level AT - applications, services, or devices that use specific software and/or hardware to achieve their goals.

The use of high-level AT, specifically, brings together several fields of study, depending on the designed application. Areas such as Universal Accessibility (UA), Decision Support Systems (DSS), Ambient Assisted Living (AAL) and Human-Computer Interaction (HCI) potentialize a new generation of AT to improve the lives of people with physical limitations (Alonso, 2015).

An example of this type of solution is the IOM (an acronym for Interface Óculos Mouse, in Portuguese), a project that develops a wearable device with sensors, which implement an interface to computer access, using data captured from head movements (Machado, 2010; Rodrigues et al., 2016; Machado et al., 2019). **Figure 1** highlights the IOM operating scheme.



**Figure 1.** IOM basic operating scheme. Source: Cardoso et al. (2018).

However, to consolidate and effectively adopt a high-level AT, such as IOM, specific applications and development frameworks must accompany it. In this scenario, this paper's primary goal is to identify the main high-level AT-based solutions, aimed at people with motor limitations, developed by the scientific community. Besides mapping this research area, this work also investigates trends concerning the main development methods, technologies, and practices used to design software applications of this nature.

To achieve these goals, a bibliographical review was executed on this topic. Thus, this paper presents the Systematic Literature Mapping (SLM) about this theme, highlighting all process stages. The SLM focuses specifically on applications for people with motor limitations, but with have preserved head movements. Based on the observations and analysis of the scientific paper set retrieved by the SLM, a taxonomy for classifying the high-level AT solutions found during the mapping is proposed. Finally, the paper answers three SLM research questions besides highlighting a series of technological and architectural characteristics perceived in the studied works.

Thus, this paper's main goal is to map this research area to identify relevant characteristics in the AT development process, in academia. The SLM outcomes will serve as a foundation for understanding the state-of-the-art of this research area. Besides that, the survey's results will guide the development of an AT-based specific framework for the IOM device, as a case study.

The paper is organized as follows: Section 2 details the SLM's organization and execution. Section 3 presents the proposed taxonomy. Section 4 highlights main characteristics, aspects and technological trends, based on the works' analysis. Section 5 discusses and answers the three SLM research questions. Finally, Section 6 presents the paper conclusions and indicates the project's next steps.

## 2 Systematic Literature Mapping

To map the state-of-the-art in the work's research area, the SLM methodology was used. The SLM performs a series of steps to generate the map of the area, that is, a set of works that builds a broad prospection of the researched theme (Petersen et al., 2008). The following subsections detail the SLM protocol used in this work. The complete flow of SLM execution is shown in **Figure 2**.

### 2.1 Initial exploratory search

To complete the protocol properly, it is necessary to perform an earlier step, the search for a reference article. This phase's aim is to find, through simple exploratory research, a work related to the research topic to be investigated.

The idea is to use this study as a calibrator during the SLM protocol completion. As this step result, the following papers were entirely examined: Ossmann et al. (2014); Salnikov et al. (2014); Miesenberger et al. (2014); Neto et al. (2012).

The comparative analysis between these works resulted in the choice of Ossmann et al. (2014) as a reference article for this SLM. This paper introduces AsTeRICS (Assistive Technology Rapid Integration & Construction Set), a development platform that enables the creation of adaptable AT solutions through reusable software components. Thus, it was considered more complete when compared to the other papers, since it allows the AT applications design in different contexts of use, through the reuse of software structures.

### 2.2 Filling the SLM protocol

The SLM protocol initially requests the definition of several elements about the research to be performed. The first one is the main goal of the bibliographic review. For this mapping, such aim was defined as:

*"Identify and characterize the state-of-the-art on AT-based solutions for people with motor limitations."*

By reaching this objective, it is expected to ground the work conceptually, allowing a broad view of this area of research. In addition to providing this conceptual basis, surveying these perceptions and trends will further assist in the design of high-level AT solutions focused on the IOM interaction device.

Due to the diversity of limitations that can affect individuals physically or cognitively, it was necessary to restrict the focus of this work. Thus, the specific application domain covered by this paper concerns AT solutions for users with preserved head movements. This choice was driven by two main motivations. First, the fact the head is the last part of the body that loses its mobility (Mulfari et al., 2015a). Also,

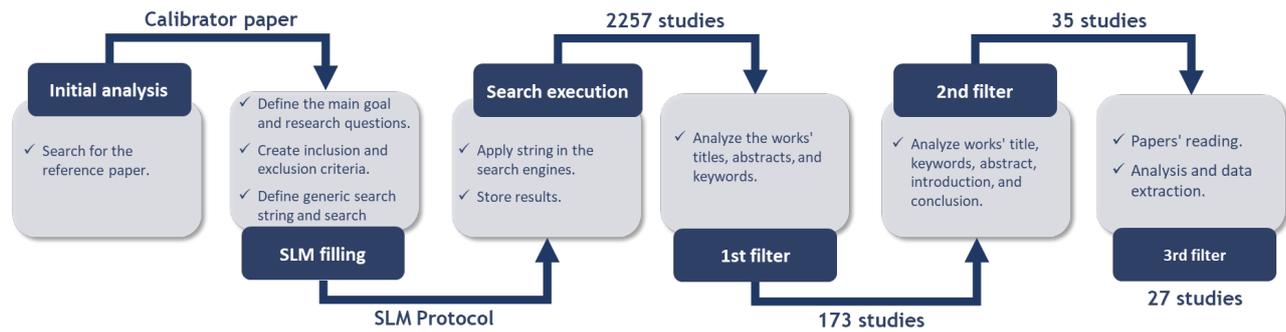


Figura 2. Systematic Literature Mapping's flow.

losing functional capacity, specifically in terms of mobility, is a natural factor throughout people's lives (da Cruz and Emmel, 2012; Nunes et al., 2010). The second aspect, as previously highlighted, is related to the IOM project, which aims to develop an alternative interaction device, aimed at people with motor limitations in the upper limbs.

Following the protocol, it is recommended that at least three researchers be involved in SLM to ensure the quality of the results. In this context, the mapping, which lasted six months, covered three research axes:

1. *AT-based Application Developments;*
2. *AT-based interfaces;* and
3. *Evaluation Methodologies for AT Solutions.*

SLM's main objective encompasses these three research axes. However, each axis focuses on different aspects described in the works retrieved by SLM. This paper specifically highlights the first subject, for which three research questions were elaborated:

1. *How does scientific research present the development and evaluation of AT software that allows people with physical limitations to use computational applications?*
2. *Are there software development frameworks specifically focused on AT? and*
3. *What does characterizes a solution for software development as AT-oriented?*

Considering the SLM main goal, the three research questions, and using the reference article as a calibrator, the protocol was completed. Firstly, the following search engines have been chosen to retrieve the SLM's studies:

- IEEE Xplore Digital Library;
- ACM Digital Library;
- Springer; and
- Science Direct.

Then, the following generic search string was elaborated to retrieve the initial articles set:

((“human computer interaction”OR HCI) AND (“assistive technology”OR accessibility) AND (motor OR physical OR impairment OR disability) AND (framework OR platform OR API OR evaluation OR test OR guidelines OR protocols))

This string was adapted to the specific syntax of each of the search engines used. The period covered by the mapping was between 2012 and 2017. It is noteworthy that date information is not part of the search string, as this filter is set separately in these search engines.

To complete the protocol, exclusion, and inclusion criteria were defined to be applied in the SLM filter stages. The following criteria were used for exclusion:

- Study published exclusively in medical area events or journals;
- Study published before 2012<sup>1</sup>;
- Abstracts, posters or articles with two or fewer pages;
- Duplicate works (retrieved by more than one search engine);
- Work-related only to non-motor deficiencies;
- Complete books; and
- Study related to seniors without motor limitations.

On the other hand, to add works to the partial set of studies, the following inclusion criteria were used.

- Study related to AT for computer accessibility; and
- Study published before 2012, but considered relevant.

The idea of applying these filters is to ensure results that are within a specific period, which deal with the development of assistive solutions aimed at people with motor limitations.

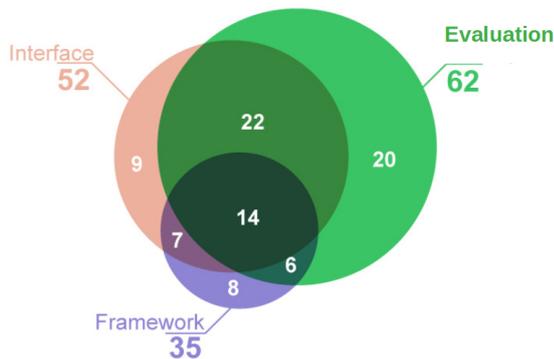
## 2.3 Running the SLM

The steps predicted in the process were executed, following the flow highlighted in **Figure 2**. In this way, the search execution step was performed, and, as a result, 2,257 bibliographic references were retrieved and stored. This article collection was then submitted to the first filter where a group of seven researchers analyzed the work's title, keywords, and abstracts, applying the exclusion and inclusion criteria previously established.

Applying the first filter resulted in a subset of 173 articles. These studies were submitted to the SLM's second filter. In this step, three expertise researchers analyzed title, abstract, keywords, introduction, and conclusions of the 173 articles. This step intended to characterize these studies in the three SLM's research axes. The three researchers' analyses were

<sup>1</sup>Even using this filter, some works before 2012 were retrieved.

crosschecked in discussions mediated by the group supervisor, resulting in the Venn diagram shown in **Figure 3**.



**Figure 3.** Articles grouped by research axis, after the second filter.

Specifically, concerning this article, we selected 35 works, identified as Framework in **Figure 3**. These papers were sent to the last filter, which consisted of fully reading and analyzing each of the 35 selected articles. This last filter resulted in 27 works that can be defined as the search area map. The next section explores these works, beyond presenting a taxonomy that classifies them according to their functionality and type.

### 3 SLM’s Taxonomy

The SLM articles’ analysis resulted in the proposition of two works’ classifications: Type of Solution and Applications’ Functionalities.

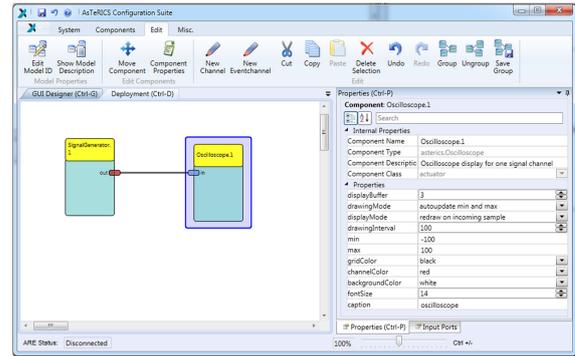
#### 3.1 Types of Developed Solutions

This classification groups the works according to the proposed software artifact. From this perspective, the studies were qualified as:

- Software frameworks: general and reusable proposals used to simplify application development; and
- Specific prototypes: solutions for special purposes. Used for validations or as case studies to solve individual problems.

In the universe of analyzed studies, four papers were categorized as Software Frameworks. Among these, AsTeRICS consists of a framework that uses concepts of prototyping through visual modeling, making feasible the development of AT solutions without the need for knowledge of advanced development techniques or even programming languages (Ossmann et al., 2014; Veigl et al., 2013). Considering the evolutionary process of building software frameworks proposed by Roberts et al. (1996), AsTeRICS is a visual programming tool, since it allows the generation of applications through visual components connection. **Figure 4** shows the configuration suite used to develop the AT-based solutions with AsTeRICS.

In turn, the ATLab (Miesenberger et al., 2014) and the GNomon (Aced Lopez et al., 2015) frameworks are solutions



**Figure 4.** AsTeRICS configuration suite. Source: Ossmann et al. (2014).

specifically designed for game development. Both have white-box framework characteristics since to develop applications through them, it is necessary to have reasonable knowledge about the operation and structure of their source code.

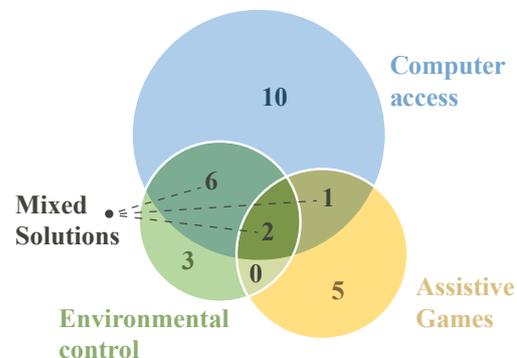
All other works retrieved by the SLM have developed specific prototypes, used for particular users or contexts. They were designed to solve individual problems, i.e. they are not intended to be reusable software frameworks applicable to different contexts or usage scenarios.

#### 3.2 Applications’ Functionalities

This classification divides studies according to their primary goals. From this perspective, the works were grouped in:

- Computer Access (CA): simplifies or allows access to the computer;
- Environment Control (EC): allows the management of the space where the user is inserted;
- Assistive Games (AG): provide games tailored to the special needs of specific user groups; and
- Mixed Solutions (MS): applications that can be used for more than one of the above purposes.

**Figure 5** highlights the distribution of the works retrieved, according to this classification.



**Figure 5.** Works grouped by functionalities.

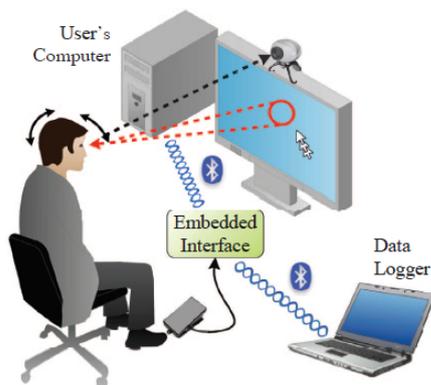
As can be seen, according to the SLM’s results, most of the works (ten papers) seek to enable or simplify CA, adapting devices and applications to overcome the problems caused by a specific disability, when using computers. Three studies describe solutions designed to work exclusively with EC. In turn, five of them are assistive games (18 in total). The nine

solutions are MS, where two apply to the three categories, one for AG and CA and the other five provide CA in conjunction with EC, totaling 27 studies retrieved by SLM. **Table 1** groups the studies considering this classification.

**Tabela 1.** Studies grouped according to functionalities.

Functionality	Studies
Computer Access	STTK (Salnikov et al., 2014), FHCI (Antunes et al., 2016), ETM (Lupu et al., 2013), Universal AT (Karpov and Ronzhin, 2014), IoT based AT (Mulfari et al., 2015a), Multimode prototype (Rantanen et al., 2011), DOSVOX Gyro - microFenix (Cruz et al., 2015), UserTracking (Martins et al., 2015), hBCI (McCullagh et al., 2013), Gaze-Based Interaction System (Galante and Menezes, 2012)
Environment Control	WPan (Paul et al., 2013), Fire Bird assistant robot (Tripathy and Raheja, 2014), SINASense (Manresa Yee et al., 2013).
Assistive Games	AT-based PS3 games (Ossmann et al., 2012), Beto in the forest (Scardovelli and Frère, 2015), Doce Labirinto (Cardoso et al., 2016), ATLab (Miesenberger et al., 2014), GNomon (Aced Lopez et al., 2015).
Mixed Solutions	MWiMT (Caruso et al., 2013), dTDS (Huo et al., 2013), SBC (Mulfari et al., 2014), Cloud-based AT (Mulfari et al., 2015b), SMARTUNIVERS (Aly et al., 2015), Activelris (Levy et al., 2013), AID (Lin et al., 2017), AsTERICS (Veigl et al., 2013; Ossmann et al., 2014).

Among the works focused on CA, the FHCI (Facial Human-Computer Interface) is a solution that helps people to use computers without using hands (Antunes et al., 2016). It is based on a control scheme that combines the current cursor position on the computer with the user's visual intent. The FHCI interface also records various usage data, besides supporting the adaptation of other sensors to simulate the buttons. FHCI contextual architecture is presented in **Figure 6**.



**Figure 6.** FHCI contextual architecture. Source: Antunes et al. (2016).

STTK (Speech-To-Text plus Kinect), is a multi-modal Natural User Interface (NUI) (Salnikov et al., 2014). It aims to improve computer access experience for users with motor disabilities in the upper limbs. The solution combines two types of data input: gestures and voice using STT (Speech-To-Text), TTS (Text-To-Speech) technologies, and gesture recognition.

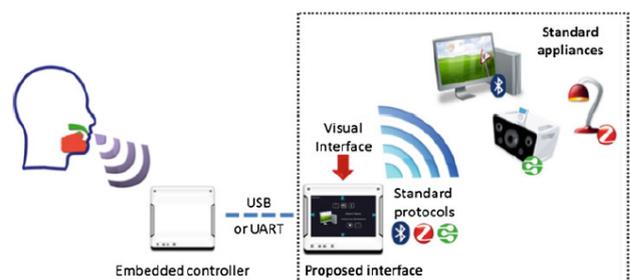
The ETM (Eye Tracking Mouse) is another work in this category (Lupu et al., 2013). It consists of a prototype that uses video glasses, webcam, and specific software running an eye-tracking algorithm. ETM allows the user to navigate its particular GUI (Graphical User Interface) just by moving their eyes. Following this research line, Rantanen et al. (2011) propose a solution that combines video-based eye tracking with eyebrow motion detection.

In turn, Martins et al. (2015) propose a multi-modal interface that uses MS Kinect to control the computer through head, eyebrows, or mouth movements, and voice commands. Finally, Galante and Menezes (2012) develop an application that uses eye-tracking for people with cerebral palsy. Its goal is that users can communicate by choosing symbols on a virtual card.

A conceptual model architecture for a universal AT is presented in Karpov and Ronzhin (2014). Its goal is to allow users with different disabilities to use the proposal through several interaction ways. Cruz et al. (2015) propose two software extensions using Brain-Computer Interface (BCI) through the Emotiv EPOC device. DOSBOX Gyro consists of an extension to navigate the DOSVOX GUI menus through head movements. The second extension is microFenix, an application that simulates mouse and keyboard actions to computer control from user-generated sounds or breaths captured by specific sensors.

Mulfari et al. (2015b) present an application that uses cloud computing to access AT-based software. The paper discusses the impact of using SaaS (Software as a Service) with web-accessible AT applications. In turn, Mulfari et al. (2015a) explore IoT (Internet of Things) concepts to use low-cost embedded systems to support interaction between users with disabilities and computers. The goal is to create AT-oriented solutions on embedded devices. As a study case, the paper details a prototype development, consisting of glasses adapted for people to control the computer without using their hands. McCullagh et al. (2013) propose a multi-modal system to control virtual environments. The solution, called hBCI (Hybrid BCI), combines sending EEG signals with eye-tracking interaction.

In terms of EC, Paul et al. (2013) present an environment control interface that can be controlled from different interaction methods, such as tongue movements. The application automatically discovers home appliances that understand wireless protocols (Zigbee and Bluetooth) in the environment, presenting services supported by these devices in its own GUI. **Figure 7** presents the solution architecture.



**Figure 7.** Device control architecture. Source: Paul et al. (2013).

SINASense is technological support to provide its users

with greater autonomy when interacting with their environment (Manresa Yee et al., 2013). It provides sensory stimulation based on the user's movements, detecting and tracking movements through a webcam and a tape placed on the user's hand. Tripathy and Raheja (2014) describe the development of an application to control a robot (FireBird V) as an assistant for people with disabilities. The robot receives commands from EEG signals, triggered by the EPOC device via a specific GUI.

Concerning works categorized as AG, for example, there are solutions like the *Doce Labirinto* (Sweet Labyrinth, in Portuguese). It consists of a game that challenges the player to move the Sphero robot to the maze's end, using head movements (captured via IOM device) to do it (Cardoso et al., 2016). **Figure 8** presents *Doce Labirinto*'s usage context.



**Figure 8.** *Doce Labirinto*'s usage scenario. Source: Cardoso et al. (2016).

In turn, Ossmann et al. (2012) present an application developed with the AsTeRICS framework to adapt PlayStation 3 (PS3) games to people with disabilities. To this end, the paper describes a model that allows controlling PS3 games via the OSKA (On-Screen Keyboard Application) keyboard. As a case study, the article explores two PS3 adapted games to use the developed control.

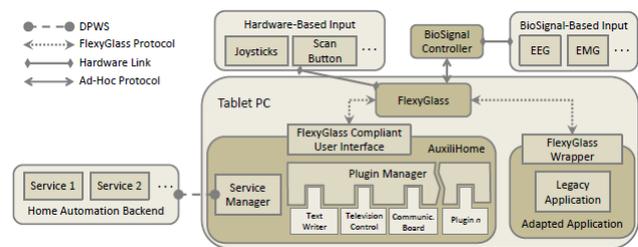
Scardovelli and Frère (2015) highlight an AT-oriented solution composed of a webcam and a 3D computer game. The game, called "Beto in the Forest", is monitored by a supervisor system running in the background. This system maps user actions via webcam so that, when movements are captured, commands are triggered in the game.

In this category, it is also worth mentioning the two works previously described in **Section 3.1** as development frameworks. The articles describing GNomom (Aced Lopez et al., 2015) and ATLab (Miesenberger et al., 2014) solutions highlight games' development to validate their respective reusable software structures. Finally, in relation to mixed solutions, articles using the AsTeRICS framework are case studies that cover prototyping in the three categories defined by the taxonomy (Veigl et al., 2013; Ossmann et al., 2014).

Lin et al. (2017) feature AID (Adaptive Interface Design) a multi-modal interface for people with arthritis. It uses a special glove designed to measure finger movements and grip strength. In addition, the eye-tracking technique is also used for alternative virtual environment interface. It provides an

environment to encourage rehabilitation exercise. This paper falls into the CA and AG categories.

The other works related to the AC and EC categories. In this context Caruso et al. (2013) introduce My-World-in-My-Tablet (MWiMT), a modular user-centric platform that supports two types of data inputs: hardware-based and bio-signal based. MWiMT uses a tablet to run its core components: *AuxiliHome* - Used for home control through accessible from a specific GUI; and *FlexyGlass/Adapters*- software module that makes the input type transparent to the controlled application. **Figure 9** highlights the MWiMT's architecture.



**Figure 9.** MWiMT's architecture. Source: Caruso et al. (2013).

In turn, Mulfari et al. (2014) propose a tool that acts as an adapter between particular assistive equipment used by users and computers. Huo et al. (2013) present the dTDS (dual-mode Tongue Drive System) to expand the TDS (an interface that works through tongue movements) by adding the use of voice commands to it.

Aly et al. (2015)'s paper introduces SMARTUNIVERS, an interface for people with different physical disabilities, designed to integrate them into the work environment. Levy et al. (2013) describe ActiveIris, an accessibility toolkit that uses a webcam to track the eyes of its users. Through its interface, ActiveIris provides computer access, facilitating access to social networks, smartphones, and Internet browsing, as well as providing options for environment control.

It was possible to realize that, despite the classification by proposed functionalities, all the works deal with an intermediate interface that mediates the interaction between user and application. This interface usually has two main purposes:

- Perform or assist the basic functions of the solution itself; and
- Configure the proposed AT-based application.

Thus, it is feasible to state that all proposals, at some point, interact with the computer, even if through a third user who sets up the application. Finally, **Table 2** highlights both the devices and the main forms of interaction used in AT solutions characterized as prototypes according to the proposed taxonomy.

## 4 Structural aspects and technological trends

Besides classifying the solutions in the SLM, the complete analysis of the recovered works allowed extracting relevant data about them. This made it possible to draw a panorama of the researched area, identifying some tendencies, techniques,

**Tabela 2.** Prototypes' characteristics.

Study	Device	Interaction type
Salnikov et al. (2014)	MS Kinect.	Voice. Gestures.
Antunes et al. (2016)	Wireless embedded interface.	Face tracking. Sensors. Mechanical control.
Lupu et al. (2013)	Webcam, video glasses.	Eye tracking.
Karpov and Ronzhin (2014)	Camera. Microphone. Adapted headsets.	Audio and video recognition. Head movement.
Mulfari et al. (2015b)	According user's AT.	AT dependent.
Caruso et al. (2013)	Tablet, BCI2000.	Adapted controls. Bio-signs.
Rantanen et al. (2011)	Glasses adapted with CMOS cameras.	Eye tracking. Eyebrow movements.
Cruz et al. (2015)	EPOC.	Voice. Bio-signs.
Huo et al. (2013)	Headset. Sensors. Microphone.	Tongue. Voice.
Martins et al. (2015)	MS Kinect. Sensors.	Head/eyebrow/-mouth movements. Voice.
Paul et al. (2013)	Specific micro-controller. LCD Module.	Tongue. Touch.
Mulfari et al. (2014)	Specific micro-controller. Raspberry Pi.	AT dependent.
McCullagh et al. (2013)	BCI2000, LED for EEG (SSVEP). Webcam.	EEG. Eye tracking
Aly et al. (2015)	Conceptual.	Voice. Gesture.
Tripathy and Raheja (2014)	EPOC, FIRE BIRD V.	EEG.
Mulfari et al. (2015a)	Specific micro-controller. Glasses with accelerometer. Arduino board.	Head movements.
Ossmann et al. (2012)	PS3. AsTeRICS HID. I/O device. Wii mote. Kinect.	Head/mouth/eyes movements.
Scardovelli and Frère (2015)	Webcam. Adapted device.	Gestures.
Lin et al. (2017)	Adapted glove.	Fingers movement. Eye tracking.
Galante and Menezes (2012)	SMI. Head device. Mechanical device.	Eye tracking. Preserved motor movement.
Manresa Yee et al. (2013)	MS Kinect. Webcam. Coloured ribbon.	Hand/arm movements.
Levy et al. (2013)	Smartphone. Webcam.	Eye tracking.
Cardoso et al. (2016)	IOM, Sphero.	Head movements.

and technologies most used. The next subsections highlight these trends.

## 4.1 Diagrams and models

In terms of modeling and design, the works use different strategies to represent their overall architecture. In this sense, two types of diagrams appear frequently: Context Diagrams and Layer Component Diagrams. The use of the first diagram makes sense once many of the works use design and development strategies based on UCD (User-Centered Design) concepts. In this way, providing a perspective of using the application, from the user point-of-view, allow contextualizing all the elements and actors involved in the interaction.

On the other hand, the works that represent their structures employing schemes of components in layers, use levels of abstraction that vary according to the specificity that they want to detail. Thus, this representation is widely used, simplifying aspects such as general functioning and communication between the components of developed AT applications. The third possibility of representation is explored in Caruso et al. (2013), where a group-by-container view is adopted.

## 4.2 Software architectures

Most of the works analyzed present architectural features based on the Client-Server model, dividing the structures into at least two layers of software. Exceptions are the projects that adopt Service Oriented Architecture (SOA) concepts in their design (Miesenberger et al., 2014; Caruso et al., 2013; Mulfari et al., 2015b; Paul et al., 2013).

Although some projects address their basic needs with Client-Server adoption, they can naturally evolve into service-based adoption. The maturation of some prototypes in market solutions may lead to the need for better structuring, to scale the solutions.

## 4.3 Perceptions about solution-user interactions

A trend towards the adoption of multi-modal solutions is easily observable since 56% of the analyzed works use at least two types of data entry in the applications. The motivations for using multi-modal interfaces found are:

- Enhancement: The second data input is used to refine the main data entry to improve the interaction quality; and
- Reducing fatigue: Alternative input aim at reducing fatigue caused by excessive movements required from the primordial interaction form of the solution.

In these cases, a clear feature in multi-modal solutions is using voice commands as the second form of interaction in applications.

Solutions that do not focus on the interaction itself, but that act as facilitators to use AT have also been found (Paul et al., 2013; Mulfari et al., 2014, 2015a). The idea behind these projects is to provide the infrastructure that allows a specific AT to be used by its users outside a previously configured

environment. In this sense, strategies for accessing an AT configuration from cloud services, for example, simplify the AT configuration process in a new environment.

Finally, considering the data output and feedback to users, applications usually adopt GUI as the main interaction way. Also, some projects use alternative data output, such as interactions through tangible interfaces, using robots, for example (Ossmann et al., 2014; Veigl et al., 2013; Cardoso et al., 2016).

#### 4.4 Technological trends

The technologies employed in the projects usually depend on the work team expertise or are linked to applications' characteristics. To reduce costs, most solutions use free tools and/or develop adapted devices. However, some works use proprietary libraries or frameworks, a practice that increases the final cost of the application, and limits the possibilities of innovation, since it is not always possible to customize or extend these tools.

Some trends have also been noted in using libraries and devices, such as the use of OpenCV for image capture and processing, and the adoption of EPOC for the BCI solutions development.

#### 4.5 Development Processes

The papers do not mention the techniques used throughout the application development process. The use of methods, similar to those practiced in the industry, would be likely since the design of assistive applications shares characteristics with conventional software development.

About tests, most of the studies perform functional evaluations on the solutions, using techniques and questionnaires that generate both quantitative and qualitative data regarding the use of the applications. No paper reports the use of software quality assurance tools, a practice that could be interesting, especially to ongoing works. Finally, another important issue is the difficulty in testing the proposals with the final target audience. Most of the developed prototypes are tested by users with no physical disability, which influences the results achieved.

### 5 Discussion

The execution of the SLM allowed covering a large and relevant set of works that explore the researched topic addressed in this paper. This analysis attempted to answer three SLM research questions highlighted below.

#### 5.1 Research Question 1

*"How does scientific research present the development and evaluation of AT software that allows people with physical limitations to use computational applications?"*

It was not noticed the existence of specific standardization in the process for the development of AT applications or devices. The papers do not describe nor mention the techniques used in the development process, focusing on the presentation

of the developed solution. There are, however, solutions that suggest the adoption of more formal methods of development, for example, in Ossmann et al. (2014); Veigl et al. (2013); Ossmann et al. (2012).

Still in this context, the article describing Doce Labirinto, for example, uses concepts of agile software development, in addition to project management strategies based on SCRUM (Cardoso et al., 2016). Thus, the use of methods, similar to those practiced in industry, would be a coherent strategy, since the applications' design of an assistive nature shares similar characteristics with conventional software development.

Specifically addressing the evaluations of the developed solutions, the works usually perform functional tests in them. In this sense, several works carry out usability tests on the solutions, using several specific tools for this purpose (Huo et al., 2013; Levy et al., 2013; Antunes et al., 2016; Martins et al., 2015). Others also evaluate the user experience (UX) aspects in using the proposed solution (Manresa Yee et al., 2013; Cardoso et al., 2016). Finally, the use of structural tests, to guarantee the level of quality or coverage of the modules, classes, or even parts of the developed software is not mentioned.

#### 5.2 Research Question 2

*Are there software development frameworks specifically focused on AT?*

Three solutions may be characterized as frameworks for AT-based development. Among these, the AsTeRICS project presents visions about both the use context of the proposed solution and the architectural model of high-level layered components. This framework is a visual editing tool, once it allows the generation of applications from the components' connection through a graphic tool (Ossmann et al., 2014; Veigl et al., 2013; Ossmann et al., 2012).

The two other papers characterized as software frameworks focus on specific fields of application, assistive games, in both cases (Miesenberger et al., 2014; Aced Lopez et al., 2015).

On the other hand, the works that have resulted in prototypes, concentrate on the creation of solutions to meet certain purposes or help to carry out some specific activity. They are not characterized as development frameworks, as they are not designed to provide software reuse in the design process of other applications.

#### 5.3 Research Question 3

*What does characterizes a solution for software development as AT-oriented?*

No evidence was found regarding the application of development techniques or the adoption of architectural standards, which would allow asserting that a device or application is assistive. The proposals share the fact that they use, or adapt, interaction devices to simplify (or make feasible) the use of technologies to a specific group of users with physical disabilities. The provision of alternative interaction modes for accessing computational resources is the closest approach to the answer to this question.

Although there is a need for specific devices for AT, the application of Universal Design principles in the mainstream products' development can eliminate the need for some of them. However, to reach this level, it is necessary to consider both similar and different characteristics in terms of design and development of products aimed at anyone, regardless of having or not any physical limitations.

## 6 Conclusion

Although broad and relevant, the result achieved with SLM left some gaps to be filled. This can be partly explained by the query string used on the search engines. To address the three axes of research and, at the same time, to respect the maximum number of characters accepted by the search engines, some keywords for this work were not used. SLM has retrieved several works that use commercial devices such as Microsoft Kinect, Leap Motion, or MYO, for example. The articles usually describe adaptations made with these devices, which allow their use by people with physical disabilities, in very specific contexts. Thus, a look at the software development structures provided by these commercial devices is an interesting point for the continuation of the work, seeking to detect the basic characteristics of them, which are used by the AT-oriented projects.

In the context of recognition of the field of research, SLM was very important because it provided a broader view of the area studied, allowing a better knowledge about trends, technologies, and approaches that are being used for the development of high-level AT. The analysis of all these works motivated the proposal of taxonomy to categorize the works according to their functionalities or type of developed solution. This classification was used initially to group the works found. However, with the progress of reading the SLM works, it has become an interesting tool to organize and detect the main uses, functionalities, and areas of development of high-level applications of AT. The goal is that this classification is extensible as new projects are developed enlarging this research area taxonomy.

This bibliographic review also found a series of characteristics and tendencies used in the area. In this perspective, developing solutions based on AT share similarities with conventional software design. Although there is still a need for specific devices for AT, the growing application of Universal Design principles in the mainstream products should gradually eliminate the need for them. However, this process takes some time until it is possible to incorporate so many particularities into the products so anyone can use them. This process tends to be long since there is no commercial interest in developing assistive, low-cost solutions for a very specific audience.

Analyzing the process involved during SLM, the result helped to draw the general map of the research area, quantitatively, highlighting a significant number of works in progress in this field. The next step in this work is the identification of specific work focuses so that the results can be expanded.

Regarding the project in which this work is inserted, an even more detailed review of the studies related to the software development frameworks will allow us to examine

the subject deeply. It is expected that the conjunction of the SLM's results with the analysis of the development frameworks of the interaction devices available in the market, allows the initial identification and specification of the characteristics and functionalities desirable to guide a practical case study.

It is expected to apply these perceptions and trends to design a specific software framework for the IOM device. This can be achieved through the development of applications that use it in different contexts. Thus, the scenarios highlighted in the taxonomy proposed in this article will be explored to raise features and functionalities that must compose such a structure for the IOM interaction device, as an object study. Lastly, the aim is to use this knowledge to propose a set of design guidelines for AT-focused architecture, specifically for users with motor disabilities.

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