Accessibility Requirements for Human-Robot Interaction for Socially Assistive Robots

by

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[Defense Month]

To Fawaz, I can still hear your laughter,

To my grandmothers Rahmah & Nijmeh,

To baba, mama, Salim and Ayla.

Malak

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Foremost, I want to thank God, who has strengthened me, in these, the best and harshest years of my life. I'd like to take this precious moment to thank all the people who contributed to this thesis.

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PUBLISHED AND SUBMITTED CONTENT

- This section includes researcher's publications that are included wholly and expanded too in the thesis:
  - Qbilat, M., Iglesias, A., & Belpaeme, T. (2021). A proposal of accessibility guidelines for human-robot interaction. Electronics (Switzerland), 10(5), 1–14. https://doi.org/10.3390/electronics10050561

- This section includes researcher's publications that are included partially in the thesis:
  - Qbilat, M., & Iglesias, A. (2018). Accessibility guidelines for tactile displays in human-robot interaction. A comparative study and proposal. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 10897 LNCS, 217–220. https://doi.org/10.1007/978-3-319-94274-2_29

  - Malak Qbilat, Ana Iglesias. Accessibility Requirements in Human-Robot Interaction. *ACM-W International Conference Informática Para Todos (IPT'18)*. Madrid. Abril'18

  - Malak Qbilat, Ana Iglesias. Accessibility Guidelines for Hardware and Software Assistive Technology in Human-Robot Interaction. *User-Centered Methods in Human-Robot Interaction Workshop at 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'18)*. Madrid, Spain. October 2018.

ABSTRACT

Accessibility was expansively investigated in Human-Computer Interaction (HCI), to guarantee that all users with different abilities and needs have equal access to software and hardware products. Thus, many accessibility guidelines are available for designers and developers of mobiles interfaces, web content, etc. In contrast, there are no such guidelines for developers and designers of Human-Robot Interaction (HRI) applications. Hence, the main aim of this thesis is to identify the accessibility barriers in HRI and propose accessibility guidelines for HRI.

The diversity in robot types is huge. Hence, we limited the scope of studied robots to Social Assistive Robots (SARs); the interaction components of twenty SARs were studied and classified under: software and hardware components. Then, a systematic review was conducted to search classifications for HRI interfaces, the results were integrated to our proposed classification of interaction components in HRI. A search was performed to identify main HCI accessibility laws and guidelines; six of the studied guidelines were selected to form a basis of our proposal; these guidelines cover hardware, software and user experience areas in HCI. Only applicable guidelines to HRI were selected.

To understand accessibility barriers in HRI deeply, the proposed classification of interaction components was mapped to users' potential disabilities, which produced a proposal of interaction components that could affect users' potential disabilities during the interaction time. Real and fictional users' cases of interaction with SAR were evaluated to elicit accessibility barriers. The evaluation has been conducted following the accessibility evaluation methodology for HRI, which was proposed in this thesis, and used in following two heuristic evaluations too. A list of accessibility barriers were identified.

The proposed accessibility guidelines for HRI were evaluated and used in three different heuristic evaluations and one user evaluation. The first evaluation was with HRI developers and designers, who agreed by majority that the proposed guidelines helped them implement and design accessible interfaces, and they showed a desire to use them in their future designs and implementations, as none of the developers or designers had applied all the proposed guidelines previously. In the other two evaluations, the proposed guidelines were used to evaluate two different applications of a SAR. Thirteen accessibility problems were elicited from the first application, and eight accessibility problems from the second. For the first application, evaluator's recommendations were implemented and evaluated through a real user evaluation in a residence home. A list of found accessibility barriers were identified. The final version of the proposed guidelines presented in this document was updated based on participants' recommendations in the first heuristic evaluation.

Keywords

Accessibility, Human-Robot interaction, Social Assistive Robots.

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Chapter 1: Introduction

According to the statistics of the International Federation of Robotics (IFR) (*International Federation of Robotics*, 2019), in 2018, the total number of Service Robots (SR) for personal and domestic use rose up to 16.3 million units with the sales forecasted to increase to 61.1 million units and 5.9 million units by 2022 for service robots for domestic tasks and entertainment respectively. Later in 2021, IFR released a report that indicates the sales of professional service robots increased in 2020 by 41% reaching 131,800 units (*International Federation of Robotics*, 2021).

The widespread use of robotics in all areas of humans' life, including all potential types of users in normal or challenging situations, poses a question about the accessibility of SR, whether there are accessibility laws, standards or guidelines for HRI. The international organization for standards (ISO) defines the accessibility term for interactive system as "the usability of a product, service, environment or facility by people with the widest range of capabilities" (ISO, 2008), that means all robot users should have an equivalent and less discriminate experience during their interaction with robots. Based on the above, to what extent do the designers and developers of the currently available SR have committed to implementing the needed accessibility requirements in their designs? It is difficult to give a confident answer comparing to the situation in the Human-Computer Interaction (HCI) discipline.

This thesis is fully dedicated for accessibility requirements of the interaction between human and Socially Assistive Robotics (SARs), where the context of use is one user with one robot. SARs greatly diverse in their applications, functions or behaviors, physical shapes and being autonomous or stationary. As a result of this variety, developers and designers in Human-Robot Interaction (HRI) should consider the accessibility requirements in their implementations for all types of users. In contrast with the HCI discipline where accessibility has been extensively investigated by researchers and industry, and there are many accessibility guidelines and standards, there are not specific accessibility standards or guidelines for HRI in the literature (Qbilat & Iglesias, 2018).

1.1 Definition of Accessibility

In this section, Accessibility, Inclusive Design and Usability terms are defined and compared, where these terms are commonly and widely used regardless of the differences between them and to indicate the same purpose. The three terms vary mainly in terms of targeted users types.

1.1.1 Accessibility vs. Inclusive Design

According to the International Organization for Standardization (ISO) (ISO, 2019a), accessibility refers to the "Extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs".

Accessibility focuses on users' needs and abilities and how to guarantee equality in access to all users during their experience.

Another term that is usually used in the same context of accessibility is Inclusive Design. Microsoft (Microsoft, 2021) terms Inclusive Design related to user center design process (UCD) as "A methodology, born out of digital environments, that enables and draws on the full range of human diversity. Most importantly, this means including and learning from people with a range of perspectives". John Clarkson & Coleman (2015) define Inclusive Design as "a general approach to designing in which designers ensure that their products and services address the needs of the widest possible audience, irrespective of age or ability".

Inclusive Design considers more issues than accessibility, for instance, culture, economic situation and geographic location. Sometimes the terms Universal Design and Design for All are used for the same contextual meaning (Rush & EOWG, 2016a). The concept of Inclusive Design is more comprehensive than the accessibility concept, see figure 4.1.

Figure 1.1 Inclusive design compared to accessibility design.

1.1.2 Accessibility vs. Usability

ISO defines Usability as the "extent to which a system, product or service can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO/IEC, 2018). Another definition for usability was set by the Institute of Electrical and Electronics Engineers (IEEE), which defines usability as "The ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component" (IEEE, 1990).

Bevan & Petrie (2009) have pointed out that there is lack of consensus about accessibility, where Web Accessibility Initiative WAI (Rush & EOWG, 2016b) proposed accessibility as a subset of usability, justifying that accessibility is considered only for a subset of users who are elderly or have a disabilities. ISO (ISO/IEC, 2018) proposed that usability as a subset of accessibility, justifying that accessibility considers issues for the largest possible range of users, including older and disabled people (Bevan & Petrie, 2009).

Aizpurua et al. (2016) have explained that the scope and extent of the relationship between accessibility and usability is difficult to define, since usability and accessibility are two qualities that interact with each other. For websites, if accessibility and usability are not incorporated, then web sites can be either accessible but hardly usable, or usable but hardly accessible (Aizpurua et al., 2016).

The association between usability and accessibility has been presented by Casare et al. (2016) from two different points of view. The first is the complementary concepts which agrees with Aizpurua et al.'s (2016) perspective, considering usability and accessibility as integrated concepts. The second point of view is to present accessibility as a sub-class of usability which agrees with Web Accessibility Initiative WAI perspective (Rush & EOWG, 2016b); Figure 4.2 shows the association between usability and accessibility according to Casare et al. (2016).

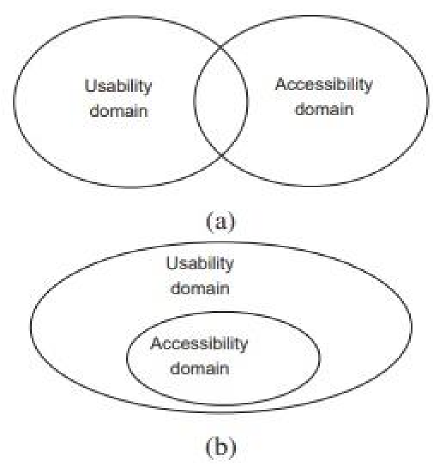

Figure 1.2 Accessibility compared to usability: (a) as complementary concepts; (b) accessibility as a sub-class (Casare et al., 2016).

In this thesis, we tend to understand accessibility as a different aspect from usability. This idea is demonstrated clearly in the AUSUS HRI evaluation framework (Iglesias et al., 2021), where the accessibility factor was adopted along with the usability factor to evaluate HRI.

1.2 Motivation

Social Assistive Robots (SARs) provide assistance for several categories of users: elderly care, people who have cognitive disabilities or in need for emotional support during rehabilitation, and encouragement through healthy diet or supporting education process and lifestyle (Contents, 1988). However, not all users have equivalent experience with the same robot due to their capabilities and abilities. For instance, cases involving permanent disabilities such as hearing, vision, motor or cognitive disabilities, or people in temporal, challenging or unique circumstances make interaction with the robot inaccessible or difficult. Developing accessible robots will guarantee equality in use (non-discrimination) for all robot users.

Furthermore, the necessity to ensure accessibility in HCI to all users with different abilities and needs has emerged and thus many countries have laws and decisions to guarantee the accessibility issue, for instance, the USA has the section 508 law (*IT Accessibility Laws and Policies | Section508.gov*, n.d.), the European Parliament approved directive 2016/2102 (European Parliament, 2016) and the 2010/2012 Jodhan decision in Canada (*Home | Canadian Internet Policy and Public Interest Clinic (CIPPIC) - Canadian Internet Policy and Public Interest Clinic (CIPPIC)*, n.d.-a). In contrast, there are not yet regulations for accessibility in HRI.

Presently, many guidelines and standards were introduced to help designers and developers implement accessible software products (websites, web applications, mobile applications, etc.): the Web Accessibility Initiative (WAI) has been developed and is continuously updating different guidelines for several web components to improve web accessibility (Lawton, 2018), the Accessibility Guidelines for United Nations' websites (UN, n.d.), the BBC Accessibility Standards and Guidelines (BBC, n.d.) and Funka Nu Mobile guidelines (*Mobile guidelines - Funka*, n.d.). None of the existing accessibility guidelines for HCI can be completely applied to HRI due to the differences in applications, hardware and software components, but the similarity in many aspects between the two disciplines can spark the start towards designing accessibility guidelines for HRI.

Some studies have focused on the main aspects that are correlated to user experience in HRI, such as robots' usability, social acceptance and societal impact, (Yanco & Drury, 2004) research work and USUS evaluation framework (Weiss et al., 2009) with the aim to provide a framework for all HRI research aspects, like HCI, CSCW (Computer Supported Cooperative Work), and SS (Social Sciences). Iglesias et al. (2021) presented AUSUS which is an evaluation framework for HRI that expands the USUS evaluation framework by including accessibility as one of the main factors to evaluate.

Obviously, there is a persistent need to investigate accessibility requirements for HRI, to extend the HRI research areas to include accessibility aspects and to offer concrete accessibility guidelines for developers and designers.

1.3 Goals

This thesis aims to study the accessibility barriers that humans may encounter while interacting with SARs. Moreover, guidelines of accessibility requirements for HRI are proposed to help and guide developers and designers of SARs to implement accessible interfaces. Hence, this thesis assumes two hypotheses: users face accessibility barriers in HRI; the proposed guidelines will help designers and developers implement accessible SARs.

Therefore, this thesis is dedicated in two disciplines:

1. Human-Robot Interaction (HRI): the interaction interfaces of SARs will be studied to extract software and hardware characteristics that could affect accessibility during the interaction with the robot, in addition to the behavioral aspect and the flow of interaction between the robot and user.
2. Software Engineering (SE): the proposed guidelines will follow the principles of SE in its documentation in order to help developers and designers implement and develop accessible robots that meet the needs of all potential users.

1.4 Limitations

Some limitations were faced during this study:

- The available accessibility guidelines for HCI do not cover all software and hardware aspects in HRI.
- The great diversity of SR types, which are defined as "robots that perform useful tasks for humans or equipment excluding industrial automation applications" (ISO, 2019b), with partial or fully autonomy and with different forms, structures and applications, and also they can be classified into personal or professional use (IFR Press Releases, 2020). Hence, the wide variety of the interaction interfaces used in SR created the necessity for limiting the scope of this Ph.D. to specific types of SARs, which are used in application domains like: mental health care, household tasks, elderly care, education, health care, work environments and public spaces. Also, some interaction interfaces that could be used in SARs were not included in this study, since they were not available for evaluation at the time, for instance, Brain Computer Interaction (BCI) Interfaces. Studying interaction components of the main SARs chosen by the researcher forms another limitation to this thesis.
- The wide range of disability types, severity degree, and the difficulty to provide a specific description to each disability type too. In this thesis, we limit the scope of user's disabilities to include: visual, auditory, motor, cognitive and speech disabilities.
- The big number of potential fictional user cases (Personas) that could be used for evaluating the interaction with SARs to elicit accessibility barriers due to the wide range, severity degree and the difficulty to provide a specific description to each

disability type. Five personas were defined, although they do not cover all possible personas, but as examples for evaluation purposes.

Purposely, to bridge the gap between the existing literature and the need to introduce guidelines for accessibility in HRI, heuristic evaluations, analyzing real HRI cases and user studies will be conducted to elicit existing accessibility problems in HRI and propose appropriate guidelines to avoid these problems.

1.5 Research Questions

Thesis goals and hypotheses will be achieved by answering the following research questions:

RQ1: What are the application domains of SARs in the society, and what are their interaction components?

RQ2: What are the accessibility laws or regulations for HCI and HRI?

RQ3: What are the main accessibility standards, guidelines and recommendations for HCI and HRI?

RQ4: What are the evaluation methodologies for HRI?

RQ5: What are the current accessibility barriers in Human-Robot Interaction?

RQ6: Could we summarize or suggest accessibility guidelines / checkpoints for HRI?

RQ7: Are the proposed guidelines usable for robot developers and designers?

1.6 Main Ph.D. Contributions

1. Identify SAR's hardware and software interaction components that are considered as interaction interfaces to the user; the physical structure and behavioral aspect were studied and analyzed for main used SARs to determine if these components are considered as interfaces to the user or not and elicit expected accessibility requirements for those components.
2. Identify accessibility barriers in HRI: extract the accessibility problems that prevent people with special needs and abilities to have full access to all SAR's functions / services during the interaction, in the same way all other users do.
3. Propose an evaluation methodology to assess accessibility as a main factor in HRI.
4. Propose and validate accessibility guidelines for HRI: the final validated draft of the proposal is going to be proposed as the core contribution of the Ph.D. study.

1.7 Content Structure

This document consists of seven chapters, Chapter 1 explains the motivation, goals, limitations and research questions of this thesis. Chapter 2 includes the literature of SARs' application domains, physical structure and behavioral aspects, besides HCI and HRI accessibility laws and guidelines and HRI evaluation methodologies. Chapter 3 presents a proposal of classification for interaction components / interfaces of SARs based on the conducted literature review of SARs in Chapter 2 and a systematic review that was performed to identify any classification of interaction components / interfaces of SARs (Chapter 3).

Chapter 4 describes a proposed evaluation methodology for HRI. Main user disabilities are defined and mapped in relation to HRI interaction components, and accessibility barriers found in the literature or those elicited from real or fictional users' cases using our proposed evaluation methodology are presented in Chapter 4. The proposed accessibility guidelines for HRI were detailed in Chapter 5. In Chapter 6, three heuristic evaluations and a user evaluation were conducted to evaluate the proposed guidelines, in addition to updating the proposed guidelines based on evaluations results and the updates of the used HCI accessibility guidelines, which were used to form the proposed HRI accessibility guidelines. Conclusions and future works are explained in Chapter 7.

Chapter 2: Literature Review

This chapter is dedicated to answer the following research questions:

- **RQ1:** What are the application domains of SARs in the society, and what are their interaction components?
- **RQ2:** What are the accessibility laws or regulations for HCI and HRI?
- **RQ3:** What are the main accessibility standards, guidelines and recommendations for HCI and HRI?
- **RQ4:** What are the evaluation methodologies for HRI?

These questions are going to be answered by studying robots in the current society, the application domains of SARs as research platforms or as commercial products for daily life use, bearing in mind that any robot can be used in multiple domains of application. Based on that, the interaction components of studied SARs will be classified, and the physical structure and behavioral aspect of them will be listed too. Moreover, this chapter searches for HCI and HRI accessibility laws and guidelines, and HRI evaluation methodologies.

2.1 Robots in the Current Society

A robot is an "actuated mechanism programmable in two or more axes, with a degree of autonomy, moving within its environment to perform intended tasks" (ISO, 2019b). Generally, all robots fall under two categories: industrial and non-industrial robots. The industrial robots are the robots used in industrial automation applications (ISO, 2012). Non-industrial robots are referred to as service robots by ISO and defined as robots used for useful tasks other than industrial automation applications (ISO, 2019), such as healthcare, household, entertainment, etc. Non-industrial robots include two sub categories: non-assistive robots and assistive robots. Assistive robots can be classified under socially and non-socially robots (M. Heerink, 2010). The scope of studied robots in this study were limited to socially assistive robots (SARs) as highlighted in figure 2.1, which refer to the robotics that present services to users through social instead of physical interaction (Feil-Seifer & Matarić, 2009). For instance, being a coach or teacher who offers motivation and guidance through providing emotional, cognitive, and social cues in the interaction with the user; this can be achieved by employing hands-off interaction strategies, such as speech, facial expressions, and gestures (Matarić & Scassellati, 2016). SAR's physical embodiment is a crucial factor of SAR's effectiveness, "as it leverages the inherently human tendency to engage with lifelike (but not necessarily humanlike or otherwise biomimetic) social behavior" (Mataric, 2015).

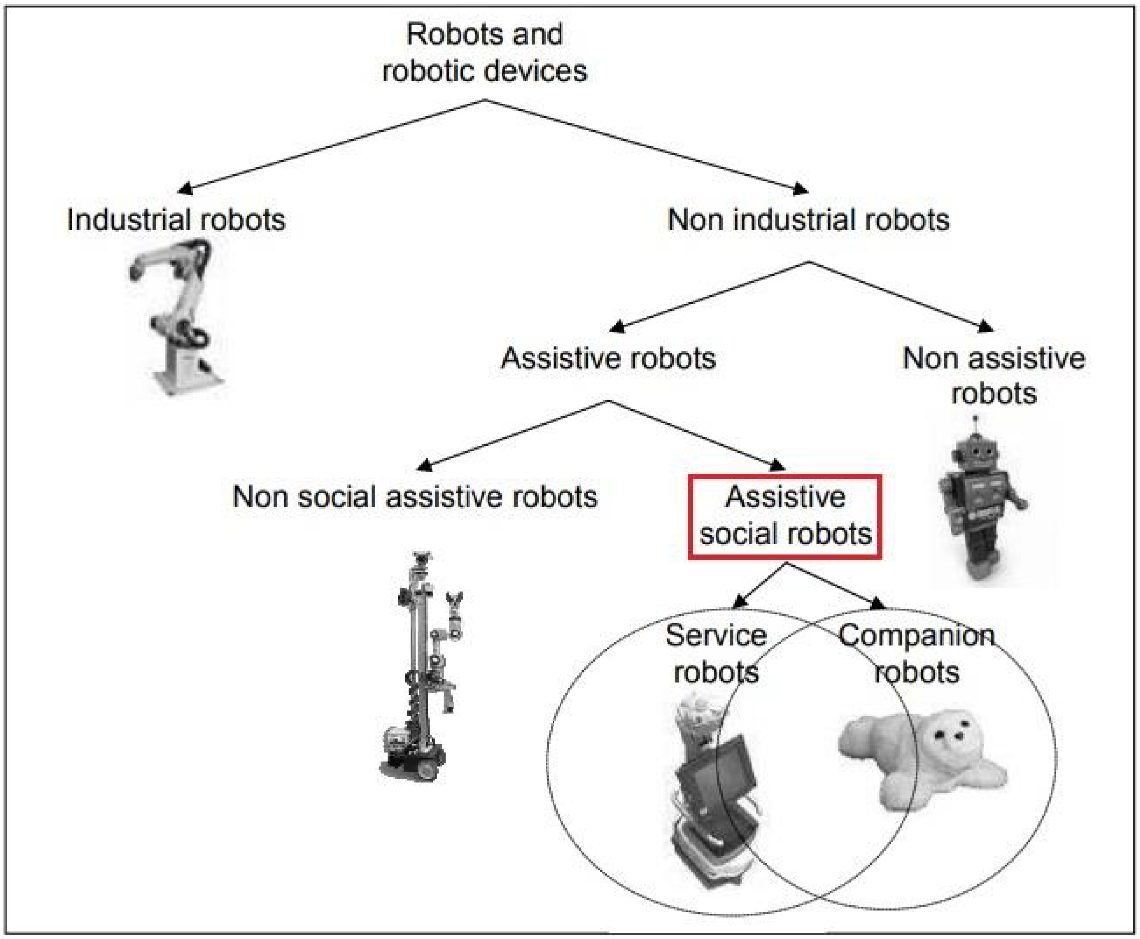

Figure 2.1 General classification of robots proposed by (M. Heerink, 2010).

This section is dedicated to answer the following research question:

- **RQ1:** What are the application domains of SARs in the society, and which are their interaction components?

A search was conducted to explore SARs' application as research platforms or as commercial products for daily life use (Section 2.2), besides identifying the interaction components of SARs.

2.2 Socially Assistive Robots in the Society

According to Heerink (2010) , assistive robots with social abilities are categorized into two types (service robots and companion robots), and he explains clearly the difficulty of classifying many robots under one of these two categories, as the robot can be implemented to provide services and companionship simultaneously.

In this subsection, the most important SARs during the last two decades were reviewed, according to whether they are specifically designed for a predefined assistive task especially those created by research projects, or SARs which are commercial SARs used for assistive tasks. For both categories, reviewed SARs were grouped according to their application domains. The physical structure and behavioral aspect for each robot were explained too.

2.2.1 SARs Specifically Designed for Assistive Tasks

- **SARs for Mental Health Care Applications**

Riek (2015) points out that different robots have been used during the last decades in the treatment of dementia, autism, and cognitive impairments; to provide companionship in loneliness cases; to help educate children with developmental disabilities; and to improve how people with visible impairments are treated. These robots diversify in their morphologies according to the required roles and functionality, and include zoomorphic, mechanistic, cartoon-like, humanoid representations (L. D. Riek, 2015). Rabbitt, Kazadin & Scassellati (2015) indicate three roles played by SARs in mental healthcare, including companion, therapeutic play partner and coach / instructor.

Many studies have been conducted to investigate the effects of companion robots on the health and psychological well-being of elderly people. There exists a spacious range of pet-like robots with companion roles, for example, Paro (Broekens et al., 2009). Paro's appearance is designed based on a baby harp seal model (figure 2.2); the robot also is provided with four principal senses (visual, audio, balance and tactile) and with the ability to generate some facial expressions and moving some of its parts like its neck and paddle (Wada & Shibata, 2007). Paro also can imitate the voice of a baby harp seal and can express many feelings like surprise, happiness, anger, shyness or sadness (*[PARO]: Paro's Functions*, n.d.). Wada & Shibata (2007) conducted a study on the sociopsychological and physiological effects on the elderly people living with seal robots like Paro. The results show playing with Paro encourages elderly participants to communicate with each other. Also, it improves the reactions of the residents' vital organs to stress.

Figure 2.2 Paro robot (Shibata, 2012).

Babyloid robot (Kanoh, 2014) is designed purposely to treat psychological suffering of elderly people or patients who are in long term treatments (figure 2.3). According to the designer, Babyloid's facial expressions, body movements and voice, which simulate human baby behavior in expressing the need to take care of him, arouse people to interact with the baby robot (Babyloid). The robot's length is 44 centimeters (cm) and weighs 4.4 kilograms (kg), which makes it easier for the elderly to carry it. The robot is provided with a camera, microphone, speaker, and 2 motors in the neck, 3 motors for each arm and touch sensors in the robot's hands, stomach and back. The robot's stomach and buttocks are filled with materials to symbolize the feeling of softness of the human body. A light sensor is located in the robot's head, in addition to the accelerometer and temperature sensor, and pyroelectric sensors that are located around the ears area. The robot is able to recognize single words and repeat them, and generate some facial expressions such as sleepiness, sorrow, shyness, happiness, pain and lucidity; those expressions are made using the motors in the mouth and jaw areas to stretch the face which is made of silicon. LEDs are located in the cheeks to simulate tears and blushing too (Kanoh, 2014).

Figure 2.3 Babyloid robot (Kanoh, 2014).

Five elderly women participated in an experiment to evaluate users' acceptance of Babyloid, where Babyloid was placed in each participant's rooms for 8 hours. The results showed that Babyloid significantly helped reduce depression level (Kanoh, 2014).

Kasper robot (Dautenhahn et al., 2009) has the appearance of a small child with a silicon mask (figure 2.4). It was designed for research studies as a playmate or companion. With minimal facial expressive features, the robot has 6 degrees of freedom (DOF) distributed in eyebrows, eyes, eyelids, lips and mouth to simulate expressions such as happiness, neutrality, sadness, thinking and surprise etc. (Dautenhahn et al., 2009). The robot sits at a table simulating a child's sitting with his feet facing each other, with ability to move its arms for a waving or peek-a-boo etc., and moving its head for titling, shaking and nodding. According to the designers, Kasper was used in studies for therapy of children with autism. The outcomes proved that the limited and simple facial expressions of Kasper suit the cognitive needs of children with autism, and the robot can provide enjoyable interaction for therapeutic purposes for children with autism.

Figure 2.4 Kasper robot (Dautenhahn et al., 2009).

Another robot with a different morphology is The Huggable (figure 2.5), with a teddy bear appearance. Stiehl et al. (2006) indicate that The Huggable is inspired by robot companion animal therapy with the purpose of enhancing the general health of individuals in hospitals, nursing homes and other facilities. The robot's silicone skin is fully provided with temperature, force and electric field sensors, in addition to two video cameras fixed in the eyes and two microphones in the ears to allow visual and auditory inputs to the robot. A speaker is fixed in the mouth to allow the audio output. The Huggable has eight actuators to provide motion for the neck, eyebrows, ears and shoulders, and an inertial measurement unit (IMU) to detect the robot's movements every time someone holds it. Moreover, The Huggable has a group of behaviors as a response to touch, visual and auditory inputs. For instance, the sensitive skin and the IMU allow The Huggable to determine its orientation (if it is sitting in someone's lap or being held) to locate and look up at users' face, besides being able to make relational touch interaction like nuzzling between someone's arms, The Huggable has the ability to detect the location of motion and faces, direct its head and video cameras to the person and act a pick me up gesture (Stiehl et al., 2006).

Figure 2.5 The Huggable robot (Stiehl et al., 2006).

In a study on the effect of a human-type communication robot on cognitive function of elderly women who live alone, Tanaka et al. (2012) used the Kabochan robot (figure 2.6), which is a humanoid robot that has the shape and some of the characteristics of a three years-old boy, such as the voice and motion. Five audio, light and motion sensors are installed in Kabochan's mouth, head, hands and the body to allow verbal interaction with sounds and motions from the surrounding environment. Moreover, Kabochan communicate with its owner by nodding and speaking in eight different ways, for example, as a 'Grandma' or 'Grandpa', and to make seven exercises with the user, including, the pose game and singing exercise to relief the stress, fatigue and symptoms of dementia (*AARP International*, 2013). Another study was conducted by Tanigaki, Kishida, & Fujita (2018) using Kabochan, showing that living with Kabochan decreased anxiety and enhanced the physical health of elderly people with mild impairment.

Figure 2.6 Kabochan robot (M. Tanaka et al., 2012).

Similarly, Van Breemen, Yan, & Meerbeek (2005) developed iCat (figure 2.7) as a research platform for the investigations in human-robot interaction. They designed the robotic platform's appearance to look like an immovable cat with the ability to generate facial expressions like happiness, anger and sadness by eyes, eyebrows, eyelids and lips. The face has thirteen motors for this purpose and to control the head movement too. A camera is fixed in the nose for object recognition purposes, besides having two microphones, one loudspeaker and two multi-color light-emitting diode (LED) and touch sensors fixed in the feet with the robot enjoying networking capabilities too (Van Breemen et al., 2005) .Heerink, Kröse, Wielinga, & Evers (2009) point out the behaviors of iCat as being able to make conversation with the user, smile, nod and look directly while listening to the user. iCat can make a profile for each user, hence, it can remember them.

Figure 2.7 iCat robot (Van Breemen et al., 2005).

Kozima, Michalowski & Nakagawa (2009) developed Keepon (figure 2.8), which is a therapeutic and entertainer robot, with a small yellow snowman-like appearance. The researchers elucidate how Keepon’s appearance and behaviors convey with the robot’s attention and emotion expressions. For instance, Keepon can gaze by directing its head to the right / left and up / down, and rock its body from left to right and / or bobs its body up and down with popping sounds, while keep gazing to a fixed target. Keepon’s design helps in generating motivation in children with different mental, physical and social developments, such as autistic children, as children share their mental states during the interaction with the robot (Kozima et al., 2009).

Figure 2.8 Keepon Robot (Kozima et al., 2009).

Salichs et al. (2020) designed Mini (figure 2.9), a robot to accompany and assist elderly people in their daily life by providing services related to safety, entertainment, personal assistance and cognitive stimulation to help caregivers and elderlies. They designed Mini as a desktop robot with a height of 50 cm and cartoon-like shape. The upper part looks like a human body consisting of the head, neck with 2 DOF, torso, arms (1 DOF x 2) and waist (1 DOF), whereas the base is a box that contains the main electronic components of the robot. Moreover, the researchers designed Mini with expressive eyes, a beating LED heart, cheeks, different body parts capable of motion and the external body is warped with foam and fabric. In addition, Mini is provided with an RGB-D camera located on the chest to detect people during short distance HRI, a microphone to detect the sounds from the surrounding environment and facilitate the automatic voice recognition, text to Speech module, four touch sensors placed in the head, shoulders and belly, and electronic beacons to determine the position of objects or users (Salichs et al., 2020). The robot has expressive capabilities as it can perform different actions by combining different movements and several colored LEDs located in the heart to simulate the beating, and in the mouth and cheeks accompanied with sounds emitted by the robot. Mini's screen-based eyes display animated images and drawings, while its gaze can reflect anger, happiness, neutrality, sadness, surprise and boresome expressions. It has a stereo speaker located on the chest to reproduce verbal and non-verbal sounds. The robot is also equipped with a tablet to enhance interaction with the user, and it can also simulate sleeping, greeting or tracking a person to get the user's attention (Salichs et al., 2020). The researchers performed an evaluation of Mini in a nursing home, where the robot was used to conduct cognitive stimulation exercises. The evaluation shows encouraging results regarding appearance and satisfaction, and more efforts should be dedicated to the usability aspect.

Figure 2.9 Mini robot while interacting with a user (Kidd & Breazeal, 2008).

Another study by Damm et al. (2013) confirmed the effectiveness of using robotics as social mediators in therapeutic sessions of children with autism spectrum disorder (ASD). The researchers used the robotic head Flobi (figure 2.10) in their study. Flobi, which was designed by Lütkebohle et al. (2010), has two cameras located in the head for vision, two microphones for speech recognition, a speaker localization, two LEDs placed behind each cheek to reflect red and white colors, and a total 18 degree of freedoms for eyes, eye brows, eye-lids, neck and mouth. Flobi's face can display facial expressions of five emotions: happiness, sadness, fear, anger and surprise (Lütkebohle et al., 2010).

Figure 2.10 Robotic head "Flobi" (Lütkebohle et al., 2010).

Kidd & Breazeal (2008) created the Autom robot (figure 2.11) as a weight loss or diet coach in an attempt to understand the long-term human-robot interaction. They designed it to be an immobile robot, where the user can place it on a surface. It has four degrees of freedom with movable head and eyes fixed above the belly of the robot, and a camera to allow face tracking, in addition to the belly that contains interactive haptic display for user input. According to Kidd & Breazeal, Autom is able to interact with the user through a five minute conversation to keep them up with the information related to their diet program. The researchers concluded that Autom helps people to commit to their diet program. Many of the participants wanted to keep working with Autom even after the trial (Kidd & Breazeal, 2008).

Figure 2.11 Autom robot (Kidd & Breazeal, 2008).

In 2013, McColl, Louie, & Nejat presented Brain 2.1 (figure 2.12), an instructor robot that is mainly designed for the elderly and cognitively impaired users. The researchers describe the scenario of a memory card game that can be performed by Brain 2.1 and the elderly user in order to train the memory functions of the elderly's brain and preserve it from diminishing. They also detail the physical structure of the robot; it has an upper humanlike appearance and can exhibit body language, gesture and facial expressions. The head motion is supported by 3 degrees of freedom, a neck with 3 degrees of freedom, two arms with 4 degrees of freedom for each to allow the robot to point to the surrounding objects, a waist with 2 degrees of freedom to allow the robot to turn left and right and to lean forward and backward, and the facial muscle has 5 degrees of freedom to allow the emotional expressions such as happy, sad and neutral. The user's face orientation is detected by a webcam fixed on the robot's left shoulder, while the user's trunk orientation is tracked by a kinect camera fixed on the chest and face. Trunk orientation is important to determine user state (distracted or attentive to the game or the robot), where the robot's behaviors are determined based on user's state, which is classified under four types: instruction, celebration, encouragement and help. Infrared (IR) cameras mounted on the robot's right shoulder are used with IR LEDs that are affixed to utensil to determine the position of the utensil. The study of using Brain 2.1 at a long term facility for the elderly is promising regarding using robots such as Brain 2.1 in cognitive interventions (McColl et al., 2013).

Figure 2.12 Brain 2.1 robot helping a user to pick up a food (McColl et al., 2013).

- **SARs for Household Tasks and Elderly Care Applications**

The main motivation behind developing Hobbit (figure 2.13) was to support aging in place with a robot that is able to prevent and detect falls and to manage emergency cases. The robot is also capable of performing tasks such as clearing the floor from objects, bringing objects, and offering entertainment to user by playing music, videos and games (Fischinger et al., 2016).

Hobbit has a mechanical appearance; its lower part is a mobile platform provided with specifications that allow it to navigate properly in crowded area. This platform contains the batteries and onboard PC and another board for control software of the robot and motion control respectively. The sensor system contains one camera located in the front of the mobile platform for self-localization, another camera mounted in the head of the robot for self-navigation, HRI and gestures recognition, objects detection and grasping, a group of infrared and ultrasound distance sensors located in the back of the lower part for detecting obstacles when moving back and two bumpers fixed in the front and the back of that platform. The robot is also provided with a 5 DOF arm and gripper with two fingers to grasp objects, and the multi modal user interfaces include touch, automatic speech recognition, text to speech, and gesture recognition interface. The adaptable touch screen mounted approximately in the middle of the robot has a small screen on the head of the robot for facial expressions. Moreover, the user can call the robot via a wireless call button (Fischinger et al., 2016).

In the same previous study, the researchers conducted a user study with 49 participants. The results revealed participants' satisfaction with the interaction with the Hobbit and their ability to accomplish all the assigned tasks with the robot.

Figure 2.13 Hobbit robot (Fischinger et al., 2016).

Another well-known robot in the household and elderly care field is Care-O-Bot 4 (Kittmann et al., 2015) with its anthropomorphic appearance like a butler. The robot (figure 2.14) consists of a head with a touch screen that can be positioned to adapt to the user's situation, and trunk and base, with the three parts joined together to reflect agility and mimic human movements like bowing, nodding and hand shaking. The neck and hip have joints with 3 DOF, the head contains a rich graphical user interface for multimodality and facial expression purposes, a camera for user and gesture recognition, microphone for speech recognition, and LEDs and speakers. In addition, the robot has two arms with natural movements and the ability to grasp objects and interact with users and the environment. The one finger hand has 2 DOF, camera for more comprehensive exploring, laser pointer and LEDs to light the dark areas (Kittmann et al., 2015).

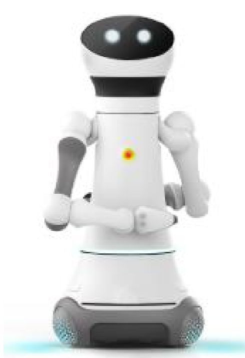

Figure 2.14 Care-O-Bot 4 (Kittmann et al., 2015).

- **SARs for Education Applications**

Saerbeck et al. (2010) used iCat (described previously in this section) to implement some social supportive behaviors in a tutoring application, which was implemented with the robotic research platform, to study the effect of social supportive behavior on the learning efficiency of students; the robot played the role of a language tutor. There was a positive impact on students, as they were significantly motivated by the robot (Saerbeck et al., 2010).

For the same role, Park, Grover, Spaulding, Gomez, & Breazeal (2017) used the Tega robot as a peer (figure 2.15) in an experiment for early literacy education. Westlund et al. (2016) designed Tega for long term interactions with children. Tega looks like a fluffy kinematic chain that allows the robot to perform unique expressive movements. The researchers state that the animated eyes, audio input and output, sensors processing, behavior and motor control are run on a smartphone that is fixed in the upper part of the kinematic chain. It has 5 degrees of freedom for head, waist and full body, in addition to an external camera positioned in the forehead and a set of speakers added to Tega's capabilities. The behavioral aspect in Tega includes a set of facial expressions and body motions that display gestures of frustration, laughter and excitement (Westlund et al., 2016). Using Tega in telling stories for 4-6 years old kids and to listen to their stories in return, helped them acquire new vocabulary after the interaction more than the kids who did not interact with Tega (Park et al., 2019).

Figure 2.15 Tega robot (Westlund et al., 2016).

- **SARs for Work Environments and Public Spaces Applications**

In 2013, Al Moubayed et al. presented Furhat (figure 2.16), a robotic head with an animated face that is back-projected on the three-dimensional mask by a micro projector. Both the mask and the micro projector are fixed on the neck of the robotic head that has 3 DOF to enable Furhat to point its attention by changing the face pose and eye gaze. The researchers provide more technical specifications of Furhat; the used animation allows Furhat to control eyes including pupil, iris and eyelids in addition to the eyebrows and mouth (Al Moubayed, Skantze, et al., 2013). Furhat is provided with pre-built expressions and gestures that can be specified to adapt to different characters as the neck is fixed on a base that contains two stereo speakers, one microphone and camera. Furhat's system supports high quality text-to-speech voices for over 30 languages (*A Human Robot Assistant | Furhat Robotics*, n.d.), besides speech recognition, speech activity detection, face tracking, and facial analysis (Al Moubayed, Beskow, et al., 2013).

Figure 2.16 Furhat robot interacting with a user (Al Moubayed, Beskow, et al., 2013).

A study was conducted using Furhat at a museum showed that the children and adults liked interacting with Furhat and they came back again to the museum to play a game with Furhat (Skantze et al., 2015).

2.2.2 Commercial SARs Used for Assistive Tasks

- **SARs for Mental Health Care Applications**

Nakashima, Fukutome & Ishii (2010) used NeCoRo (figure 2.17) in an elderly care facility, which is a commercial pet robot that looks like a cat. The robot has the ability of expressing satisfaction, surprise, hatred and anger emotions corresponding to factors like sudden loud sounds and when it is stroked or picked up. Moreover, NeCoRo also behaves like a real cat by showing its interest in the surrounding things and its desire to sleep or fawn over. Fifteen actuators are inside NeCoRo's body in addition to implanted sensors: sound sensor fixed in the ear, two touch sensors located in two different places in the head and another two on the back and neck, sight sensor fixed on the nose and speaker in the mouth (Libin & Libin, 2004). Nakashima et al. (2010) confirm in their study the positive effect of NeCoRo on the communication process between the users in the facility, where it became easier, calmer and comfortable.

Figure 2.17 NeCoRo robot (Nakashima et al., 2010).

Another example of a pet-like companion robot is the Aibo robot (figure 2.18) which has a dog appearance, but without fur. Fujita (2001) describes Aibo, which is equipped with a group of sensors and actuators, and has four legs and a neck both with three degrees of freedom and one degree of freedom for the robot's tail to generate the required motion. In addition, it has a camera, stereo microphone, acceleration sensor and touch sensors. The behavioral aspect in Aibo includes reflexive and deliberative behaviors, such as, expressing simulated feelings like being angry or surprised, sleeping when it is tired, finding a ball and playing with it and giving the paw (Fujita, 2001). The latest version of Aibo (*aibo - Specification*, 2019) is provided with 22 axes in the head with three Degrees of Freedom (3 DOF): mouth (1 DOF); neck (1 DOF); waist (1 DOF); legs and paws (3 DOF x 4); ears (1 DOF x 2) and tail (2 DOF) (Robots, n.d.), 2 organic light-emitting diode (OLED) in the eyes, speaker and 4 microphones, front camera and another one near the tail. In addition, there are a group of sensors: Time-of-Flight (ToF) sensor, 2 ranging sensor, touch sensors in the head, back and jaws, two 6-axis motion sensors in the head and torso, motion sensor, light sensor and 4 paw pads contact sensors, and voice recognition ability.

Aibo was used in a study to investigate the effectiveness of an entertainment robot in the care of elderly people who suffer from severe dementia, where Aibo enhances communications between the patients (Tamura et al., 2004).

Figure 2.18 Aibo robot (aibo - Specification, 2019).

NAO (figure 2.19) is a humanoid robot that has played a therapeutic role in mental healthcare. It has the size and walking style of a two-year-old kid, with 25 degrees of freedom for its head, arms, pelvis, legs and hands (Gouaillier et al., 2009). NAO has two ultrasonic sensors for distance estimation purposes, four sensitive resistors to measure resistance variation caused by feet pressure. The head is equipped with a video camera, and 20 LEDs are located around the ears, eyes and foot, in addition to four microphones, two loudspeakers and networking capabilities (Gouaillier et al., 2008). Pot, Monceaux, Gelin, Maisonnier, & Robotics (2009) classified the pre-programmed behaviors of NAO into high level functions such as walk, dance, speech recognition and synthesis, turn, lying down and stand up; and low level functions like reading sensors and turning the LEDs on and off. Conti, Di Nuovo, Buono, Trubia, and Di Nuovo, (2015) used NAO in their experiment of using robotics as a therapeutic tool for autistic children by focusing on their imitation skills. The results confirmed that SARs can be used effectively in psychological therapies.

Figure 2.19 NAO robot (Gouaillier et al., 2008).

Another example is the Pleo robot (figure 2.20), which has been used in ASD therapies. Fernaeus, Håkansson, Jacobsson, and Ljungblad (2010) describe Pleo's appearance as looking like a small dinosaur with the size of a cat. Its mechanical body is covered with a rubber skin and it has 14 motors that enable the robot to move the tail and neck and control the mouth, eye-lid motion and the speed of walking. Pleo has two speakers, one camera and two infrared sensors fixed in the nose, and four push buttons fixed in the feet. In addition, there is a sensor that measures the slope and two microphones placed below the eyes (Fernaeus et al., 2010). Kim, Paul, Shic, & Scassellati (2012) used the Pleo platform in their study; they pre-programmed the robot with 8 social expressive behaviors like excitement, greeting and affirmation, fear and surprise, fear and uncertainty, fatigue, boredom, enthusiastic affirmation and elation. Moreover, the researchers describe how Pleo can move the different parts of its body, such as wagging the tail, raising the head and shaking the hips. All these movements can be accompanied with non-verbal sounds like "Eech!", "Woohoo!" and other sounds, in order to simulate the 8 social expressive behaviors. They also pre-programmed Pleo with 4 more behaviors, 3 of them are about walking style and one for the idling behavior. The study was the largest on the interaction between human and autistic people. The results illustrate the effectiveness of robotics in eliminating collaborative barriers between the autistic people and their therapists (Kim et al., 2012).

Figure 2.20 Pleo robot (Fernaeus et al., 2010).

- **SARs for Education Applications**

NAO robot (described previously in this section) was used in an experiment (Janssen et al., 2011), which included 20 children from elementary school. The experiment depended on the principle of learning by playing where the children interacted with the robot to solve an arithmetic task as part of a game. The robot played three roles: buddy, educator and motivator during the session. The results show that the children were very motivated to play with the robot, hence, the use of a social robot for long-term interaction is promising (Janssen et al., 2011).

F. Tanaka et al. (2015) conducted an experiment on the educational application of a humanoid robot called Pepper (figure 2.21). Pepper was used in this experiment as a peer in the learning process, where the teacher gives the lesson remotely to the children who are learning together in the classroom with Pepper. The study introduces the main specifications of Pepper. It has 20 degrees of freedom to support natural movement and expressions, with the head having four microphones, two cameras and touch and 3D sensors. In addition, two gyroscope sensors are positioned in the trunk and leg for navigation purposes, the hands include two touch sensors, and the leg has two ultrasonic sensors for distance estimation and reaction to real world obstacles. There are six laser sensors and three bumper sensors positioned in the leg to avoid collisions with the surroundings obstacles (F. Tanaka et al., 2015). Pepper was designed to make a conversation when it sees a person using the speech recognition and dialogue capability for 15 languages, the touch sensors, LEDs, microphones and display that allow the multimodal interaction with the users (SoftBank Robotics, 2021).

Figure 2.21 Pepper robot (F. Tanaka et al., 2015).

- **SARs for Health Care Applications**

SARs can be used in health care services to help patients and medical staff accomplish daily tasks and routines that are required for their therapy.

An experiment was conducted on the quality of monitoring instruments for hospitalized patients (Van Der Putte et al., 2019), where the researchers used the Pepper robot (described previously in this section) to administrate five questionnaires on medical history, defecation, pain, memory and sleep for 35 patients. The results of the study reveal that the social robots can be used as a nurse assistant in order to enhance the efficiency of collecting data from hospitalized patients.

The study was organized to motivate diabetic children to use an online diary to follow up on their health and feelings on a daily basis in turn to get the appropriate therapy (Van Der Putte et al., 2019). The robot NAO, described previously in this section, was used via webcam to interact and support the children to keep an online diary. The researcher found that children shared notably more information when they interacted with NAO, even with the presence of a human actor to translate the data for the robot.

Table 2.1 includes the interaction components, description of robot’s appearance and behaviors of each studied robot. BCI interfaces were excluded from this classification, as they are not available for evaluation during study time.

Table 2.1 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)

Paro (Broekens et al., 2009; Wada & Shibata, 2007; *[PARO]: Paro's Functions*, n.d.)	- Companion robot	- Baby harp seal like appearance (artificial fur)
		- Two 32 bit reduced instruction set computer (RISC) chips.
		- **Interaction components:**
		  - Ubiquitous surface of tactile sensors are implanted between the fur and the hard inner skeleton.
		  - Sensors: posture sensor and two light sensors.
		  - Three microphones.
		  - Speaker.
		  - Stereo whisker tactile sensor.
		  - Seven actuators (body and facial expressions): eyelids, neck, front and rear flippers.
			- Proactive behavior: Paro has basic behavioral patterns that allow it perform many movements and poses similar to a real seal and a lifelike behavior, for example Paro is responding to stroking positively and for beating negatively, and imitating the voice of a real baby harp seal.
			- Reactive behavior: responding to a sudden motivation, for example, Paro pays attention to loud sounds by looking in the same direction of the sound, and expressing feelings like surprise, happiness, anger, shyness or sadness.
			- Physiological behavior: such as sleeping.

Babyloid (Kanoh, 2014)	- Companion robot	- Large fluffy doll, Length of 44 cm and weight of 4.4 kg.
		- **Interaction components:**
		  - Camera.
		  - Microphone.
		  - Speaker.
		  - Motors in mouth and jaw areas, 2 motors in the neck and 3 motors for each arm.
		  - Touch sensors in hands, stomach and back.
		  - Light sensors in head, accelerometer and temperature sensor, and pyroelectric sensors around ears area.
		  - LEDs in the cheeks area.
			- Facial expressions, body movements and voice which simulate human baby behavior in expressing the need to take care of him.
			- Recognizing single words and repeating them.
			- Generating some facial expressions as sleepiness, sorrow, shyness, happy, pain and lucidity.

Kasper (Dautenhahn et al., 2009)	- Playmate / companion robot	- Small child appearance.
		- **Interaction components:**
		  - 6 DOFs in eyebrows, eyes, eyelids, lips and mouth.
		  - Movable arms and head.
			- Generating facial expression as happiness, neutrality, sadness, thinking and surprise.
			- Waving arms or doing peek-a-boo, moving head for titling, shaking and nodding.

Table 2.2 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)
The Huggable (Dautenhahn et al., 2009)	- Companion robot	- Teddy bear-like appearance. - **<u>Interaction components:</u>** - Silicone skin that is fully provided with temperature, force and electric field sensors. - Inertial measurement unit (IMU). - Two video cameras in the eyes. - Two microphones in the ears. - Speaker in the mouth. - Eight actuators to allow the motion of The Huggable's neck, eyebrows, ears and shoulders.	- When the person is physically touching The Huggable (touch input): determining its orientation (if it is sitting in someone's lap or being held) to locate and look up at the user's face and nuzzling between someone's arms. - (Without touch input): detecting the location of motion and faces and directing its head and video cameras to the person and acting a pick me up gesture.
Kabochan (M. Tanaka et al., 2012; *AARP International*, 2013)	- Companion robot	- Three years- old boy voice, motion and appearance. - **<u>Interaction components:</u>** - Five sound, light and motion sensors are installed in the mouth, head, hands and the main body. - Remote-controlled speaker.	- The ability to speak with its owner in eight different ways, as a 'Grandma' or 'Grandpa' - Nodding. - Capable of performing seven simple exercises with the user as the pose game and singing exercise to relieve the stress, fatigue and symptoms of dementia.

Table 2.3 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)

iCat (Van Breemen et al., 2005; Heerink et al., 2009)	- Companion robot / Tutor	- Immovable cat appearance.
		- **Interaction components:**
		  - Actuators: for facial expressions and head movements iCat face contains thirteen actuators in eyes, eyebrows, eyelids and lips.
		  - Camera fixed in the nose for object recognition.
		  - Two microphones and one loudspeaker fixed in the feet.
		  - Two multi- color LED and touch sensors are fixed in the feet.
		  - Networking capabilities: it can be connected to a home network to control devices (video cassette recorder (VCR), television (TV)) or to use the Internet.
		  - Speech synthesis.
			- Nodding, smiling, giving attention, speaking, generating facial expressions like happiness, anger and sadness.

Keepon (Kozima et al., 2009)	- Therapeutic and entertainer robot	- Small yellow snowman- like appearance.
		- **Interaction components:**
		  - A marionette- like mechanism to drive the body.
		  - Upper part with two eyes (cameras) and a nose (microphone).
			- Attentive: (gazing) directing the head to a specific target and making any eye contact with it.
			- Emotive: (pleasure and excitement) rocking its body from left to right and/or bobbing its body up and down with popping sounds.

Table 2.4 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)
Mini (Salichs et al., 2020)	- Companion / care robot	- Cartoon-like shape, desktop robot with a height of 50 cm, the upper part looks like a human body. - **Interaction components:** - 2 DOFs for neck, (1 DOF x 2) for arms and 1 DOF for waist. - Expressive eyes, beating LED heart and cheeks. - RGB-D camera in chest. - Microphone. - Voice recognition. - Text to Speech module. - 4 touch sensors in head, shoulders and belly. - Electronic beacons. - Tablet. - Stereo speaker in the chest.	- Expressive capabilities; combining different movements, several colored LEDs in heart, mouth and cheeks and displaying images in the eyes. - Generating angry, happy, neutral, sad, surprised, and bored expressions. - Generating verbal and non- verbal sounds. - Simulating sleeping, greeting or tracking a person.
Flobi (Lütkebohle et al., 2010)	- Therapeutic and entertainer robot	- A comic-like human face. - **Interaction components:** - Two cameras and two microphones. - Two LEDs placed behind each cheek. - 18 DOFs for eyes, eyebrows, eyelids, neck and mouth. - Speech recognition and speaker localization.	- The ability to display facial expressions of five emotions: happiness, sadness, fear, anger and surprise.
Autom (Kidd & Breazeal, 2008)	- Coach robot	- Humanoid shape (head positioned above the belly). - **Interaction components:** - Actuators: four degrees of freedom (movable head and eyes). - Camera fixed in the head. - Interactive haptic display for user input (belly part). - Text to Speech ability (5 minutes conversation).	- Speaking and making small gestures with its head and eyes like looking at the user directly and looking at the haptic display to indicate the importance of answering the question displayed on it.

Table 2.5 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)
Brain 2.1 (McColl et al., 2013)	- Instructor robot	- A waist up humanlike appearance - **Interaction components:** - Actuators: head motion is supported by 3 DOF, the neck with 3 DOFs, the arms with 4 DOFs for each, the waist with 2 DOFs and the facial muscle has 5 DOFs. - Webcam fixed on the robot's left shoulder. - Kinect device fixed in the chest. - IR cameras mounted on the robot's right shoulder. - IR LEDs that is affixed to utensil that is part of the activity, and it is utilized with IR cameras to determine the position of utensil.	- Exhibiting body language, gesture and facial expressions (happy, sad and neutral). - The robot can communicate with the user by a synthesized voice.
Hobbit (McColl et al., 2013)	- Care robot	- Mechanical appearance - **Interaction components:** - The lower part is a mobile platform. - Camera located in front of the mobile platform for self-localization. - Camera mounted in the head of the robot for self-navigation, HRI and gestures recognition, objects detection and grasping. - A group of infrared and ultrasound distance sensors located in the back of the lower part for detecting obstacles. - 5 DOFs arm and gripper with two fingers to grasp objects. - Multi modal user interfaces include an adaptable touch screen, automatic speech recognition, text to speech, and gesture recognition interface (small screen on the head of the robot for facial expressions). - A wireless call button. - Automatic speech recognition. - Text to speech. - Gesture recognition.	- Preventing and detecting falls and managing emergency cases, clearing floors from objects, bringing objects, offering entertainment to user by playing music, videos and games.

Table 2.6 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)
Care-O-Bot 4 (McColl et al., 2013)	- Household and care robot	- Anthropomorphic appearance (butler): head, neck, trunk, hip and base. - **<u>Interaction components:</u>** - A head contains a rich graphical user interface for multimodality and facial expressions purposes: adaptable touch screen, camera for user and gestures recognition, microphone for speech recognition, LEDs and speakers. - One finger hand has 2 DOFs, camera for more comprehensive exploring, laser pointer and LEDs to light the dark areas. - Neck and hip have joints with 3 DOFs. - Gestures recognition. - Speech recognition.	- Bowing, nodding and hand shaking. - Facial expressions. - The arm has natural movements and the ability to grasp objects and interaction with users and environment.
Tega (Westlund et al., 2016)	- Peer in the educational process	- Fluffy kinematic chain appearance - **<u>Interaction components:</u>** - Animated eyes, audio input and output, sensors processing, behavior and motor control are run on smartphone that is fixed in the upper part of the kinematic chain. - 5 DOFs for head, waist and full body. - An external camera positioned in the forehead. - Set of on- board speakers. - Text to speech ability.	- Facial expressions and body motions, such as frustration, laughter and excitement.

Table 2.7 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)
Furhat (*A Human Robot Assistant | Furhat Robotics*, n.d.; Al Moubayed, Beskow, et al., 2013; Al Moubayed, Skantze, et al., 2013)	- Companion robot at public places	- A robotic head houses an animated face that is back-projected on the three- dimensional mask by a micro projector. - **<u>Interaction components:</u>** - A neck with Three DOFs. - Two stereo speakers, one microphone and camera fixed on the base. - Text to speech voices for over 30 languages. - Speech recognition. - Speech synthesis. - Face tracking and facial analysis.	- Pointing its attention by changing face pose and eye gaze. - Pre-built expressions and gestures that can be specified to adapt different characters.
NeCoRo (Nakashima et al., 2010**;** Libin & Libin, 2004)	- Companion robot	- Cat like appearance (Artificial fur). - **<u>Interaction components</u>:** - Fifteen actuators located in different parts of the robot's body. - Sound sensor fixed in the ear. - Four touch sensors located in two different places: two in the head and another two on the back and neck. - Sight sensor fixed on the nose. - Speaker fixed in the mouth.	- The robot has the ability of expressing satisfaction, surprise, hatred and anger emotions corresponding to factors like sudden loud sounds and when it is stroked or picked up. - The robot behaves like a real cat by showing its interest in the surrounding things and its desire to sleep or fawn over.

Table 2.8 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)
Aibo (*aibo - Specification*, 2019; Fujita, 2001)	- Companion robot	- Dog-like appearance. - **Interaction components:** - Degree of freedom: 22 axes in head (3 DOF), mouth (1 DOF), neck (1 DOF), waist (1 DOF), legs and paws (3 DOFs x 4), ears (1 DOF x 2) and tail (2 DOFs). - Display: two OLEDs eyes as a responsive interface, based on what it sees. - Speaker. - Four microphones. - Sensors: two cameras (front and another one near the tail), four microphone, ToF sensor, two ranging sensor, touch sensors in the head, back and jaws, two 6-axis motion sensor in the head and torso, motion sensor, light sensor and four paw pads contact sensor. Voice recognition ability.	- Expressing simulated feelings like joy, sadness, anger, disgust, surprise, and fear and sleeping when it is tired. - Acting with a wide range of behaviors as a lifelike dog: finding a ball and playing with it and acting like it gives its paw.
NAO (Gouaillier et al., 2008, 2009; Pot et al., 2009)	- Therapeutic and entertainer robot / Educator / Motivator	- Humanoid robot, the size of a two-year-old kid. - **Interaction components:** - 25 DOFs for its head, arms, pelvis, legs and hands. - Two ultrasonic sensors for distance estimation purpose. - Four sensitive resistors to measure the resistance variation caused by pressure of feet. - One video camera fixed in the head. - 20 LEDs located around ears, eyes and feet. - Four microphones and two loudspeakers. Networking capabilities.	- High level functions: walk, dance, speech recognition and synthesis, turn, lie down and stand up. Low level functions: reading sensors and turning the LEDs on and off.

Table 2.9 Interaction components, appearance and behavioral aspects for each studied SAR.

Robot's Name	Role	Physical Specifications/ Interaction Components	Behaviors/ Actions (examples)
Pleo (Fernaeus et al., 2010; Kim et al., 2012)	- Therapeutic and entertainer robot	- Small dinosaur, the size of a cat. - **Interaction components:** - 14 motors to move the tail and the neck, and control the mouth, eye-lid motion and the speed of walking. - Two speakers. - One camera is fixed in the nose. - Two infrared sensors fixed in the nose. - Four push buttons fixed in the feet. - Slope sensor and tow microphone positioned under the eyes.	- Eight social expressive behaviors: excitement, greeting and affirmation, fear and surprise, fear and uncertainty, fatigue, boredom, enthusiastic affirmation and elation by wagging the tail, raising the head and shaking the hips. All these movements can be accompanied with non-verbal sounds like "Eech!", "Woohoo!". - Three waking styles: forward, left, right. - Idling behavior: while not doing any behavior of the 11 behaviors, Pleo moves the head and tail for example.
Pepper (F. Tanaka et al., 2015)	- Peer in the educational process / Nurse assistance	- Humanoid robot, standing 120 cm tall. - **Interaction components:** - Total 20 DOFs. - Four microphones, two cameras, touch and 3D sensors placed in the head. - Two gyroscope sensors positioned in the trunk and leg. - Two touch sensors, two ultrasonic sensors in the leg. - Six laser sensors and three bumper sensors positioned in the leg. - LEDs. - Speech recognition.	- Talking (speech recognition and dialogue in 15 languages).

2.3 Accessibility Guidelines and Laws

In this section, the accessibility guidelines and laws for HCI and HRI were explored and searched. Although the search results showed many accessibility guidelines and laws for HCI, there were no accessibility guidelines or laws for HRI.

2.3.1 Accessibility Laws and Regulations for HCI and HRI

This subsection is dedicated for answering the following research question:

- **RQ2:** What are the accessibility laws or regulations for HCI and HRI?

Information Technology has played a major role in the daily activities of humans, therefore, the necessity to ensure accessibility to all users with different abilities and needs has emerged and many countries and organizations issued laws and decisions to guarantee the accessibility issue.

In this search, main accessibility laws, regulations and acts in different countries and international or regional organizations were reviewed. The search was limited to a maximum of two accessibility laws, regulations or acts for each country or organization. The search is also limited to the laws, regulations and acts that explicitly provide accessibility in HCI. Many laws have articles that could be explained and used implicitly for accessibility in HCI.

At countries level:

For HCI, the United States of American (USA) has the **Section 508 law** (IT Accessibility Laws and Policies | Section508.gov, n.d.), which is a regulation that expects all federal agencies to guarantee access to all federal agencies' information and communication technology (ICT) such as computers, websites, copiers machines, printers, etc. for people with disabilities (U.S. Access Board, 2021). Another accessibility law in the USA is **Section 255 of the Telecommunications Act,** which is dedicated to the telecommunication industry, such as all types of telephones including mobile phones, faxes, computers with modems, etc. (Govoni, 2012).

Further, In United Kingdom (UK), the **Equality Act 2010** (HM Government, 2010) requires website accessibility for people with disabilities, while **The Public Sector Bodies (Websites and Mobile Applications) (No. 2) Accessibility Regulations 2018** (UK Statutory Instruments, 2018) maintains mobile applications and websites accessibility.

Likewise, **UNE 139803:2012** (*UNE 139803: 2012*, 2012) is a Spanish regulation that aims to guarantee the accessibility of web content. Additionally, the **German Act on Equal Opportunities for Persons with Disabilities** (BGG) (*BGG*, 2002) and **Barrier-Free Information Technology** (BITV) (*BITV 2.0*, 2011) are digital accessibility laws in Germany. While China has the **Law on the Protection of Persons with Disabilities 1990**

(NATLEX database, 1990), which provides for the development and implementation of equipment that eases the difficulties facing people with disabilities.

In Portugal, **Decree-Law No. 83/2018** (*Decreto-Lei 83/2018, 2018-10-19 - DRE*, 2018) is a national directive that requires web accessibility and mobile applications for all users. As well, **The 2010/2012 Jodhan decision** (Home | Canadian Internet Policy and Public Interest Clinic (CIPPIC) - Canadian Internet Policy and Public Interest Clinic (CIPPIC), n.d.-b) and **Policy on Communications and Federal Identity** (Canada, 2016) are policies in Canada that require web accessibility.

Correspondingly, India has the **National Policy on Universal Electronic Accessibility** (PIB, 2013), which covers the accessibility issues of electronics and ICT products. France has a law for accessibility of all online public communication services in the country which is **Law N° 2005-102 Article 47** (Leplège & Welniarz, 2015).

At regional and international level:

The European Union (EU) has the **European Parliament approved directive 2016/2102** (European Parliament, 2016), which is a directive that mainly covers accessibility for websites and mobile applications. Moreover, the United Nations (UN) implemented **The United Nations Convention on the Rights of Persons with Disabilities** (United Nations, 2020). The convention is concerned with protecting the rights of people with disabilities in several areas, including access to information.

In this research, no accessibility laws, regulations or acts for HRI were found, neither at the countries level nor at the international level. Table 2.2 shows the main accessibility laws, regulations and acts for HCI found in this search.

Table 2.10 Main accessibility laws, regulations and acts for HCI.

#	Accessibility laws/ regulations/ acts	Covered area	Owner
1	**Section 508 law**	ICT e.g. computers, websites, copiers machines, printers.	USA
2	**Section 255 of the Telecommunications Act**	Telecommunication industry, e.g. All types of telephones, faxes, computers with modems.	
3	**Equality Act 2010**	Websites accessibility.	UK
4	**The Public Sector Bodies (Websites and Mobile Applications) (No. 2) Accessibility Regulations 2018**	Mobile applications and websites.	
5	**UNE 139803:2012**	Web content.	Spain
6	**German Act on Equal Opportunities for Persons with Disabilities (BGG)**	Digital Accessibility	Germany

Table 2.11 Main accessibility laws, regulations and acts for HCI.

#	Accessibility laws/ regulations/ acts	Covered area	Owner
7	**Barrier-Free Information Technology (BITV)**	Digital Accessibility	Germany
8	**Law on the Protection of Persons with Disabilities 1990, as amended in China**	Development and implementation of equipment that eases the difficulties of people with disabilities.	China
9	**Decree-Law No. 83/2018**	Web and mobile applications.	Portugal
10	**The 2010/2012 Jodhan decision**	Web accessibility.	Canada
11	**Policy on Communications and Federal Identity**	Web accessibility.	Canada
12	**National Policy on Universal Electronic Accessibility**	Electronics and ICTs products.	India
13	**Law N° 2005-102 Article 47**	Online public communication services in the country.	France
14	**European Parliament approved directive 2016/2102**	websites and mobile applications	EU
15	**The United Nations Convention on the Rights of Persons with Disabilities**	Access to information.	UN

2.3.2 Accessibility Guidelines and Standards for HCI and HRI

This subsection is dedicated for answering the following research question:

- **RQ3:** What are the main accessibility standards, guidelines and recommendations for HCI and HRI?

In this section, the main accessibility guidelines and standards for HCI and HRI were reviewed. The focus was on well-known companies and accessibility organizations' guidelines or standards, where it was noticed that many countries have policies to comply with such guidelines and standards. For example, in the UK the **BS 8878** (Bsi, 2012) standards for web accessibility were replaced with **ISO 30071-1** (ISO/IEC 30071-1, 2019).

For instance, the **World Wide Web Consortium (W3C)** developed accessibility guidelines, such as the Web Content Accessibility Guideline (WCAG 2.1) (Chisholm et al., 2001) for web, non-web content and ICT; the User Agent Accessibility Guidelines (UAAG 2.0) for user agents which render the web content such as browsers, media players, etc.; the Authoring Tool Accessibility Guidelines (ATAG); and the Web Accessibility

Initiative-Accessible Rich Internet Applications (WAI-ARIA) (Diggs et al., 2016). These guidelines help authors specify the proper semantic meaning of web content, hence, allowing Assistive Technologies (AT) to provide user interface behaviors and structural information to the user. W3C accessibility guidelines are comprehensive as they consider several web components such as web content, user agents, authoring tools and assistive technologies. These guidelines are presented for those interested among different types of supporting documents, like success criteria which work as a quick checklist, techniques, best practices and examples that explain how to achieve accessibility. And documents for more understanding and additional guidance for both success criteria and techniques. In addition, the guidelines have a conformance level model which starts with "A" the basic level for accessibility, "AA" the medium level for accessibility and ends with "AAA" the higher level for accessibility.

Funka Nu guidelines (Mobile guidelines - Funka, n.d.) which are accessibility guidelines for mobile interfaces by the Swedish consultancy for accessibility and user experience. The guidelines are presented in one document with a brief description for each guideline. **BBC guidelines** (BBC, n.d.) for BBC's Digital products were designed to manipulate the accessibility issue from software perspective such as web accessibility. **IBM accessibility checklists** (IBM, 2014a) address accessibility issues from software and hardware perspectives such as web, non-web software, documentation and designing accessible hardware like personal computers, servers, printers, etc.

Further, **Apple** introduced their accessibility guidelines (Apple., n.d.) for designing and implementing accessible applications that run on their platforms too. Apple accessibility guidelines are supported with resources and documentation which include a description for each guideline with additional learning sources, coding and graphical examples too. Correspondingly, **Android developers** (Google, 2020) present their accessibility guidelines for android applications. The guidelines are presented along with coding and graphical examples, and additional resources (links) to provide more explanations.

The European Telecommunications Standards Institute (ETSI), European Committee for Standardization (CEN) and European Committee for Electrotechnical Standardization (CENELEC) implemented **EN 301 549** (ETSI org, 2018), which is a group of Accessibility guidelines for ICT products and services. These guidelines are explained in a document along with their test procedures and evaluation methodology. Moreover, the latest version of these guidelines adopted WCAG 2.1. A few graphical examples are attached to the guidelines, besides referencing technical reports, ISO and WCAG 2.1 as support documents that could help in implementing the accessibility guidelines.

Also, ISO implemented **ISO/IEC 30071-1** (ISO/IEC 30071-1, 2019) standards for establishing organizational accessibility for ICT systems, such as mobile interfaces, websites, social media, wearable applications, etc. by adopting accessibility policies, and embedding accessibility decisions in ICT systems' lifetime starting from implementing, procuring and installing processes and ending with maintenance process. Table 2.3 shows main accessibility guidelines or standards found in this search.

Table 2.12 Main accessibility guidelines and standards for HCI.

<table>
<tr><th>#</th><th>Accessibility guidelines</th><th>Covered areas</th><th>Owner</th><th>Presentation style</th></tr>
<tr><td>1</td><td>WCAG 2.1</td><td>Web content, non-web content and ICT. E.g. desktops, tablets, laptops and mobiles.</td><td rowspan="4">W3C</td><td rowspan="4">Supporting documents, like:
- Success criteria (Checklists).
- Technique explanations to reach accessibility.
- Additional in depth guidance or explanation for success criteria and techniques.
- Conformance level model.</td></tr>
<tr><td>2</td><td>UAAG 2.0</td><td>User agents. E.g. web browsers, media players, and readers.</td></tr>
<tr><td>3</td><td>ATAG 2.0</td><td>Authoring tools for developers and users. E.g. web page and multimedia authoring tools.</td></tr>
<tr><td>4</td><td>WAI-ARIA 1.1</td><td>Semantic meaning of web content.</td></tr>
<tr><td>5</td><td>Funka Nu</td><td>Mobile interfaces and applications.</td><td>Swedish consultancy for accessibility and user experience</td><td>One document contains all guidelines with brief descriptions for each one. No examples or techniques' explanations are available in the documents.</td></tr>
<tr><td>6</td><td>BBC</td><td>BBC's digital products. E.g. HTML accessibility</td><td>BBC</td><td>The guidelines were available on the BBC website, each guideline was attached with an HTML coding example. The guidelines explained briefly.</td></tr>
<tr><td>7</td><td>IBM</td><td>- Software. E.g. web, non-web software, documentation.
- Hardware. E.g. personal computers, servers, printers.</td><td>IBM</td><td>Each guideline (checklist) is attached with technique explanations to reach accessibility and test the technique too.</td></tr>
<tr><td>8</td><td>Apple's accessibility guidelines for their applications</td><td>For all apple's applications (software) which run on different apple's platforms.</td><td>Apple</td><td>Resources and documentation:
- Each guideline is described thoroughly and attached to graphical examples or / and additional sources sometimes (links), such as code examples.</td></tr>
</table>

Table 2.13 Main accessibility guidelines and standards for HCI.

#	Accessibility guidelines	Covered areas	Owner	Presentation style
9	**Android developers accessibility guidelines**	Android applications (software).	Android developer/ Google	Resources are available for designing and developing android application: - Each guideline is described thoroughly, and attached to coding or / and graphical examples; additional resources (links) are also available for more explanations.
10	**EN 301 549**	ICT product and services. E.g. for web and mobile applications, hardware, etc.	ETSI, CEN and CENELEC	- The guidelines are explained briefly in the document along with, - Test procedures and evaluation methodology - A few graphical examples are attached to the guidelines. - Supported documents are referenced in the document, like WCAG 2.1, ISO and other technical reports.
11	**ISO/IEC 30071-1:2019**	ICT products and services	ISO	- Guidelines for establishing and maintaining accessibility for organizations' ICT systems. - Providing guidelines for organizational accessibility policy rather than technical requirements. - Guidelines for embedding accessibility decisions in ICT systems implementation, installation, procurement and maintenance processes.

Accessibility requirements in HCI have been extensively investigated by researchers and industry, where many guidelines and standards were introduced to help designers and developers to create accessible products. However, none of these guidelines can be completely applied to robotics designing due to the differences in physical components and application areas.

In this review, no accessibility guidelines, standards or recommendations for HRI were found.

2.4 Evaluation Methodologies for HRI

This section is dedicated to answer the following research question:

- **RQ4**: What are the evaluation methodologies for HRI?

Following, main HRI evaluation frameworks and methodologies are reviewed according to their date of appearance, in addition to highlighting evaluation metrics adopted in each framework or methodology.

There are two works that contributed to forming early theoretical frameworks for HRI, the first one is Thurn's (2004) work which sorted robots under three categorizations: industrial robots, professional service robots and personal service robots, besides describing the interaction interfaces for the three mentioned robots types. The second work is by Yanco & Drury (2004) who provided another classification for HRI, where the proposed classification rely on 11 categories: task type; task criticality; robot morphology; ratio of people to robots; composition of robot teams; level of shared interaction among teams; interaction roles; type of human-robot physical proximity; decision support for operators; and time / space taxonomy and autonomy level. A further step towards defining HRI metrics was taken by Steinfeld et al. (2006), whose work focuses on task-oriented mobile robots. The metrics aim to measure navigation, perception, management, manipulation and social acceptance for mobile robots. They also defined biasing factors that could affect measuring robot effectiveness, communications (e.g. delay, bandwidth and jitter), robot response, user… etc.

Bartneck et al. (2009) developed five questionnaires to measure users' perceptions of robots in terms of five concepts: anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety. They performed a literature review on how the five mentioned concepts were measured, then they used the results to propose their evaluation questionnaires. Heerink et al. (2010) proposed the Almere model with the aim of evaluating acceptance of assistive social agents in the perceptions' of elderly users. Basically, the Almere model was built based on another well-known model, which is the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). UTAUT was developed as a model to measure user acceptance of information technology in terms of four constructs: performance expectancy, effort expectancy, social influence and facilitating conditions. The Almere model adopted UTAUT's four constructs, and to adapt the later model to the context of social robots, some constructs were renamed and new constructs were added. Thus, the Almere model include 12 constructs for measuring user acceptance of social robots: perceived adaptivity; anxiety; social presence; perceived sociability; social influence; attitude; perceived usefulness; perceived ease of use; perceived enjoyment; trust; facilitating conditions; and intention to use (Heerink et al., 2010).

The USUS (usability, social acceptance, user experience, and societal impact) evaluation framework is a well-developed evaluation framework for HRI proposed by Weiss et al. (2009). USUS is concentrated to measure four factors: usability, social acceptance, user experience and societal impact. A multi-level indicator model is adopted in the framework to measure each factor.

A methodological evaluation approach that considers user experience (UX) perspective is ANEMONE (action and intention recognition in human robot interaction) (Lindblom & Alenljung, 2020). ANEMONE evaluates to what extent users are able to recognize action and intention of a robot, through a procedure consisting of 5 phases: preparation; selection of UX evaluation type; plan and conduct of the UX evaluation; analysis of collected data and identifying UX problems; organizing the identified UX problems in terms of scope and severity.

Iglesias et al. (2021) presented the AUSUS (accessibility, usability, social acceptance, user experience, and societal impact) evaluation framework as an extension of the USUS evaluation framework (Weiss et al., 2009). AUSUS includes an additional evaluation factor which is accessibility, and describes a set of evaluation methods to assess accessibility in HRI.

Table 2.4 shows main HRI evaluation frameworks and methodologies reviewed in this section.

Table 2.14 Main HRI evaluation frameworks and methodologies.

#	Evaluation framework	HRI Measured aspects/ framework contribution
1	Framework for HRI (Thurn, 2004)	- One of the earliest works that helped in forming the theoretical framework for HRI. - Categorization of robots types: industrial robots, professional service robots and personal service robots. And a description of interaction interfaces of the three mentioned robots types.

Table 2.15 Main HRI evaluation frameworks and methodologies.

#	Evaluation framework	HRI Measured aspects/ framework contribution
2	Taxonomy for HRI (Yanco & Drury, 2004)	- One of the earliest works that helped in forming the theoretical framework for HRI. - Classification for HRI, based on 11 categories: task type; task criticality; robot morphology; ratio of people to robots; composition of robot teams; level of shared interaction among teams; interaction roles; type of human-robot physical proximity; decision support for operators; time / space taxonomy and autonomy level.
3	Common metrics for HRI (Steinfeld et al., 2006)	- Define five metrics for HRI evaluation: navigation, perception, management, manipulation, social acceptance for mobile robots. - Define biasing factors that could affect measuring robot effectiveness; communications and jitter); robot response; user … etc.
4	Measurement Instruments for HRI (Bartneck et al., 2009)	- Develop five questionnaires to evaluate users' perception of robots in terms of anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety.
5	Almere model (Marcel Heerink et al., 2010)	- Built based on the UTAUT model which has four constructs: performance expectancy, effort expectancy, social influence, and facilitating conditions that aim to evaluate user acceptance toward information technology. - Then, a new model (Almere model) was presented to measure users' acceptance towards social robots in terms of 12 constructs: perceived adaptivity; anxiety; social presence; perceived sociability; social influence; attitude; perceived usefulness; perceived ease of use; perceived enjoyment; trust; facilitating conditions; intention to use
6	USUS evaluation framework (Weiss et al., 2009)	- Evaluation framework measures four factors in HRI: usability, social acceptance; user experience and societal impact. A multi-level indicator model dedicated to measure each factor.
7	ANEMONE methodological evaluation approach (Lindblom & Alenljung, 2020)	- ANEMONE presents a five-step procedure to evaluate the extent to which users are able to recognize the robot's action and intent.

Table 2.16 Main HRI evaluation frameworks and methodologies.

#	Evaluation framework	HRI Measured aspects/ framework contribution
8	AUSUS evaluation framework (Iglesias et al., 2021)	- It is an extended evaluation framework of the USUS model. - In AUSUS, USUS's evaluation factors remain the same, but an additional factor was added which is accessibility, besides a description of a set of methods to implement the evaluation framework.

2.5 Summary

This thesis aims essentially to propose accessibility guidelines for HRI, hence, the initial step was to study the relevant topics which were encapsulated in four research questions associated with this chapter. Following, a summary explains how each research question was answered in this chapter.

The first research question associated to this chapter, is:

- **RQ1:** What are the application domains of SARs in the society, and what are their interaction components?

This research question encompasses two issues: **the application domains of SARs** and **SARs' interaction components**. Three sections were dedicated to answer this research question. In Section (2.2), twenty SARs were studied and classified under two categories; **SARs Specifically Designed for Assistive Tasks** and **Commercial SARs Used for Assistive Tasks**. The application domain, physical specifications and behavioral aspects for each robot were identified in table 2.1.

The second research question associated to this chapter, is:

- **RQ2:** What are the accessibility laws or regulations for HCI and HRI?

Accessibility laws, regulations and acts at countries level and international levels were reviewed. **Fifteen accessibility laws, regulations and acts were identified, in addition to the area covered by each one**. The guidelines varied in terms of software and hardware aspects. Table 2.2 includes **main accessibility laws, regulations and acts for HCI**. No accessibility laws, regulations or acts for HRI were found during this review.

The third research question associated to this chapter, is:

- **RQ3:** What are the main accessibility standards, guidelines and recommendations for HCI and HRI?

A search was conducted to review the main accessibility guidelines, standards and recommendations for HCI and HRI. **The owner, covered area and presentation style of 11 HCI accessibility guidelines and standards were identified** in table 2.3. No accessibility guidelines, standards, or recommendations for HRI were found during this review.

The fourth research question associated to this chapter, is:

- **RQ4:** What are the evaluation methodologies for HRI?

The main HRI evaluation frameworks and methodologies are reviewed in this search following their chronological order. **Evaluation metrics / factors were identified for each studied evaluation framework or methodology, besides the relativity between some evaluation frameworks were explained too**. Table 2.4 presents main HRI evaluation frameworks and methodologies have been studied. In this thesis the AUSUS evaluation framework will be followed in a user evaluation.

Chapter 3: Analysis and Classification of Robot's Interaction Components

In order to find an adequate answer to the first research question which is:

- **RQ1:** What are the application domains of SARs in the society, and what are their interaction components?

A list and a proposal of a classification for interaction components / interfaces of SARs are presented in this chapter. This proposal was introduced based on the literature review of SARs conducted in the previous chapter. Then, a systematic review was conducted to identify any classification of interaction components / interfaces of SARs. The results of the systematic review were integrated into our proposed classification of SARs' interaction interfaces at the end of this chapter.

3.1 Discussion of Social Assistive Robots Review

According to the literature review of SARs application domains, and aiming to present a list and a proposal of a classification for interaction components / interfaces of SARs, the following methodology was followed:

1. For the most important SARs during the last decades, the physical structure and behavioral aspects were studied and analyzed in the previous chapter, then the **interaction components were specified for them**, along with the appearance and behavioral aspects for each robot, see table 2.1.
2. The **interaction components were grouped under two categories**, hardware components and software components. Figure 3.1 presents a proposal of a classification for SARs interaction components.

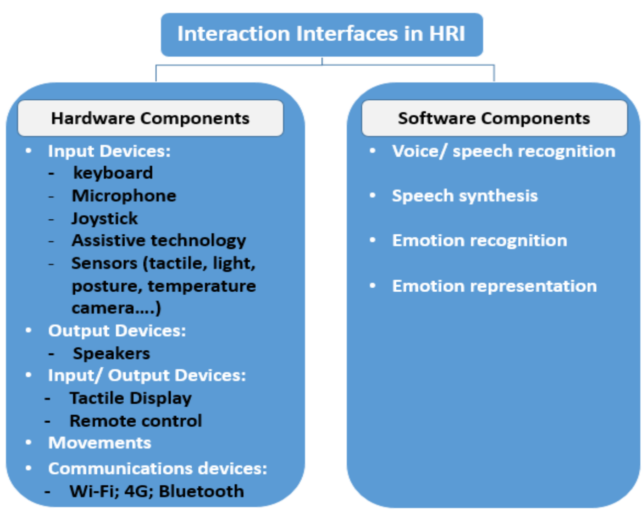

Figure 3.1 Classification for interaction interfaces of SARs.

3.2 Interaction Components of SARs (Systematic Review)

The following systematic review was conducted to identify **any classification or identification of the interaction components or interfaces of SARs**, according to the procedures introduced by Kitchenham (2004).

Review Protocol

The PICO (Population, Intervention, Comparison and Outcomes) for this systematic review is described to define the range and specificity:

- **Population**: the researchers, designers and developers in the HRI field.
- **Intervention**: the interaction components or interfaces of SARs.
- **Comparison**: it is not applicable in this systematic review.
- **Outcomes**: a comprehensive review on the available research and studies regarding any classification of interaction components or interfaces of SARs.

Four major databases were selected to conduct this systematic review, including ACM Digital Library and IEEE Xplore, as these two databases include the majority of peer-reviewed HRI and general robotics published studies (L. Riek, 2012), besides, Scoups and Web of Science. Search processes were limited to peer- reviewed publications, written in English language and published between (2010- 2021). The general search strings used were: **((interaction OR user) AND Interface* AND (“components” OR “hardware” OR “software”) AND ((social* AND robot*) OR “socially assistive robots” OR “SARs”))**. Table 3.1 shows the specific protocol applied in each database.

Table 3.1 The specific protocol applied in each database.

#	Database	Applied string	Note
1	**IEEE Xplore**	("Abstract":(user OR "Abstract":interaction)) AND ("Abstract":interface*) AND ("Abstract":(components OR "Abstract":hardware OR "Abstract":software)) AND ("Abstract":(social* AND "Abstract":robot*) OR "Abstract":"socially assistive robots" OR "Abstract":SARs")	- Search string was applied in the abstract field.
2	**ACM Digital Library**	[[Abstract: interaction] OR [Abstract: user]] AND [Abstract: interface*] AND [[Abstract: components] OR [Abstract: hardware] OR [Abstract: software]] AND [[[Abstract: social*] AND [Abstract: robot*]] OR [Abstract: "socially assistive robots"] OR [Abstract: sars]] AND [Publication Date: (01/01/2010 TO 12/31/2021)]	- Search string was applied in the abstract field.

Table 3.2 The specific protocol applied in each database.

#	Database	Applied string	Note
3	**Scoups**	TITLE-ABS-KEY ((interaction OR user) AND interface* AND ("components" OR "hardware" OR "software") AND ((social* AND robot*) OR "socially assistive robots" OR sars)) AND PUBYEAR > 2009 AND PUBYEAR < 2022 AND (LIMIT-TO (OA , "all")) AND (LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "ENGI"))	- Search string was applied in the title, abstract and key fields. - The search was limited to computer science and engineering subject area.
4	**Web of Science**	AB= ((interaction OR user) AND (interface*) AND ("components" OR "hardware" OR "software") AND ((social* AND robot*) OR (" socially assistive robots") OR SARs)) and Computer Science or Engineering or Robotics or Automation Control Systems or Telecommunications or Science Technology Other Topics (Research Areas)	- Search string was applied in the abstract field. - The search was limited to computer science, engineering; Robotics, Automation Control Systems, Telecommunications , Science Technology Other Topics and research areas.

In the selection phase, the title and abstract of the obtained publication was reviewed. In most cases, the introduction and conclusion are also reviewed during initial selection due to the specificity of what this review is searched for. All obtained publications were included or excluded in initial selection based on the following inclusion (IC) and exclusion criteria (EC):

- **IC1**: researches that study the different interaction interfaces or components of SARs, and the hardware and software components together.
- **IC2**: researches and studies that propose or suggest a classification of interaction interfaces or components of SARs.
- **EC1**: researches and studies that do not focus mainly on interaction interfaces or components of SARs.
- **EC2**: researches and studies that consider one aspect (hardware or software) of interaction interfaces or components for SARs.
- **EC3**: researches and studies focus on one type of SARs.

- **EC4**: researches and studies that are already included from one of the searched databases in this systematic review, to prevent duplication.

Results

Table 3.2 shows a summary of initial selection results. (93%) of the obtained publications were excluded by (EC1) since they have no relation with SARs interaction interfaces. (4%) of the obtained publications were excluded because they do not consider all interaction components of SARs, instead they focus on one aspect (e.g. hardware or software) or even a part of any studied aspect. The lowest percentage, which is (3%) of excluded publications, that relate to those that focus on interaction interfaces of one type of SARs.

Table 3.3 Summary of first selection.

Searched database	Obtained publications	EC1	EC2	EC3	EC4	Selected publications
IEEE Xplore	0	-	-	-	-	0
ACM Digital Library	293	283	8	2	-	0
Scoups	53	43	5	3	-	2
Web of Science	26	19	2	4	-	1
Total	**372**	**345**	**15**	**9**	**-**	**3**

Three of all obtained publications were selected, as they study the interaction interfaces of SARs, both hardware and software aspects, and present those interaction components in explicit classification or organized in a framework for developing SARs and designing interaction. Table 3.3 presents some details about the three selected publications.

Table 3.4 Selected publications.

#	Publication	Publication description	Classification context
1	**Tzafestas (2016)**	In this publication, a layered classification of the interaction interfaces in human-robot social interaction is presented. Human robot interfaces are classified under unimodal and multimodal based on the diversity of input and output channels, then modality itself is classified under visual-based modality, audio- based modality and sensor-based modality (figure 3.2).	- Explicit layered classification of interfaces in human-robot social interaction.

Table 3.5 Selected publications.

#	Publication	Publication description	Classification context
2	**Glas et al. (2012)**	This publication aims to provide a framework for developing social robots by supporting teamwork of interfaces programmers and interaction designers. The classification of the interaction interfaces of social robots was presented in a framework / system consisting of four layers: robot driver layer, information processing layer, behavior layer and application layer. The low level layers (robot driver and information processing layers) present a hardware and software interaction interfaces classification for social robots respectively, both layers labeled in red in figure 3.3.	- Implicit two layers classification (hardware and software) that is presented in a four-layer framework for developing social robots.
3	**Coronado et al. (2021)**	This publication introduces a framework for programming interfaces and behaviors of social robots. The proposed framework called Robot Interfaces From Zero Experience (RIZE) allows designers and developers from different backgrounds to work as a team using RIZE software tools. The architecture of software tools were described through a number of modules, two of them (sensory and perceptual modules) describe the interaction interfaces of social robots. Both modules are highlighted in red in figure 3.4.	- Implicit two layers classification (sensory & perceptual systems) that is presented in a framework for programing interfaces and behaviors of social robots.

To answer the research question elaborated in this section, the presented classifications in the three papers were reviewed and analyzed. It is important to clarify that, the selected publications present interaction interfaces of SARs through two different contexts, explicit classification as in Tzafestas (2016), and implicit through a framework for programming interfaces and design interaction of SARs represented in Glas et al. (2012) and Coronado et al. (2021):

1) **Tzafestas (2016)** distinguished human-robot interfaces under unimodal and multimodal classification, and defined modality as the diversity of input and output channels used in HRI. Moreover, the modality is detailed into: visual-based modality, audio-based modality and sensor-based modality (figure 3.2).

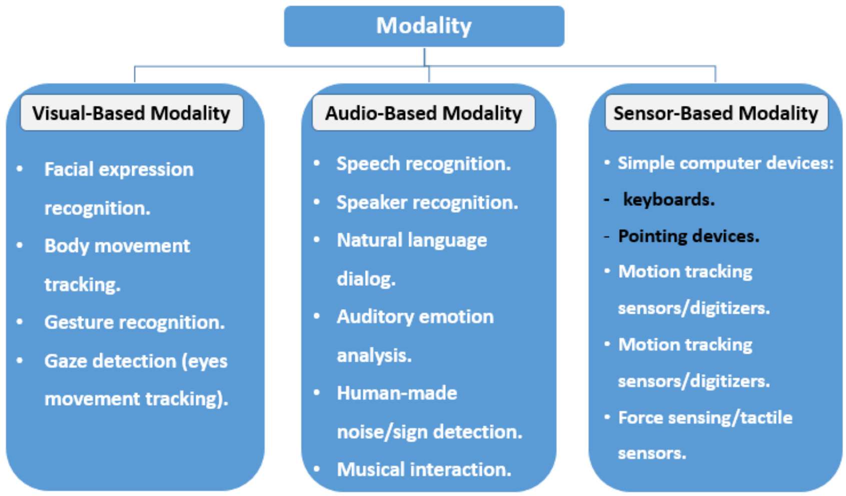

Figure 3.2 Interaction components in HRI according to Tzafestas (2016).

2) **Glas et al. (2012)** introduced a four-layer framework for developing social robots. The two lower layers of the framework are dedicated to programmers (robot driver and information processing layers), while the two upper lowers are dedicated to interaction designers. The purpose of this framework is to support the teamwork of interfaces programmers and interaction designers, to hide the complexity of manipulating data and information in the low level layers from interaction designers, and to allow each one in the team to focus only on her / his role. After studying the framework hierarchy, it was found that the two lower layers present hardware and software interfaces respectively (figure 3.3).

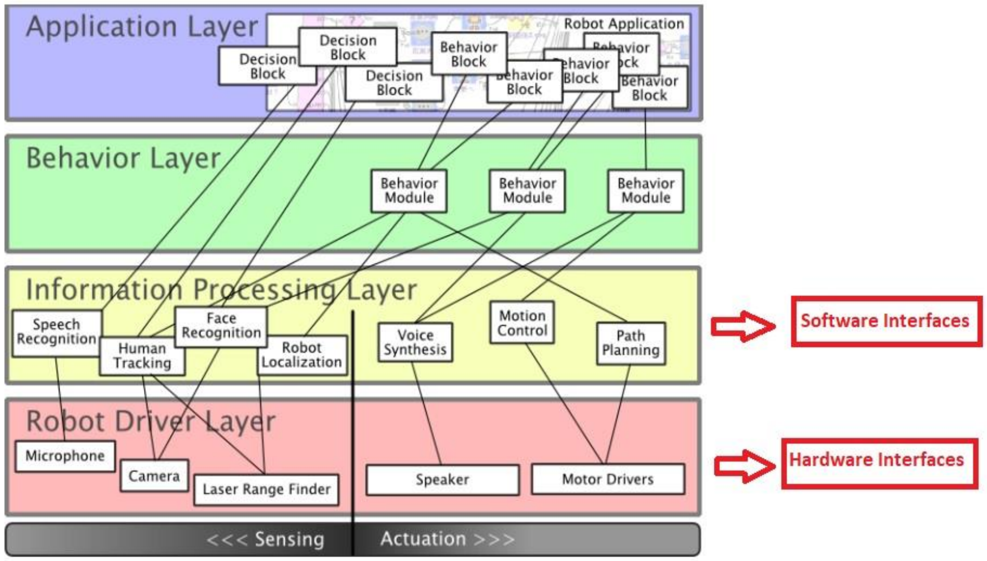

Figure 3.3 Interaction components in HRI elicited from Glas et al. (2012) work.

3) **Coronado et al. (2021)** introduced a framework called the Robot Interfaces From Zero Experience (RIZE), which allows designers and developers from different backgrounds to work together, and program interfaces and behaviors of social robots as a team using RIZE software tools. The architecture of the RIZE software tools consists of a set of modules two of them, being the sensory and perceptual modules. The sensory system obtain data from the environment, such as cameras, microphones, touch and range sensors, while the perceptual system generates data used in forming behavioral primitives, benefiting from speech recognition, emotion recognition, touch interpretation, human proxemics behaviors interpretation, face recognition and object recognition technologies. After studying the proposed framework, it was found that the sensory system represents hardware interfaces, while the perceptual system represents software interfaces of social robots. Both modules are highlighted in red in figure 3.4.

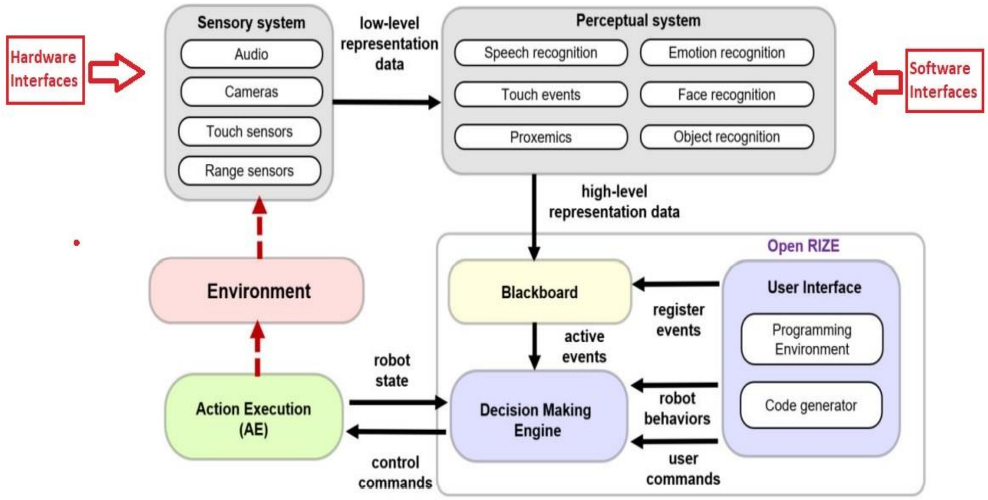

Figure 3.4 Interaction components in HRI elicited from Coronado et al. (2021) work.

To conclude an answer for the research question of this section, it was found that Tzafestas' (2016) work represents the most detailed and comprehensive classification for interaction interfaces of social robots, compared to the other two classifications found in this systematic review. To integrate the results found in this section with our proposed classification for interaction interfaces of SARs (figure 3.1), it was decided to add the interaction interfaces presented in the three classifications that were found in the systematic review to our proposed classification. Provided that only the interaction interfaces extracted from the three classification, which are not found mainly in our proposed classification, will be added to our proposed classification. Table 3.4 presents added interfaces from each classification found in the systematic review.

Table 3.6 Added interfaces from each classification found in the systematic review.

#	interfaces classification	Added interaction interfaces	
		Software components	**Hardware components**
1	**Tzafestas (2016)**	– Emotion recognition • Gaze recognition. • Facial recognition.	– Posture and motion sensors.
		– Gesture recognition.	
		– Body movement tracking.	
		– Speaker recognition.	
		– Musical interaction.	
		– Human-made noise/sign detection.	

Table 3.7 Added interfaces from each classification found in the systematic review.

#	interfaces classification	Added interaction interfaces	
		Software components	**Hardware components**
2	**Glas et al. (2012)**	– Robot localization.	– Replacing "Movements" with motor drivers.
		– Motion control. – Path finding.	– Range sensors.
3	**Coronado et al. (2021)**	– Object recognition. – Touch interpretation.	-

Figure 3.5 shows the updated classification for interaction interfaces of SARs, where all interfaces listed in table 3.4 were added to our proposed classification.

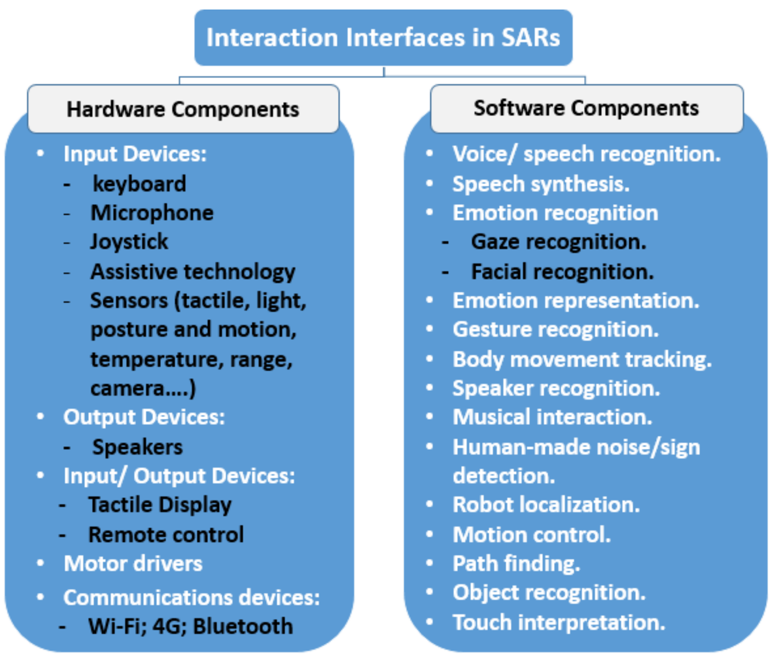

Figure 3.5 The updated classification for interaction interfaces of SARs.

3.3 Summary

This chapter is devoted to extend the search to find an appropriate answer for the following research question:

- **RQ1:** What are the application domains of SARs in the society, and what are their interaction components?

More specifically, this chapter focuses on searching for the interaction components of SARS based on the literature review of SARs conducted in Chapter 2. The interaction components of a 20 studied SARs were classified under two categories: hardware and software (Section 3.1). Figure 3.1 presents **the proposed classification of the interaction components / interfaces of SARs**.

In Section (3.2), a systematic review was conducted to expand the search for an adequate classification for interaction interfaces of SARs. The systematic review resulted in three of them, which were compared to our proposed classification (figure 3.1). **An integrated classification** is **presented** in figure (3.5), where new interaction interfaces were added from the three classifications found in the literature to our proposed classification.

Chapter 4: Study of Accessibility Barriers in Human-Robot Interaction

This chapter is dedicated to answer the following research question:

- **RQ5:** What are the current accessibility barriers in Human-Robot Interaction?

In order to elicit accessibility barriers in HRI, we proposed an evaluation methodology for HRI in this chapter, and user disabilities are defined and mapped to HRI interaction components. Furthermore, accessibility barriers found in the literature, or those elicited from real or fictional users' cases using our proposed evaluation methodology are presented in this chapter too.

4.1 Proposed Accessibility Evaluation Methodology for HRI

Weiss et al. (2009) proposed an evaluation framework for HRI, which targets four factors: usability, social acceptance, user experience and social impact. The study excluded accessibility as an evaluation factor. In this section, a proposal of an evaluation methodology for HRI is explained. The proposed methodology followed in this thesis, to elicit any existing or potential accessibility barriers in HRI.

The Website Accessibility Conformance Evaluation Methodology (WCAG-EM) 1.0 is an approach to specify how well a website complies to WCAG guidelines using software programs or online services besides the manual review. This methodology is considered a guidance on how to perform the accessibility evaluation of the websites (Velleman & Abou-Zahra, 2014). Five main steps should be followed in WCAG-EM, which include: specifying the scope or the goal of the evaluation, exploring the website to specify main web pages; functions; type of content; etc., select sample, evaluate and report the results. (Velleman & Abou-Zahra, 2014).

WCAG-EM is adapted for the needed HRI evaluations in this thesis to elicit accessibility barriers in HRI. The proposed methodology evaluates all robot's interfaces (hardware and software interaction components) and then evaluates the complete interaction process for any service that could be presented by the robot for any specified application. SE and HRI methods were combined to the proposed methodology such as observations, questionnaires and interviews, personas and scenarios, standards and guidelines, and heuristic evaluation. These methods were selected to help in evaluation processes that could be conducted along the interaction design process stages: detecting users' needs, analysis of users' needs, set a potential solution, prototyping and implementing, and launching (Interaction design Foundation, 2020). Next, explanations of when these selected evaluation methods can be used among interaction design process are presented, in addition to an investigation of some of the positives and negatives of these methods:

- **Observations, questionnaires and interviews** can help evaluators find accessibility problems in real cases faced by the targeted users, and can be performed at any time of the product development cycle (Petrie & Bevan, 2009).
- **Personas and scenarios** can diversify and extend the coverage of the potential accessibility problems by using fictional cases. This method helps the designers and developers focus on a specific fictional user case and avoid thinking of all types of users at the same time (Chapman & Milham, 2006). Personas can be used to understand users' needs and behaviors stage (Siang, 2021).
- **Experts' evaluation** refers to the process where the evaluators rely on their expertise, existing guidelines and standards and /or walk through a certain task to find accessibility problems in the product. It is quicker and simpler than using real cases for evaluations. This method can be performed to evaluate the initial prototype (Petrie & Bevan, 2009).

However, we know that each method mentioned above has its own negatives, so it is necessary to combine them to try to cover their limitations. For instance, observations (including questionnaires and interviews) limit the user populations to those were selected for the evaluation at that time where participants tend to be influenced by the presence of the evaluators and the cost of sitting it up (Dix et al., 1998). In personas and scenarios, it is difficult to verify to what extent the personas are accurate, as the more the personas' specifications, the lower the user population it represents (Chapman & Milham, 2006). In experts' evaluation, the difference in knowledge and experience level between experts may affect the reliability of the evaluation results (Petrie & Bevan, 2009). Therefore, this methodology diversifies the use of these methods, to cover the gap caused by the limitations of each method. For example, using the observation method for real user evaluations would cover the limitations of personas and scenarios methods that are used for fictional users' evaluations. The same thing applies to depending on expert knowledge to ensure an accurate and complete personas analysis.

It is important to mention that **the proposed evaluation methodology is open for any applicable evaluation method as long as it suits one of the three evaluation contexts (real users' case, fictional user's case and expert evaluation)**.

The proposed methodology is described as follows:

Step 1. Define the Evaluation Scope

The evaluation scope should include all robot's interfaces, considering the software and hardware interaction components. In addition to specifying the robot's services which need to be evaluated.

Step 2. Explore the Target Robotic Application (Software and Hardware)

All robot's interaction components (hardware and software) should be specified and explored.

Step 3. Audit the Robotic Application

Check All Initial Interaction Components (Software and Hardware): the evaluators audited the interaction components of each interface without entering any inputs or performing tasks / functions.

Check All Complete Processes: the evaluators checked the complete process of all services presented by the robot during the interaction with the user, where the evaluated cases can be:

- Real user cases evaluated using observations, questionnaires and interviews.
- Fictional user cases evaluated using personas and scenarios methods, and considering accessibility guidelines in HCI, such as WCAG (Web Accessibility Initiative, 2012), BBC (BBC, n.d.), Funka Nu (*Mobile guidelines - Funka*, n.d.) and IBM (IBM, 2014b) etc.
- Experts' evaluation using heuristic evaluation for a specific robot services without users; they may rely on their expertise, existing guidelines and standards and / or walk through a certain task.

For the three evaluation cases (real user cases, fictional user cases and expert evaluation), the proposed evaluation methodology is open for any applicable method that can be used for any of the three mentioned evaluation contexts.

Step 4. Reporting the results (the elicited accessibility barriers).

The above methodology is followed in this thesis to elicit accessibility barriers in HRI from: real user cases in an evaluation that was conducted in a summer camp at the European University of Madrid (UEM), and from fictional user cases. The proposed evaluation methodology is also used to evaluate SAR's interfaces for two different applications.

4.2 User's disabilities

In the literature, there are two commonly mentioned models of disability, the social model and medical model. The idea of the social model of disability arose from the Fundamental Principles of Disability document first published in the mid-1970s (UPIAS 1976), which debated that people were not disabled by their impairments but by the disabling barriers they faced in society (Oliver, 2013). The social model differentiates between Impairment and Disability, where impairment is "lacking all or part of a limb, or having a defective limb, organism or mechanism of the body" (Anastasiou & Kauffman, 2013), and disability is "a disadvantage or restriction of activity caused by a contemporary social organization which takes little or no account of people who have physical impairments and thus excludes them from participation in the mainstream of social activities” (Anastasiou & Kauffman, 2013).

In contrast, the medical model of disability considers disability as “an impairment that needs to be treated, cured, fixed or at least rehabilitated, disability is seen as a deviation from the normal health status” (Degener, 2016). Table 4.1 highlights some of the main differences between the social and medical models, which were found in Owens (2015) study and agree with previously mentioned definitions of the two models.

Table 4.1 Comparison between the social and medical models of disability (Owens, 2015).

#	Social Model of Disability	Medical Model of Disability
1	Impairment and disability are separate and not the same.	Impairment causes disability.
2	Persons with impairments may experience disability due to physical, structural and cultural barriers they face.	Person with impairment is a disabled person.
3	Disability can be greatly reduced or eliminated if people with impairments encounter no barriers.	To decrease disability, people with impairments need therapy or medical intervention to prevent, cure or ameliorated impairment.

This study is focused on the definition of disability from the medical model, considering physical, sensorial and cognitive disabilities to classify the main interaction barriers that users could face during interaction with robot’s interfaces.

People contrast in their visual, auditory, motor, cognitive and speech abilities and needs due to temporal reasons such as undergoing surgery, permanent reasons like chronic diseases, or challenged situations like being in noisy environments. In addition, people with disabilities may vary in the disability severity.

As stated by the world health organization (WHO report, 2011), a disability can be complex, dynamic and multidimensional, and people with disabilities are diverse and heterogeneous. For example, Disability includes a child who is born with Cerebral Palsy (CP), a man who loses his leg in a war, a middle-aged woman with arthritis, or elderly with dementia, and many other cases. Moreover, there are people who are described as people with disabilities, but do not see themselves as a disabled persons (Riddell et al., 2005). It is difficult to address the wide range of disability types or to provide a specific description to each type of disability too. Furthermore, one person could have different disabilities at the same time, developing other types of capabilities above and beyond what is usual in individuals. Hence, in this thesis we limit the scope of studied user’s disabilities to include: visual, auditory, motor, cognitive and speech disabilities as individual disabilities.

According to WebAIM (WebAIM, 2013), different types of disabilities can create accessibility barriers for users during their interaction with a computer. The same disabilities can create accessibility barriers for users during their interaction with the robot in varying degrees:

- **Visual Disabilities:** three main visual disabilities which are:
  - Blindness: the World Health Organization (WHO) defines Blindness as the "Profound inability to distinguish light from dark, or the total inability to see" (WHO, 2015). Later, they have modified this definition to include people who have light perception but are still less than 3/60 in the better eye (Geneva, 2008)
  - Low Vision: is the degree of visual acuity which is defined as less than 6/18 and equal to or better than 3/60 in the better eye with best correction (*WHO | Priority eye diseases*, n.d.).
  - Color-Blindness: "is the inability to perceive differences in various shades of colors, particularly green and red, that others can distinguish. It is most often inherited (genetic)" (Andrew A. Dahl, 2020).
- **Auditory disabilities:** people who cannot hear with thresholds of 25 decibels (dB) or better in both ears are considered to have 'hearing loss' that is classified according to its degree. People who have hearing loss vary between mild to severe and are considered to have 'hard hearing', while profound hearing loss is considered deafness (Braaten, 2018).
- **Motor disabilities:** "physical disabilities (sometimes called "motor disabilities") include weakness and limitations of muscular control (such as involuntary movements including tremors, lack of coordination, or paralysis), limitations of sensation, joint disorders (such as arthritis), pain that impedes movement, and missing limbs" (W3C Web Accessibility Initiative, 2018a).
- **Cognitive disabilities:** according to the World Wide Web Consortium (W3C) (W3C Web Accessibility Initiative, 2018b), cognitive, learning, and neurological disabilities embrace neurodiversity and neurological disorders, behavioral and mental health disorders even if it is neurological, and may impact partly of individual's nervous system and control how well the individual hear, move, see, speak, and understand information. All of these disabilities do not necessarily mean that a person's intelligence will inevitably be affected.
- **Speech disabilities:** "speech disabilities include difficulty producing speech that is recognizable by others or by voice recognition software" (W3C Web Accessibility Initiative, 2018c). Speech disabilities causes may be genetic, or due to other learning disabilities, auditory disabilities, Autism spectrum disorder, traumatic brain injury, stroke, and cancer (*Speech Disabilities | Web Accessibility Basic Concepts - Wells Fargo*, n.d.).

4.3 Mapping SAR's interaction components to main affected users' disabilities

In this section, each SAR's interaction component in the proposed classification of HRI Interaction components (figure 3.5) were mapped to main potential accessibility disabilities and not to all types of disabilities. Those mapped disabilities were limited to physical, sensorial and cognitive disabilities, which were studied in section (4.2) based on the medical model adopted in this study. The potential barriers in HRI were explained too, considering if the interaction component is input, output component or both, see table 4.2. Some interaction components, such as the assistive technology, sensors and communication devices (Wi-Fi; 4G; Bluetooth) were not matched to any potential disabilities or accessibility barriers, as they are not affected by user's disabilities. Cognitive and learning disabilities are attached to most of the interaction components, where this type of disabilities affects how the user manipulates the information and other abilities such as hearing, visual, motor and speech (W3C Web Accessibility Initiative, 2018a). Potential barrier severity may vary from user to another depending on the severity of disability s/he has.

Table 4.2 SAR's interaction components mapped to the disabilities that affect the interaction process with this component.

<table>
<tr><th>H/S</th><th>In/Out Device</th><th>#</th><th>Interaction component</th><th>Main disabilities that affect interaction process with this component</th><th>Potential barriers</th></tr>
<tr><td rowspan="5">Hardware Components</td><td rowspan="5">Input Devices</td><td>1</td><td>Keyboard</td><td>- Motor disabilities
- Visual disabilities
- Cognitive & learning disabilities.</td><td>- Not being able to press the keys of the keyboard.
- Not being able to see the keyboard.
- Not being able to understand how to interact with the keyboard.</td></tr>
<tr><td>2</td><td>Microphone</td><td>- Speech disabilities
- Cognitive & learning disabilities.</td><td>- Not being able to interact through speech.</td></tr>
<tr><td>3</td><td>Joystick</td><td>- Motor disabilities
- Visual Disabilities
- Cognitive & learning disabilities</td><td>- Not being able to use the joystick.
- Not being able to see the position of the cursor on the robot's display.
- Not being able to understand how to interact with the joystick.</td></tr>
<tr><td>4</td><td>Assistive technology</td><td colspan="2">Assistive technologies used to bypass the effect of disabilities on the interaction.</td></tr>
<tr><td>5</td><td>Sensors (tactile, light, posture, temperature, range, camera, etc.)</td><td>NA</td><td>NA</td></tr>
</table>

Table 4.3 SAR's interaction components mapped to the disabilities that affect the interaction process with this component.

H/S	In/Out Device	#	Interaction component	Main disabilities that affect interaction process with this component	Potential barriers
Hardware Components	Output Device	6	**Speakers**	- Auditory disabilities - Cognitive & learning disabilities	- Not being able to hear the robot's voice or sounds. - Not being able to understand speech.
	Input/ Output Devices & actions	7	**Haptic display**	- Motor disabilities - Visual disabilities - Cognitive & learning disabilities	- Not being able to touch the haptic display. - Not being able to see the outputs on the haptic display. - Not being able to understand how to interact with the haptic display.
		8	**Remote control**	- Motor disabilities - Visual disabilities - Cognitive & learning disabilities	- Not being able to press the buttons of the remote control - Not being able to see the colors of the buttons. - Not being able to understand how to interact with the remote control.
		9	**Motor drivers**	- Motor disabilities - Visual disabilities - Cognitive & learning disabilities.	- Not being able to move different body parts, where the robot sometimes detects the body movements. - Not being able to see the robot movements. - Not being able to understand the meaning of the robot movements.
	Communications devices	10	**Wi-Fi; 4G; Bluetooth**	NA	NA

Table 4.4 SAR's interaction components mapped to the disabilities that affect the interaction process with this component.

H/S	In/Out Device	#	Interaction component	Main disabilities that affect interaction process with this component	Potential barriers
Software Components	**Input Software**	**11**	- **Voice/ speech recognition** - **Speaker recognition**	- Speech disabilities - Cognitive & learning disabilities - Hearing disabilities	- Not being able to speak to the robot. - Not being able to speak clearly or loudly enough.
		12	**Emotion recognition** - **Gaze recognition** - **Face recognition**	- Motor disabilities - Cognitive & learning disabilities - Hearing disabilities	- Not being able to generate facial expressions to express the emotions. - Not being able to understand speech emotions. - Not being able to represent speech emotions due to having hearing disabilities.
		13	- **Gesture recognition** - **Body movement tracking**	- Motor disabilities. - Cognitive & learning disabilities.	- Not being able to generate gestures. - Not being able to recognize/ perceive the proper gesture to perform, to interact with the robot at that time.
		14	**Human-made noise**	- Motor disabilities. - Speech disabilities. - Cognitive & learning disabilities	- Not being able to generate movements/noises. - Not being able to speak.
		15	**Robot localization**	NA	NA
		16	**Objects recognition**	NA	NA
		17	**Touch interpretation**	- Motor disabilities. - Cognitive & learning disabilities	- Not being able to generate movements/touch. - Not being able to recognize/ perceive to interact/ touch the robot.

Table 4.5 SAR's interaction components mapped to the disabilities that affect the interaction process with this component.

H/S	In/Out Device	#	Interaction component	Main disabilities that affect interaction process with this component	Potential barriers
Software Components	Output Software	18	- **Speech synthesis** - **Musical interaction**	- Auditory disabilities - Cognitive & learning disabilities.	- Not being able to hear the robot's voice. - Not being able to understand what the robot says.
		19	**Emotion representation**	- Visual disabilities - Cognitive & learning disabilities. - Hearing disabilities	- Not being able to see the robot facial expressions or gazes which express its virtual emotions. - Not being able to understand the meaning of the represented emotions by the robot due to having cognitive & learning or hearing disabilities.
		20	**Path planning**	NA	NA

4.4 SAR's Accessibility Barriers Found in the Literature

In section (2.2), appearance, behavioral and physical aspects of a number of SARs were studied; the study included research for evaluating different SARs types. We could find some accessibility barriers, which were reported by the researchers who performed these evaluation studies. These accessibility barriers were associated to the related disability, as follows:

People who have **visual disabilities** may face accessibility barriers when they try to distinguish and perceive the hardware components of the robot, the software components of the robot's display screen too, and any lights coming out of the robot. Furthermore, if users' assistive technologies are not compatible with the robot, or there are no implemented alternatives in the robot to their assistive technologies, then they will not be able to access the robot's information. In a study that was conducted to investigate the effectiveness of robotics in eliminating collaborative barriers between people with autism spectrum disorders (ASD) and their therapists (Kim et al., 2012), they used the platform of a robot called Pleo (Fernaeus et al., 2010), which has the appearance of a small dinosaur with the size of a cat. Basically, Pleo interacts with users through social expressive behaviors like excitement, greeting and affirmation, fear and surprise, etc., and imitating non- verbal sounds. Pleo's interaction characteristics would not be accessible for Individuals who have ASD and visual disabilities at the same time.

For people who have **auditory disabilities**, providing captions and transcripts for audio content and media players and controlling the volume of audio content and high-quality foreground audio (W3C Web Accessibility Initiative, 2018a) would help in making the web content accessible for them. But it is different in HRI, for example, not all the robots have display screens to provide the needed textual information for HRI. An example on an inaccessible robot for people who have auditory disabilities is NAO, which is a humanoid robot at the size of a two year old kid and 25 (DOF) degrees of freedom for its head, arms, pelvis, legs and hands (Gouaillier et al., 2009). NAO has pre-programmed behaviors that are considered high level functions such as, walk, dance, speech recognition and synthesis, turn, lie down and stand up, and low level functions like reading sensors and turning the LEDs on and off (Pot et al., 2009). Nevertheless, people who have auditory disabilities still need an interface to receive the textual or visual information such as a display screen or to interact through sign language during interaction with NAO, bearing in mind that sign languages differ sometimes between countries.

Adopting certain mechanisms by web developers could help people with **cognitive disabilities** during their interaction with web pages, for examples, keeping a reminder of the overall web content could help people who have memory deficits, providing warning messages and instructions during and before starting a specific task would be helpful for people who have problem-solving deficits and using icons. Likewise, audio and video as a supplemental media, structural elements like headings and list items, highlighting the items and white space in the margins and between paragraphs and other content unites would decrease accessibility barriers for people who have reading, linguistic, and verbal comprehension deficits (Webaim, n.d.). In 2018, a robot called Silbot (Law et al., 2019) was used to conduct a study on developing assistive robots for people who have mild cognitive disabilities and mild dementia. The robot was designed to help users in their daily activities like waking them up, reminding them about their medications and checking their mood. The robot has a touch screen head, tow arms to generate needed gestures, a camera, microphones and mobile base provided with sensors to handle the navigation process. The researchers pointed out that users can interact with the robot through voice interaction and the touch screen. The interviews with participants revealed how the robot's arm movements, face expressions and flashing lights caused a distraction to them (Law et al., 2019). This kind of distraction could also create accessibility barriers for people who have attention deficits.

For people who have **motor disabilities**, hardware and software assistive technologies are very effective in HCI. For instance, mouth stick and head wand for people who cannot use their hands to type, and handle trackball mouse and web navigation. in addition to single-switch access and sip and puff switch technologies, that depend on a special software to interpret and extend the use of clicks or user's breath; for more complicated functionality like navigating a computer, and voice recognition and eye-tracking software and many other assistive technologies (WebAIM, 2012). In addition, developers can support the accessibility of web content, for instance, by providing large clickable areas and control the time limits for completing any action or process.

In HRI, people with motor disabilities must be able to operate all robot hardware and physical controls with one hand and minimum dexterity. If they do not use any hand, they must be able to operate the robot through vocal or speech input or even by their hardware or software assistive technologies that they are used to in HCI. For example, a study (Andreasen Struijk et al., 2017) demonstrated the possibility of using a wireless intraoral control system by people with tetraplegia to control an assistive robotic arm. One of the participants had difficulties seeing the grippers' position in order to grasp objects due to the distance between the assistive robotic arm and the participants' eyes (Andreasen Struijk et al., 2017). The distance between the user and the robotic arm created an accessibility barrier to the user.

4.5 Eliciting SAR's Accessibility Barriers through Real Users' Case (NAOTherapist)

With the intention of studying accessibility barriers in child-Robot Interaction (cHRI), a user evaluation was conducted by two evaluators who have expertise in this field to evaluate the actual interaction between children with Cerebral Palsy (CP) with hemiplegia or Obstetric Braxial Plexus Palsy (OBPP) and the NAO robot in therapy sessions. Children with hemiplegic cerebral palsy mainly have movement and posture problems in the upper and lower limbs of one side of their body, cognitive and visual problems are common accompanying deficits in CP cases, in addition to hearing problems and psychiatric and conduct disorder (Sankar & Mundkur, 2005), while children with OBPP have movement and sensation problems in one of their upper limbs (Socolovsky et al., 2016).

The NAO robot played a role in the therapy sessions for 11 children with hemiplegic cerebral palsy or OBPP (figure 4.3). A remote accessibility evaluation was performed as evaluators and users were separated in terms of location and time. The therapy sessions were video recorded to enable analysis by the evaluators later (Garc et al., n.d.).

Figure 4.1 Patient interacting with NAO robot in therapy session (Garc et al., n.d).

In this study, the proposed methodology in section (4.1) was followed to implement the evaluation.

Evaluation Design
Objective

Eliciting accessibility barriers in the interaction between children with CP with hemiplegia or OBPP and NAO robot in therapy sessions.

Participants: eleven (2 females and 9 males) children who have CP with hemiplegia or OBPP participated in this study to interact with the NAOTherapist platform in upper-limb rehabilitation sessions. Their ages ranged between 5 and 13 years with no hearing or visual deficits, only one case has confirmed cognitive deficits (Garc et al., n.d.).

Materials: the NAOTherapist platform (Pulido et al., 2017) with a RGB-D sensor (Microsoft Kinect 2) was used (Garc et al., n.d.) to perform gamified upper-limb rehabilitation sessions. The used robot in this study (NAO) was described in section (2.2).

The rehabilitation activities were implemented according to Charles & Gordon's (2006) protocol, and conducted in a summer camp, which lasted 21 days at the European University of Madrid (UEM) in the summer of 2017.

The sessions were recorded by video camera to enable subsequent reviews by evaluators. Observation methods were used to elicit the accessibility problems in the recorded interaction.

Protocol

To execute the evaluation, the evaluators adhered to the proposed methodology in section (4.1), as follows:

Step 1. Define the Evaluation Scope

The evaluation scope includes all NAOTherapist Platform's interfaces, considering the software and hardware aspects. Interaction flow of NAOTherapist is sequential as follows: welcoming story, gamified exercise where the patient is asked to imitate some poses performed by the robot, reward the patient with story or dance and goodbye story (Garc et al., n.d.).

Step 2. Explore the Target Robotic Application (Software and Hardware)

NAOTherapist interfaces can be audial based on loudspeakers, microphones, text to speech synthesis and voice recognition technologies to guide and direct the patient to perform the exercises and correct wrong poses, visual with LEDs placed in different locations like ears and eyes changing from white to green to indicate whether the pose is right or not, and movements that represent how the robot shows patient how to perform the exercises correctly (Garc et al., n.d.).

Audial and movement interaction form the majority of the total interactions between the patient and NAOTherapist. The autonomous behavior of the robot is realized by the automated planning technique (Garc et al., n.d.).

Step 3. Audit the Complete Processes: The evaluators checked the complete videos that include patients' interaction with the robot in the therapy sessions. Moreover, for each patient two therapy sessions, each lasted 20-30, minutes were evaluated.

Results

Table 4.3 shows the final list of accessibility problems that were extracted from the interaction between NAOTherapist and 11 patients, which both evaluators agreed on.

Table 4.6 Extracted accessibility problems of NAOTherapist interfaces.

#	Extracted accessibility problem	Interaction component type
1	**The short height of the robot** caused a notable difference between the height of the patient's stature and the robot's stature, which affected the correctness of the poses that the patient performed during the exercises, as he was bending his head and body forward while looking at the robot. One of the patients performed while sitting on his knees in the second session to be at the same height as the robot, although the poses must be performed while standing.	Hardware

Table 4.7 Extracted accessibility problems of NAOTherapist interfaces.

#	Extracted accessibility problem	Interaction component type
2	**Sudden fast movements:** the robot sometimes scared the patient by doing fast and sudden movements, especially when the robot change from a sitting position to a standing position. This distracts patients' attention, causing a loss of part of the therapy interaction.	Movements
3	**The conversational interaction** between the patient and the robot was often not smooth, besides the conversation was not interactive and seemed static. The robot seemed to narrate a dialogue and not respond to the patient when s/he tried to tell or ask about the exercise or anything. In this case, the patients start asking therapists and people there, then losing part of the therapy interaction with the robot. This extends to include another problem that appeared during the interaction, as the robot failed to motivate a patient who stopped doing the exercises.	Software (application)
4	**The joyful interaction** should be extended to include all the exercises; however, a big part of the interaction was fun for the patient, yet some of the patients seemed bored and did not do the exercises properly at the end of the session, which is the main goal of the whole interaction.	Software (application)
5	There should be **a lasting way to make the patient always know / remember where s/he is in the interaction process.** The robot failed to guide/ remind the patient in memory game when s/he was not able to remember the requested exercise.	Software (application)
6	At the beginning of the interaction, **the patient was scared of the mechanic / robotic appearance of the robot**. The patient took some time to feel safe and start interacting normally with the robot.	Hardware / external appearance

Patients differed in the number and type of accessibility problems they encountered while interacting with NAOTherapist. Figure 4.4 shows the number of users who encountered each problem separately. All the extracted accessibility problems are related to software,

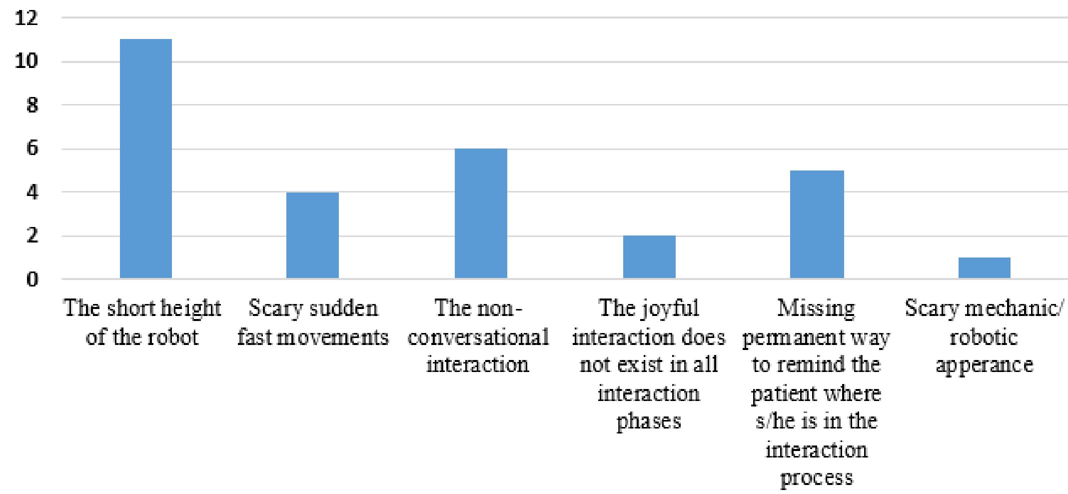

Figure 4.2 Number of patients who encountered each accessibility problem during therapy sessions with NAOTherapist.

hardware and interaction design. All patients experienced the same problem of the short height of the robot in all their therapy sessions.

4.6 Eliciting SAR's Accessibility Barriers through Fictional Users' Case (NAOTherapist)

In addition to the extracted accessibility barriers in Section (4.5), and to expand the investigation of any potential accessibility problems that users may encounter while interacting with NAOTherapist (Pulido et al., 2017), a second study was performed using the Personas (Cooper et al., 2014) method to involve fictional users with different characteristics other than the studied in Section (4.5). The context of interaction in this study is the same as in the previous study, as users are supposed to interact with NAOTherapist for therapy. Personas in this study were selected based on the fact that patients with CP may develop visual, hearing, cognitive and speech disabilities, and psychiatric and conduct disorders such as depression, anxiety, hyperkinesia and inattention mainly because they have CP (Sankar & Mundkur, 2005).

Evaluation Design
Objective

Expand the coverage of the study on accessibility barriers in the interaction between children with CP with hemiplegia or OBPP and NAO robot in therapy sessions by involving different types of potential users with different characteristics.

Participants: Two evaluators with expertise in HCI and HRI accessibility participated to create personas and scenarios to detect potential accessibility barriers that could be faced by patients who interact with NAOTherapist.

Materials: previous studies (Section 4.5) were considered to determine personas and scenarios for this study; users' characteristics in this study are related to the potential characteristics of patients with CP or OBPP which were defined in previous studies such as (Cans et al., 2002) and (Sankar & Mundkur, 2005), while scenarios were built according to the context of use of NAOTherapist in the previous section. The proposed methodology in section (4.1) was also followed, bearing in mind that the evaluation scope and targeted robotic application are the same as in the previous study.

Protocol

To carry out this study, evaluators committed to implement the following protocol:

1. **Creating Personas:** personas are descriptive models of users which are created based on research information to predict the behaviors of different types of users during their interaction with a product and how they think and what they want to accomplish (Cooper et al., 2014). Five personas in this study were defined based on the observations and results of the previous study and information from Surveillance of Cerebral Palsy in Europe (SCPE) network (Cans et al., 2002), which set up a central database to provide information of over 6000 children with cerebral palsy (CP) from 13 geographically defined populations in Europe. Users' characteristics were elicited and determined based on the **associated disabilities** among children with CP, which are defined by SCPE (Cans et al., 2002) and (Sankar & Mundkur, 2005) such as cognitive, speech, visual and hearing disabilities, in addition to psychiatric and conduct disorders. Epileptic seizures cases were excluded in this study, as the patient will not be able to interact with the NAOTherapist itself during epileptic seizures. Moreover, the hemiplegic CP cases' characteristics are included in the study only as NAOTherapist is designed to interact with hemiplegic CP patients only. Other types of CP like Monoplegia, Diplegia and quadriplegia are excluded, as they are not considered in the therapy interaction of NAOTherapist (Garc et al., n.d.). Associated disabilities could influence the interaction with NAOTherapist according to its type and what channels the robot uses for input and output interaction, for example, displays, lights and movements for visual interaction, speech recognition and synthesis for audial interaction. **Age group** of the targeted users of NAOTherapist, which varies between 5 to 14 years (Garc et al., n.d.) is another factor. Age can affect the interaction in case the patient is very young, and s/he might need more explanations or simple language from the robot to understand how to perform the exercises. If the children are older, they may need more entertainment while interacting with the robot so that they do not get distracted while interacting with the robot. **Sex** and **nationality**, patient's language is very essential in the interaction with the robot, since if the robot could not speak or present the patient's language, the whole interaction will be not accessible. Table 4.4 shows the common characteristics and their potential values of personas in this study.

Table 4.8 Personas' common characteristics and their potential values in the study.

Characteristics	**Potential values**
Motor disabilities (One side of upper and lower limbs is affected)	Yes
Cognitive disabilities (Mental retardation (MR), Intelligence Quotient (IQ) less than 50)	Yes or No
Speech disabilities	Yes or No
Visual disabilities (Visual perceptual problems)	Yes or No
Hearing disabilities	Yes or No
Psychiatric (depression, anxiety, hyperkinesia) or conduct problems	Yes or No
Experience with robots	Yes or No
Age	5 - 14 years
Sex	Male or Female
Nationality	Local/ International

Inspired by these characteristics, personas were created to present different types of users with different kinds of disabilities, bearing in mind that all patients with CP or OBPP have motor disabilities. Table 4.5 presents the characteristics for each persona in this study. It is important to mention that it is possible to create a large number of personas using these characteristics, but in this study five personas which are not covering all possible personas were defined as examples for evaluation purposes.

Table 4.9 Personas and their defined characteristics for this study.

	CP or OBPP	**Motor disabilities**	**Cognitive disabilities**	**Speech disabilities**	**Hearing disabilities**	**Visual disabilities**	**Psychiatric/ Conduct problems**	**Experience with robots**	**Age**	**Sex**	**Nationality**
Oliver	OBPP	Yes	No	No	No	No	No	No	11	M	American
Lucas	CP	Yes	Yes	Yes	No	No	No	No	6	M	Spanish
Maria	CP	Yes	No	No	No	Yes	No	No	14	F	Spanish
Pedro	CP	Yes	No	No	No	No	Yes	No	7	M	Spanish
Sofia	CP	Yes	No	No	Yes	No	No	No	9	F	Spanish

All personas in table 4.5 have motor disabilities, as this is a common symptom of all CP and OBPP patients. In addition to motor disabilities, each persona has one more type of disability listed in table 4.5 to allow studying the effect of each disability while interacting with the robot separately without being affected by the rest of the disabilities. As an exception, only one of the personas have two different kinds of disabilities besides motor disabilities, where speech disabilities and cognitive disabilities in CP cases are present (Sankar & Mundkur, 2005). Five personas were created to cover the different types of disabilities of CP and OBPP patients. Giving a life to a persona helps the designers fully engage in its goals, and personas should be carefully described and given a goal, task, name and face (Blomquist & Arvola, 2002). Figure 4.5 presents an example of the used personas in this study, see Appendix A for the rest of the five personas. (All personas' pictures were generated by Artificial Intelligence (Generated Photos, 2021)).

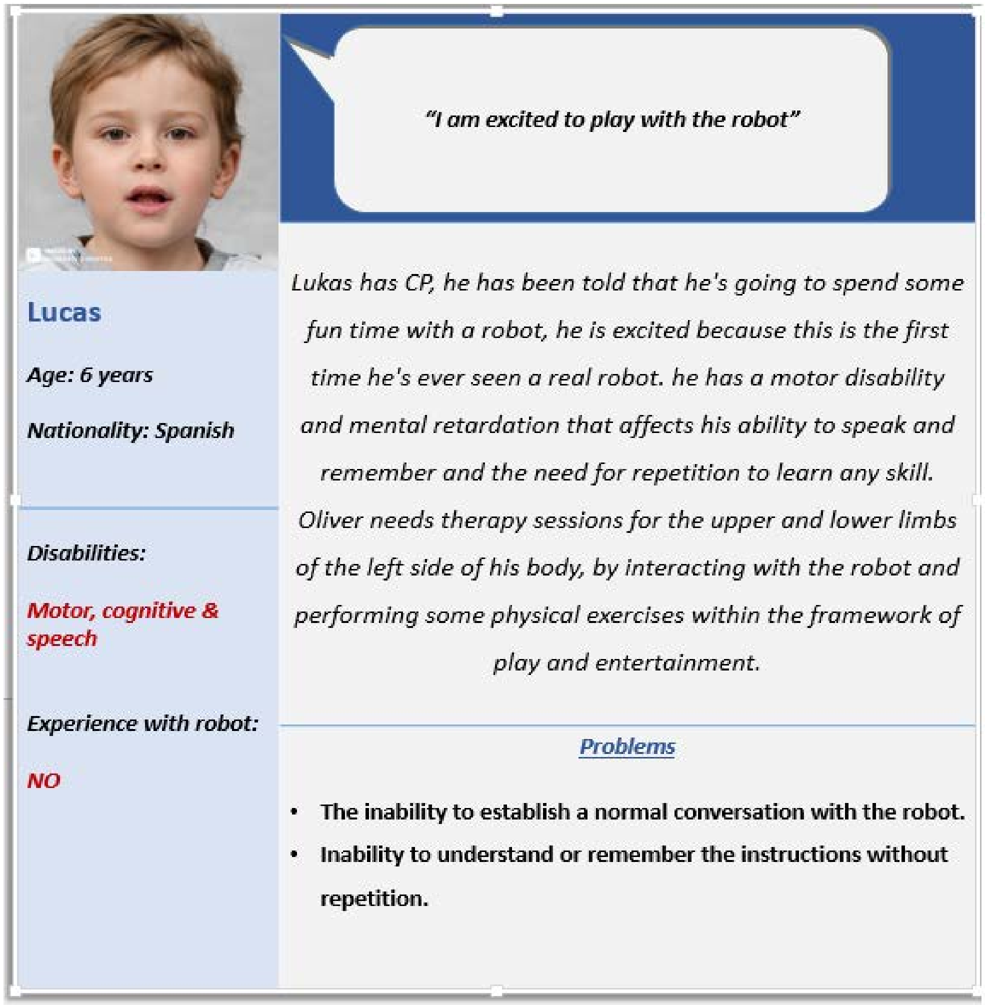

Figure 4.3 An example of the used personas in the study.

2. **Creating scenarios:** scenario is a description of a potential group of events that might reasonably happen. The purpose behind developing scenarios is to stimulate thinking of potential incidents, their assumptions, potential chances and risks, and courses of action (Jarke et al., 1998). With the aim of obtaining more accessibility problems from the interaction of NAOTherapist and users with different characteristics, two scenarios were created to combine them with the created personas to elicit any potential accessibility problems. Scenarios were implemented based on NAOTherapist's therapeutic activities, which are presented in four stages: welcome story, gamified activity, reward and farewell story (Garc et al., n.d.). The context in which the therapeutic activities are carried out through interaction with the robot is similar for the entire interaction, where the patient either listens to the robot or imitates its movements. Hence, almost all activities fall under only two scenarios avoiding repeating the same results. Each character was associated with each of the scenarios. The scenario consists of settings, actors, knowledge, capabilities and tools or objects that the actors may manipulate (Rosson, Mary Beth

and Carroll, 2007). Table 4.6 and table 4.7 show an example of the used scenarios in this study.

Table 4.10 Memory activity Scenario.

Actor	**Lucas**
Goal	Playing with the robot
Settings	The patient with the robot conducting a therapy session in a hospital.
Activity description	The robot tried to guide the patient in the **memory activity** by showing him how to do different upper limb poses and then asked the patient to perform all poses. Lucas understood what the robot was asking for, but he could not remember all poses; he remembered only the first pose due to the memory disability he has. However, when the robot detected the problem, it repeated the poses again, but Lucas still was not able to remember all poses with their sequence.
Problems	Inability to remember all exercise's poses.
Other actors	**Maria** faced some difficulty in recognizing the different poses as she has a visual disability, but the robot still could guide her verbally. But she could not see the robot's eyes turn to green as a confirmation of her poses. **Pedro** lost his interest in the robot and refused to do the poses when the robot asked him to repeat all poses, because the robot detected some wrong poses in his first try. Pedro could not stay in one pose for a long time as he has hyperkinesia. **Sofia** could not interact with the robot as she did not hear the robot voice; the robot failed to guide her in the session. **Oliver** could not interact with the robot as he could not understand the language.

Table 4.11 Welcoming Story Scenario.

Actor	**Oliver**
Goal	Discovering how to interact with the robot and get a therapeutic session.
Settings	The patient with the robot conducting a therapy session in a hospital.
Activity description	**Welcome Story**: the robot started the session with a story telling the patients that it came from space and is lost here on the earth. They could help him to self-repair and go back to his planet by doing exercises with him. During the story, the robot performed some movements and turned on the LED lights to get the patient's attention. During that, the patient was standing or sitting listening to the story.
Problems	Inability to understand the robot's story as the patient could not understand the robot language.
Other actors	**Sofia** could not hear the robot's story as she did not hear the robot voice.

3. **Audit the Complete Process by combining Personas to Scenarios:** each persona was combined to each scenario to elicit any potential accessibility problems the users may encounter in their interaction with NAOTherapist as they have different disabilities and abilities.

Results

Table 4.8 presents the extracted accessibility barriers which users of NAOTherapist may face during their therapeutic sessions. Both evaluators reviewed and agreed on the results to report a final list of extracted accessibility problems as a result of combining the personas with each scenario.

Table 4.12 List of extracted accessibility barriers in this study.

Scenario	**Persona**	**Accessibility barriers**	**Disability Type**	**Interaction Component**
Memory activity	**Lucas**	Inability to remember all exercise's poses.	Cognitive	- Software (the application)
	Maria	Difficulty in recognizing the different poses as she has visual disability and could not see the robot's eyes turn to green as a confirmation of her poses.	Visual	- Movements - LED light sensor
	Pedro	He cannot stay in one pose for a long time, so he refused to do the poses.	Conduct disorder (inattention)	NA
	Sofia	She did not hear the robot voice, hence, the robot failed to guide her in the session.	Hearing	- Speakers
	Oliver	He could not interact with the robot at all as he could not understand the language.	Different Language	- Speech synthesis
Welcoming Story	**Sofia**	She could not hear the robot's story.	Hearing	-Speakers
	Oliver	He was unable to understand the robot's story as he could not understand the robot's language.	Different Language	- Speech synthesis

4.7 Summary

The main aim for this chapter is to identify HRI accessibility barriers that could be faced by people with disabilities. The associated research question to this chapter is:

- **RQ5:** What are the current accessibility barriers in Human-Robot Interaction?

The path to answer this research question passed through four phases. **First**, it was important to **propose an accessibility evaluation methodology (Section 4.1)** in order to enable performing evaluations for real and fictional users' cases. The proposed accessibility evaluation methodology for HRI was built based on the evaluation accessibility methodology WCAG-EM for web accessibility (Velleman & Abou-Zahra, 2014) and as the AUSUS evaluation framework recommended (Iglesias et al., 2021).

Second, **the medical model of disabilities was adopted to review the different types of disabilities** (Section 4.2), however, it is difficult to identify the wide range of disabilities, where each person with any type of disabilities is a different case. Thus, the scope of studied user's disabilities was limited to include: visual, auditory, motor, cognitive and speech disabilities. Bearing in mind that, people with disabilities may have different severity degrees and a combination of other disabilities. Then, a contribution is presented in this chapter, where **the classification of SAR's interaction components, proposed in Section (3.2), is mapped to any potential disabilities that could affect the interaction through any of these interfaces (table 4.2).**

Third, Section (4.4) represents **HRI accessibility barriers that were found in the literature**, which were studied in Section (2.2). The accessibility barriers were reported by researchers who performed evaluations of SARs. In addition, two evaluations were conducted to **elicit accessibility barriers in HRI using the proposed accessibility evaluation methodology**: **real users' cases** were studied to evaluate the actual interaction between children with Cerebral Palsy (CP) with hemiplegia or Obstetric Braxial Plexus Palsy (OBPP) and NAO robot in therapy sessions (Section 4.5). Extracted accessibility problems of NAOTherapist interfaces are presented in table 4.3. All participants experienced the problem of the short height of the robot during the therapy sessions. While one participant experienced an accessibility problem related to the robot's appearance. In the second evaluation (Section 4.6), **fictional users' cases** were implemented and studied using personas and scenarios methods. The same proposed accessibility evaluation methodology was applied in the second evaluation. Table 4.8 presents a list of extracted accessibility problems from the second evaluation.

Chapter 5: Proposal of Accessibility Guidelines for Human-Robot Interaction

Introduction

This chapter is dedicated to answer the following research question:

- **RQ6**: Could we summarize or suggest accessibility guidelines / checkpoints for HRI?

Aiming to propose accessibility guidelines for HRI, six main HCI accessibility guidelines were selected to form a basis for the proposal, which are: WCAG 2.0, BBC, Funka Nu, IBM, WAI-ARIA and personal user experience (PUX) (*PUX*, 2018). These HCI accessibility guidelines were specifically selected to ensure including the hardware and software aspects in the proposal, in line with the robotics technology. WCAG 2.0, BBC, Funka nu and WAI-ARIA guidelines manipulate software aspects such as, websites, mobile interfaces and assistive technology, while IBM guidelines manipulate hardware aspects and PUX is for developing a positive user experience. Moreover, two of the selected guidelines (WCAG and WAI-ARIA) are W3C (W3C, 2017) guidelines, which have the most complete and detailed HCI accessibility guidelines nowadays.

Then, a comparison between three accessibility guidelines for HCI: WCAG 2.0, BBC and Funka Nu were introduced in this chapter to elicit the applicable requirements to HRI and eliminate the redundancy in accessibility requirements. This is because the three former guidelines manipulate the same accessibility aspect for websites and mobile interfaces. The comparison also ensures including all accessibility aspects that the compared guidelines proposed. Later, the other three accessibility guidelines: IBM, WAI-ARIA and PUX were involved in the proposal following a scientific methodology to form the proposed accessibility guidelines for HRI based on these six guidelines.

5.1 A Comparison of the Accessibility Guidelines

A comparison was conducted between three of the most famous and used accessibility guidelines and standards: WCAG 2.0, Funka Nu and BBC. These three guidelines have been selected to be compared because they are three of the most used and cited guidelines around the world, and moreover they share the same aspect of handling accessibility from the software perspective, allowing for a comparison between them, as follows:

Step.1 Analysis of the documentation of the accessibility requirements of the three guidelines, according to the characteristics of robot's components in HRI, to check whether the guidelines requirements can be applied for HRI or not. It is important to clarify that two accessibility requirements were excluded from the initial document, but later in Section (6.3) they were included again in the final version of the proposed guidelines. Both requirements are from the Funka Nu guidelines, and in the initial document were considered not applicable for robotic technology but applicable for mobile technology; table 5.1 presents the two guidelines. Further investigation was performed after the first evaluation of the proposed guidelines (Section 6.1), which revealed that the two excluded requirements could be applicable for robotic technology. Hence, they were included in the final version of the proposed guidelines (Section 6.3).

Table 5.1 Excluded accessibility guidelines from the initial document of proposed accessibility guidelines for HRI.

#	Excluded accessibility guidelines	Exclusion justification
1	Do not use frames in web interfaces, because frames and (iframe) inline frames work poorly on mobile devices. (*Mobile guidelines - Funka*, n.d.)	Mobile performance standards and tablet (robots' display) are not the same.
2	Minimize the use of scripts on the client page. (*Mobile guidelines - Funka*, n.d.)	

Step.2 Combining the intersected requirements of different guidelines without repetitions (See table 5.2, sub criterion and entitled requirements columns).

Step.3 The requirements in the final checked list was grouped under three general aspects, as follows (Qbilat & Iglesias, 2018):

- **Perceivable**: related to interface components and appearance, interface structure and assistive technologies.
- **Understandable**: related to errors and help, readability, predictability and design.
- **Operable**: related to keyboard, time, navigation, interface and conformance.

The three guidelines were compared to each other, in order to determine which of these guidelines consider the accessibility requirements from the three aspects: Perceivable, Understandable and Operable, and which one does not, and to what extent each guideline of the three consider those requirements for the three aspects, where √ = completely, …… = Nothing and P = Partially (see table 5.2, adherence degree column).

Table 5.2 shows the complete work done to accomplish the previous explained steps.

Table 5.2 Comparison of WCAG 2.0, Funka Nu & BBC guidelines for perceivable, understandable and operable aspects' requirements.

Criterion	Sub Criterion	Entitled Requirements	Adherence degree			Guidelines references as mentioned in the original documents		
			WCAG 2.0	Funka Nu	BBC	WCAG 2.0	Funka Nu	BBC
Perceivable	Interface Component and Appearance	[Non-text alternatives]	√	P	P	1.1 Perceivable	8. Design 9. Design 22. Layout and Design	18. HTML Accessibility 19. HTML Accessibility
		[Multimedia alternatives]	√	……	……	1.2 Perceivable		
		[Prerecorded multimedia]				1.2.1 Perceivable 1.2.2 Perceivable		
		[Pre recorded and live multimedia]				1.2.3 Perceivable 1.2.4 Perceivable		
		[Sign language and prerecorded multimedia]				1.2.5 Perceivable 1.2.6 Perceivable 1.2.7 Perceivable		
		[Separable content]	√	……	P	1.3 Perceivable		
		[Presentation and meaning]				1.3.1 Perceivable 1.3.2 Perceivable 1.3.3 Perceivable		17. HTML Accessibility
		[Variant presentation]				1.3.4 Perceivable 1.3.5 Perceivable		
		[Recognizing the importance of the information]	√	P	P	1.4 Perceivable		
		[Minimum luminosity contrast]				1.4.1 Perceivable 1.4.2 Perceivable	27. Layout and design	16. HTML Accessibility
		[High luminosity contrast]				1.4.3 Perceivable 1.4.4 Perceivable		
		[Blinking content]	√	……	……	2.2.2 Operable		

Table 5.3 Comparison of WCAG 2.0, Funka Nu & BBC guidelines for perceivable, understandable and operable aspects' requirements.

Criterion	Sub Criterion	Entitled Requirements	Adherence degree			Guidelines references as mentioned in the original documents		
			WCAG 2.0	Funka Nu	BBC	WCAG 2.0	Funka Nu	BBC
Perceivable	Interface Component and Appearance	[Seizures and photosensitivity]	√	……	……	2.3 Operable		
		[General and red flash]				2.3.1 Operable		
		[Three flashes]				2.3.2 Operable		
		[Familiar icons were used]	……	√	……		25. Layout and design	
		[Objects with clickable appearance]	……	√	……		26. Layout and design	
		[Zoomable interface]	……	√	……		46. User settings	
		[Inverting colours]	……	√	……		47. User settings	
		[Changeable font]	……	√	……		48. User settings	
		[Minimum text size]	……	……	√			8. HTML Accessibility
		[Resizable text]	……	……	√			9. HTML Accessibility
		[Reduce the use of images]	……	√	……		43. Content	
		[Aggregating buttons and links]	……	√	……		21. Layout and design	
		[Tabindex value]	……		√			10. HTML Accessibility
	Interface Structure	[Prioritized design]	……	√	……		14. Layout and design	
		[Grouping relative elements]	……	√	……		15. Layout and design	

Table 5.4 Comparison of WCAG 2.0, Funka Nu & BBC guidelines for perceivable, understandable and operable aspects' requirements.

Criterion	Sub Criterion	Entitled Requirements	Adherence degree			Guidelines references as mentioned in the original documents		
			WCAG 2.0	Funka Nu	BBC	WCAG 2.0	Funka Nu	BBC
Perceivable	**Interface Structure**	**[Minimizing interface objects]**	……	√	……		16. Layout and design	
		[Small side header]	……	√	……		17. Layout and design	
		[Minimizing quantity of information]	……	√	……		24. Layout and design	
		[Consistent design]	……	√	……		37. Interaction	
	Assistive Technology	**[Parsable content]**	√	……	……	4.1.1 Robust		
		[Name, role and value]	√	……	……	4.1.2 Robust		
		[Recognized standard doctype]	……	……	√			2. HTML Accessibility
		[Main landmark]	……	……	√			6. HTML Accessibility
		[Title attribute]	……	……	√			11. HTML Accessibility
		[Recognizable data table]	……	……	√			21. HTML Accessibility
Understandable	**Errors & Help**	**[Avoiding mistakes]**	√	√	……	2.5 Operable	42. Interaction	
		[Errors identifications]				2.5.1 Operable		
		[Contextual help]				2.5.4 Operable		
	Readability	**[Readable and understandable texts]**	√	**P**	**P**	3.1 Understandable		
		[Interface language]				3.1.1 Understandable		4. HTML Accessibility
		[Components language]				3.1.2 Understandable		

Table 5.5 Comparison of WCAG 2.0, Funka Nu & BBC guidelines for perceivable, understandable and operable aspects' requirements.

Criterion	Sub Criterion	Entitled Requirements	Adherence degree			Guidelines references as mentioned in the original documents		
			WCAG 2.0	Funka Nu	BBC	WCAG 2.0	Funka Nu	BBC
Understandable	**Readability**	**[Unusual words]**				3.1.3 Understandable		
		[Abbreviations]				3.1.4 Understandable	45. Content	
		[Reading level]				3.1.5 Understandable		
		[Pronunciation meaning]				3.1.6 Understandable		
		[Line length]					23. Layout and design	
	Predictability	**[Placement and functionality of content]**	√	**P**	……	3.2 Understandable		
		[On focus]				3.2.1 Understandable		
		[On input]				3.2.2 Understandable		
		[Navigation]				3.2.3 Understandable	29. Interaction	
		[Consistent identification]				3.2.4 Understandable	37. Interaction	
		[Change on request]				3.2.5 Understandable		
		[Using pre implemented objects]	……	√	……		38. Interaction	
	Design	**[Main purpose]**	……	……	√			1. HTML Accessibility
		[Avoiding JavaScript and CSS]	……	……	√			3. HTML Accessibility
Operable	**Keyboard**	**[Accessible by keyboard]**	√	……	……	2.1 Operable		

Table 5.6 Comparison of WCAG 2.0, Funka Nu & BBC guidelines for perceivable, understandable and operable aspects' requirements.

Criterion	Sub Criterion	Entitled Requirements	Adherence degree			Guidelines references as mentioned in the original documents		
			WCAG 2.0	Funka Nu	BBC	WCAG 2.0	Funka Nu	BBC
Operable	Keyboard	[No time constraints (exceptions)]				2.1.1 Operable		
		[No time constraints (No exceptions)]				2.1.2 Operable		
		[Adapting virtual keyboard]	……	√	……		11.Desgin	
		[Controllable by keyboard]	……	√	……		31. Interaction	
		[Visible by focus]	……	……	√			13. HTML Accessibility
	Time	[Time controlling]	√	P	……	2.2 Operable	41. Interaction	
		[Control time limits]				2.2.1 Operable		
		[Pausing the content (Exceptions)]				2.2.3 Operable		
		[No timing]				2.2.4 Operable		
	Navigation	[Facilitate navigation process]	P	P	P	2.4 Operable		
		[Repeated content]				2.4.1 Operable		
		[Multiple ways of access]				2.4.2 Operable		
		[Titling pages]				2.4.3 Operable		5. HTML Accessibility
		[Purpose identification (In context)]				2.4.4 Operable		
		[Descriptive Titles, headings and Labels]				2.4.5 Operable	44.Content	7. HTML Accessibility
		[Focusable and meaningful navigation]				2.4.6 Operable		
		[Location orientation]				2.4.7 Operable		

Table 5.7 Comparison of WCAG 2.0, Funka Nu & BBC guidelines for perceivable, understandable and operable aspects' requirements.

Criterion	Sub Criterion	Entitled Requirements	Adherence degree			Guidelines references as mentioned in the original documents		
			WCAG 2.0	Funka Nu	BBC	WCAG 2.0	Funka Nu	BBC
Operable	**Navigation**	**[Purpose identification (Link only)]**				2.4.8 Operable		
		[Recognizable links]						14. HTML Accessibility
		[Recognizable focus]						15. HTML Accessibility
		[Using all control buttons]					30. Interaction	
		[Shortcuts to navigate long pages]					32. Interaction	
		[Adopting gesture]					34. Interaction	
		[Gestures alternatives]					35. Interaction	
	Interface	**[Practical test]**	……	√	……		13. Design	
		[Large clickable areas]	……	√	……		18. Layout and design	
		[No frequently used buttons on the edges]	……	√	……		19. Layout and design	
		[No buttons or functions on the right edge]	……	√	……		20. Layout and design	
		[Minimizing text input]	……	√	……		33.Interaction	
		[Controlling the interface with one finger]	……	√	……		36. Interaction	
		[User feedback]	……	√	……		39. Interaction	
		[Clear status information]	……	√	……		40. Interaction	

Table 5.8 Comparison of WCAG 2.0, Funka Nu & BBC guidelines for perceivable, understandable and operable aspects' requirements.

Criterion	Sub Criterion	Entitled Requirements	Adherence degree			Guidelines references as mentioned in the original documents		
			WCAG 2.0	Funka Nu	BBC	WCAG 2.0	Funka Nu	WCAG 2.0
Operable	Interface	[Portrait and landscape Display format]	……	√	……		28. Layout and design	
		[Submit button]	……	……	√			20. HTML Accessibility
	Conformance	[Ensure Accessibility]	√	……	……	4.2 Robust		
		[level one]				4.2.1 Robust		
		[Content is created by keyboard] and [Seizures and photosensitivity]				4.2.2 Robust		
		[Level 2]				4.2.3 Robust		
		[Level one + Level two]				4.2.4 Robust		

Comparison results

Table 5.3 shows that WCAG 2.0 overlaps twice in some of its accessibility requirements related to Readability, one time with Funka Nu and the other with BBC. There was no overlapping in accessibility requirements related to Design.

Table 5.9 The overlapping between the accessibility requirements of the three guidelines.

Understanding Aspect			
Errors & Help	**Readability**	**Predictability**	**Design**
- WCAG 2.0 and Funka Nu	- WCAG 2.0 and Funka Nu - WCAG 2.0 and BBC	- WCAG 2.0 and Funka Nu	NA

Table 5.4 shows that the guidelines do not consider accessibility requirements related to Understanding. The three guidelines consider accessibility requirements regarding Readability.

Table 5.10 Guidelines that do not consider the Understanding aspect in their accessibility requirements.

Understanding Aspect			
Errors & Help	**Readability**	**Predictability**	**Design**
- BBC	- NA	- BBC	- WCAG 2.0 and Funka Nu

The main conclusions are:

– **Understanding**: BBC guidelines do not take into account requirements to address errors and help and predictability issues, where WCAG 2.0 and Funka Nu have no requirements to meet design issues. WCAG 2.0 and Funka overlap in errors and help, readability and predictability issues, while WCAG 2.0 and BBC overlap in the readability issue only.

– **Perception**: Funka Nu guidelines do not take into account requirements to meet assistive technology issues. WCAG 2.0 and BBC do not take into account requirements to meet interface structure issues. WCAG 2.0, Funka and BBC guidelines overlap in interface components and appearance issues.

– **Interaction**: BBC guidelines do not take into account requirements to meet time and conformance issues, WCAG 2.0 has no requirements to meet interface issue, while Funka Nu does not have requirements for conformance issues. WCAG 2.0, Funka and BBC guidelines overlap in navigation issues. WCAG 2.0 and Funka overlap in time issues.

5.2 A Proposal of Accessibility Guidelines for HRI

After performing the comparison between the three guidelines, WCAG 2.0, Funka Nu and BBC, one document was obtained which represents integrated and applicable software accessibility requirements for HRI (table 5.2).

In this section, other three accessibility guidelines were considered to obtain more accessibility guidelines related to hardware, assistive technology and positive UX to ensure covering accessibility requirements for diverse aspects in HRI. To get these requirements and integrate them into software accessibility requirements obtained in Section 5.1 (see Table 5.2) and to arrive at the complete proposal for accessibility guidelines for HRI, the following methodology was followed:

Step 1. HCI accessibility guidelines selection: three more main accessibility standards, guidelines and recommendations for hardware (IBM, 2014b), assistive technologies (King et al., 2018), in addition to personal user experience guidelines (*Personal User Experience (PUX) Recommendations and Lessons Learned*, 2018) were studied to check whether they apply to robotic interfaces or not based on the similarity to robot technology:

Table 5.5 shows IBM hardware accessibility guidelines, all of them were included in the proposed accessibility guidelines for HRI, as they are all applicable to HRI.

Table 5.11 Included and excluded IBM hardware accessibility guidelines.

#	Accessibility guideline description	(✓) Included (X) Excluded	Exclusion justification
1	**Controls and latches:** they must be reachable easily operated with one hand, besides adopting multiple input methods.	✓	-
2	**Keys, keyboards and keypads:** visual, auditory or tactile feedback are provided to distinguished keys status, with slow key repeat rate.	✓	-
3	**Alternate external connections:** for input and output devices.	✓	-
4	**Color and contrast:** colors are not the only way to distinguish or convey information about hardware controls and labels.	✓	-
5	**Sounds:** provide different mechanisms / interfaces for volume control.	✓	

Table 5.6 shows summarized WAI-ARIA accessibility guidelines. It is important to clarify that WAI-ARIA is a set of very detailed and comprehensive accessibility guidelines which could help developers build dynamic content that can operate well with assistive

technologies. All the technical details provided by the guidelines fall under three main purposes described in table 5.6. Hyperlinks to the technical details (WAI-ARIA) are going to be attached to the proposal of accessibility guidelines for HRI. All WAI-ARIA guidelines were included in our proposal.

Table 5.12 Included and excluded WAI-ARIA accessibility guidelines.

#	Accessibility guideline description	(✓) Included (X) Excluded	Exclusion justification
1	Designing accessible patterns and widgets following WAI-ARIA; defining their roles, properties and states in the code.	✓	-
2	Define the organization or structure of the web page using ARIA landmark roles in the code, as headings and regions.	✓	-
3	Support keyboard navigation in the code for user interface (UI) objects and events and according to WAI-ARIA.	✓	-

Similarly, table 5.7 shows PUX included and excluded recommendations. Basically, PUX is a set of recommendations that aim to develop and design aiding assisted living (ALL) systems which provide users with positive UX. The recommendations are organized in the document under 5 sections: general recommendations; development process which explains the methodology of designing ALL systems; applying standards which recommends following a set of guidelines from WCAG and ISO; privacy and security recommendations; and recommendations regarding building business model. For implementing our proposal, only Section 1 (general recommendations) was considered, where the other four mentioned sections are not in the line of our proposed guidelines but relate more to the design and implementation methodology.

Table 5.13 Included and excluded PUX recommendations.

#	Accessibility guideline description	(✓) Included (X) Excluded	Exclusion justification
General recommendations			
1	Make systems adaptable and adaptive by allowing user to adjust systems' functionality, and to change system's choices. Immediate and continuous adoption for user interface settings choices and store it in the system. Recommendations (1.1 - 1.4)	✓	-

Table 5.14 Included and excluded PUX recommendations.

#	Accessibility guideline description	(✓) Included (X) Excluded	Exclusion justification
General recommendations			
2	Save user's preferences, not their disabilities. Recommendation (1.5)	X	- Privacy issue, not an accessibility recommendation.
3	Do not exclude any users' group, make your system beneficial and attractive for all. Recommendation (1.6)	X	- Although this recommendation is in line with the main purpose of our proposed guideline, it does not provide a specified recommendation for accessibility but a general one.
4	Design usable systems. Recommendation (1.7)	X	- This recommendation does not provide a specified recommendation for accessibility but a general one.
5	Design human-friendly systems. Recommendation (1.8)	X	- This recommendation does not affect the access to the robot's information.
6	Diversify content' format (text, audio, video) and navigation methods. Recommendation (1.9)	X	- This recommendation does not provide a specified recommendation for accessibility but a general one.
7	Design interface components consistently and make them easy to recognize. Recommendation (1.10)	✓	-
8	Single sign-on for all apps. Recommendation (1.11)	X	- This recommendation does not affect the access to the robot's information.

Step 2. Integrate included accessibility guidelines in tables (5.5, 5.6 and 5.7) with the included guidelines in table (5.2) by removing redundant guidelines and summarize them in one document, and classify the guidelines based on the WCAG 2.0 classification and under four aspects: perceivable, operable, understandable and general. To ensure it fits the new added accessibility requirements, where the first three aspects include accessibility requirements that users need to perceive, understand and operate the robot's hardware or software components during HRI. The rest of accessibility requirements that do not belong to the previous three aspects were grouped under general aspects.

Table 5.8 shows the general classification of the proposed guidelines' requirements; table 5.9 represents the complete guidelines, which were published in a journal article and entitled "A Proposal of Accessibility Guidelines for Human-Robot Interaction" (Qbilat et al., 2021).

Table 5.15 General classification of the proposed guidelines requirements.

Aspects	Checkpoints
Perceivable	Multiple modalities for interaction
	Color and contrast
	Location of hardware and software components
	Alternatives for non- text elements
	Blinking components
	Flashing visual content
	Displays
	Assistive technology and web interfaces
Operable	Hardware controls and physical operation
	Keys, keyboards and keypads
	Navigating on displays
	Time
Understandable	Predictable interaction
	Errors, help and feedback
	Natural voice
	Displays
General	Adopting user's interaction preferences
	Reachable human support

Table 5.16 Proposed guidelines for accessibility requirements in Human-Robot Interaction.

Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
1	**Multiple modalities for interaction**	User can operate the robot using different channels for input and output.	a) Provide multiple modalities for interaction (for examples, see **annex 1**). b) Verify that all functions are accessible via keyboard, virtual keyboard, mouse, tactile displays, voice (Automatic Speech Recognition and Text-To-Speech techniques) or gestures (according the interaction modalities chosen).
2	**Color and Contrast**	Color is not the only way to distinguish keys, controls and labels or to convey information, and it is easy to distinguish foreground from the background.	a) Make sure that color is not the only way to indicate hardware controls, keys and labels of the robot. This also applies to software widgets (buttons, labels, etc.) or for information displayed on the robot (for examples, see **annex** 1). b) Careful use of luminosity, contrast, and background audio. WCAG 2.0 (guideline 1.4).
3	**Location of hardware and software components.**	User can easily perceive and access robot's interfaces (hardware and software) components.	a) Make sure the display of visual information is visible to people who are of short stature or seated in wheelchairs. Place interface components in a perceivable and accessible place, for example, place hardware buttons in the middle of the robot's body. b) Design consistently, and group related elements together. For example, place software buttons and links horizontally, vertically or on a grid, and important objects at the top of the interface and the less important objects at the bottom. c) Avoid unnecessary information and objects. Use images only when necessary Funka Nu (43.content) and BBC guidelines (HTML Accessibility).
4	**Alternatives for non- text elements**	All non-text interface elements on the robot's display and all spoken information must have accompanying text or synchronized alternatives for multimedia elements.	a) Provide captions, description or labels for all non-text interface elements. b) For prerecorded and live multimedia, provide captions, audio descriptions, or sign language. For robot voice, provide text or sign language. WCAG 2.0 (guideline 1.1, 1.2).

Table 5.17 Proposed guidelines for accessibility requirements in Human-Robot Interaction.

Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
5	**Blinking components**	For any blinking component on the robot’s interface (lights, display contents, etc.) the blinking stops after a certain period, or can be switched off by the user.	- Provide a mechanism to allow the user to stop blinking, or specify the blinking times for the content to be a fixed number. WCAG 2.0 (guideline 2.2.2)
6	**Flashing visual content**	Avoid flashing components on the robot’s interface that are known to cause seizures.	- Any flashing component should not exceed three flashes in one second. Red flash should be avoided. WCAG 2.0 (guideline 2.3)
7	**Displays**	Separation of content and presentation.	a) Make sure presentation and structure of the content is determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.0 (guideline 1.3). b) The meaning of colored information should also be clear without color through the context for example. c) Do not rely on shape, size, location or color to represent the meaning of user interaction elements. Add a text label as well. WCAG 2.0 (guideline 1.3).
		Large clickable areas, icons and objects on the interface are familiar and should appear clickable.	- Use familiar icons, and design objects with clickable appearance and large clickable areas. Funka Nu (25. Layout and design).

Table 5.18 Proposed guidelines for accessibility requirements in Human-Robot Interaction.

Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
7	**Displays**	User can invert the screen contrast (dark text on a light background, and vice versa).	- Provide a setting for invert colors or contrast.
		User can change font type and size, and zoom in or out on the interface.	a) Provide a setting for changing font type and size within a minimum text size. b) Make sure the user can zoom the interface up to 200%. BBC guidelines (HTML accessibility).
8	**Assistive Technology and web interfaces**	User can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	**For web interfaces :** a) Design accessible patterns and widgets based on WAI-ARIA by defining roles, properties and states of the widgets in the code. (for examples, see **annex 1**). b) Identify the organization and structure of a web page by using ARIA landmark roles in the code such as headings and regions. c) Provide keyboard navigation in the code based on WAI-ARIA for UI objects and events. (for examples, see **annex 1**) WAI-ARIA best Practices. **For hardware:** d) Provide industry standard ports for alternate input and output devices, e.g., assistive tools.

Table 5.19 Proposed guidelines for accessibility requirements in Human-Robot Interaction.

Operable			
#	**Requirement**	**Description**	**How to achieve it**
9	**Hardware controls and physical operation**	User can operate all hardware and physical controls with one hand and minimum dexterity	- Design the input devices, such as, keyboards, remote controls (including the joysticks, buttons, etc.) so the user can operate them with one hand and minimum dexterity (for examples, see **annex 1**).
10	**Keys, Keyboards and Keypads**	User can verify the status of locking or toggle keys visually, through touch or sound, or tactically.	- Provide visual, auditory or tactile feedback to verify the status of locking or toggle keys (for examples, see **annex 1**).
11	**Navigating on displays**	Facilitate navigation process while interacting with the robot's display.	- Provide methods that help the user navigate, find content and determine where s/he is in a structure (for examples, see **annex** 1).
12	**Time**	Time does not affect users' ability to finish any interactive task with the robot, s/he has started.	- Allow the user to control the time limits, turn off, adjust or extend the time limit, except when time is an essential part of activity or real-time event.
Understandable			
13	**Predictable interaction**	Interaction with the robot is consistent and predictable.	a) Use a simple and familiar interaction and navigation mechanism. b) A change in operation of the robot should preferably be initiated by the user.

Table 5.20 Proposed guidelines for accessibility requirements in Human-Robot Interaction.

Understandable			
#	**Requirement**	**Description**	**How to achieve it**
14	**Errors, Help and feedback**	User can review and correct interaction information before submitting; this can avoid errors. User can at all times query what the robot is doing or processing.	a) Provide a clear mechanism controlling the robot and reviewing commands before execution (for examples, see **annex 1**). b) Design the robot's system to detect and explain errors to the user, and where possible explain how to correct them (for examples, see **annex** 1). c) Inform the user about progress status during their interaction with the robot.
15	**Natural voice**	Robot's voice should be clear and natural, the user can choose the robot's voice s/he prefers, and adjust/ set the voice volume.	a) Provide the robot with a set of different clear and appropriate voices and allow the user to choose the voice that matches his/her hearing abilities or preferences. b) Where possible, allow the user to select a preferred voice accent. c) Provide a mechanism to allow the user to adjust the robots' voice volume.
16	**Displays**	Predictable UI components and functionality.	- Use familiar user interface components and widgets (for examples, see **annex** 1).
		(Readability) Text on the robot's display should be legible for the user.	a) Provide additional information for unusual words or phrases; avoid the use of abbreviations. b) Make sure the line length does not exceed 70 characters. c) If necessary, identify a specific pronunciation of words to give them the correct meaning. d) Ensure the readability of all text (http://www.readabilityformulas.com/freereadability-formula-tests.php).

Table 5.21 Proposed guidelines for accessibility requirements in Human-Robot Interaction.

General			
#	**Requirement**	**Description**	**How to achieve it**
17	**Adopting user's interaction preferences**	User adjusts /sets the interaction settings of the robot, preferences are stored.	- Design the robot to adapt and store the users' interaction abilities, preferences and settings (for examples, see **annex 1**).
18	**Reachable Human support**	User can easily ask for human help or support.	- Design the robot with a mechanism for calling human support or help (for examples, see **annex 1**).

Annex 1

1. **Multiple modalities for interaction:**
   b) **For example**: users with visual disabilities can operate the robot using keyboard or voice, users with hearing or speech disabilities can operate the robot using alternatives to speech input, or people who are tetraplegic can use vocal input, among others.

2. **Color and Contrast:**

   a) **For example**: providing different visual means, such as, different shapes for hardware keys and controls, and text to describe the function of software components and widgets (buttons, labels, etc.) on the robot's display.

8. **Assistive Technology and web interfaces:**

   a) **For example**: in the code, mark-up is used to describe the type of the widgets, such as "button" or "tree item". Moreover, the developer can describe the state of the widgets using properties, such as "checked" for check boxes.

   c) **For example**: when the focus is on a closed node in a tree view widget, then the Right arrow opens the node without moving the focus.

9. **Hardware controls:**
   For example: provide extra-large buttons which are easy to press, with non-slip texture.

10. **Keys, Keyboards and Keypads:**
    For example: use a small light for visual feedback, e.g., Caps Lock. A binary position, e.g., depressed, not depressed for the tactile feedback.

11. **Displays:**
    For example: enable the user to bypass the repeated content viewed on robots' display, and provide descriptive titles, headings and labels for any content on the page.

14. Errors, Help and feedback:

a) **For example**: give the user options to fill the required field (checkboxes, radioboxes, etc.), and provide a mechanism, a button control for example, where the user can press it after filling the required fields.

b) **For example**: if the user makes an error during the interaction with the robot, provide the user with error messages that can be expressed through the multichannel output, and considering the user-selected interaction model, allow him/ her to check and reconfirm the submitted interaction information.

16. Displays:

For example: use the integrated objects that are contained in the operating system instead of implementing new components with the same functionality. For example, use the PLAY ▶ symbol instead of designing a new symbol.

17. Adopting users' interaction preferences:

For example: adapting the mode of interaction or the robot's voice volume and font size to the user's preference.

18. Reachable Human support:

For example: a robot is used as a medical assistant in a hospital, at any time while interacting with the robot, patients can call the doctor/nurse by pressing a button on the robot's display.

5.3 Summary

The associated research question to this chapter is:

- **RQ6**: Could we summarize or suggest accessibility guidelines/ checkpoints for HRI?

To answer this research question, six main HCI accessibility guidelines were included as a basis to form a proposal of HRI accessibility guidelines. The guidelines were studied in two phases based on their specialty, where in phase one three HCI software accessibility guidelines (WCAG 2.0, Funka NU and BBC) were studied and compared to conclude with one document that includes software accessibility guidelines without redundancy and which are applicable to HRI. Phase two included HCI accessibility hardware guidelines, accessible content for assistive technologies guidelines and recommendations for positive UX in AAL systems (IBM, WAI-ARIA and PUX).

In phase one (Section 5.1), **a comparison between HCI software accessibility guidelines was necessary**, as the three guidelines share a great part of their guidelines and to come out with one document that contains software accessibility guidelines that are applicable to HRI. To achieve that, the first step was to **analyze the accessibility requirements of the three guidelines**, based on the characteristics of robot's components in HRI studied in Section (2.2) to investigate whether the guidelines requirements are applicable to HRI or not. The second step was to **merge the similar guidelines without repetitions**. The third step was to **classify all the obtained guidelines under three categories**: perceivable, understandable and operable following WCAG 2.0 classification (table 5.2).

In phase two (Section 5.2), other three accessibility guidelines were considered to expand and diversify the guidelines' coverage for all HRI aspects. For the three guidelines, IBM, WAI-ARIA and PUX guidelines, there was no need for a comparison in this phase as the later guidelines maintain different aspects of HCI accessibility, hardware, accessible content for assistive technologies and positive UX for Ambient Assisted living (AAL) systems' users. The first step to form the final document for our proposed guidelines was to **check the applicability of those guidelines to HRI separately**. Tables (5.5, 5.6 and 5.7) illustrate the included and excluded guidelines for the three guidelines: IBM, WAI-ARIA and PUX. In the second step, **included accessibility guidelines in tables (5.5, 5.6 and 5.7) and the included guidelines in table (5.2) were integrated in one document**. The **redundant guidelines were again checked and summarized**. **All the integrated guidelines were classified under perceivable, understandable and operable following WCAG 2.0 classification, a new category was added which is "general"** to fit the new added guidelines which do not relate to perceivable, understandable and operable aspects. **Table 5.9 represents our proposal for accessibility guidelines in HRI.**

Chapter 6: Evaluation

The proposed accessibility guidelines for HRI will be evaluated in this chapter according to the methodology defined at section (4.1), to answer the following research question:

- **RQ7:** Are the proposed guidelines usable for the robot's developers and designers?

Three different heuristic evaluations and a user evaluation were conducted to evaluate the proposed guidelines:

1. **Designers' Evaluation.** The first heuristic evaluation involved HRI designers and developers. Questionnaire interview, observation and expert evaluation methods were used to evaluate four factors: usability, user's experience, user's satisfaction and societal impact of the proposed guidelines.
2. **Accessibility Expert's Evaluation.** In the other two heuristic evaluations, the proposed guidelines were used to evaluate the accessibility level of two different applications implemented to be integrated in a Social Assistive Robot in a real scenario (a residence home where older users will interact with the ROSI robot (*ROSI – Robotic assistants for nursing homes*, n.d.)): town crier and telepresence applications. The main aim of these heuristic evaluations is to elicit any accessibility problem in the applications implemented, looking for Universal Accessibility. The proposed methodology in section (4.1) was followed in these two evaluations and moreover, recommendations were provided on how to solve the accessibility problems found.
3. **User's Evaluation.** Finally, a users' evaluation was done for the town crier application. The proposed guidelines were implemented within the robots' interfaces for users' evaluation, which involved real users in a residence home interacting with the ROSI robot.

Next, the evaluations are detailed in the following sections.

6.1 Designers' Evaluation of the Proposed Accessibility Guidelines for HRI

The main aim of this evaluation, which was published in a journal article (Qbilat et al., 2021), is to assess the usability, user's experience, user's satisfaction and societal impact of the new proposed guidelines from developers' and designers' perspective.

Evaluation Design

Objective

With the intention of conducting a heuristic evaluation of the new proposed guidelines to inspect usability, user's experience, user's satisfaction and societal impact issues, three experts performed the evaluation.

Participants

A convenience sample was selected to include participants with HRI designer or developer roles. Seventeen volunteers were enrolled in the accessibility guidelines evaluation. The participants were all HRI designers and / or developers: one expert in interaction design, one in rehabilitation robotics, two in robotics, one in social collaborative robotics, one in sociology (robotics and artificial intelligence (AI)), one in user acceptance of robotics, one in deep learning, one in automated planning robotics, one in artificial intelligence applied to robotics, one in artificial intelligence applied to socially assistive robots, one in machine learning and planning, one in sociology (user-centered design and participatory design), one in electronic technology, one in multimodal human robot interaction and one in telematics engineering. Table 6.1 summarizes the demographic data of participants using descriptive statistics.

Table 6.1 Characteristics of participants.

Characteristics	Percentages
Age	(21–35) 41%
	(36–50) 59%
Gender	(Male) 65%
	(Female) 35%
Proficiency in English language	(Fluent) 35%
	(Fairly fluent) 65%
Education level	(PhD) 71%
	(Master degree) 29%
Experience	(More than six years) 64.71%
	(Five to six years) 23.53%
	(One to two years) 5.88%
	(Less than one year) 5.88%
Familiarity with accessibility	(Fairly familiar) 29.41%
	(Somewhat familiar) 29.41%
	(Not very familiar) 23.53%
	(Not familiar at all) 17.65%

Materials

The evaluators deployed the following methods to obtain quantitative and qualitative results:

- **Questionnaire interview:** first a pre-test questionnaire was applied to gather participants' demographic information. Then, participants were asked to answer the post-test questionnaire which consisted of nine 5-point Likert Scale questions with 1 being (strongly disagree) and 5 being (strongly agree). Also, three open-ended questions were structured to measure usability, user experience, user satisfaction and societal impact factors from experts' point of view. Face to face interviews were carried out at Ghent University, Free University of Brussels and University

Carlos III of Madrid. The rest of the interviews were audio-conference interviews. All interviews were audio recorded, so evaluators could refer later to participants' feedback, especially answers to open-ended questions, where the users enriched the evaluation by exposing their experience in an informal way.

- **Observations:** evaluators observed participants during the evaluation sessions, which enabled assessing the efficiency indicator.
- **Expert evaluation:** based on the study and analysis of user recommendations by experts, the proposed guidelines were reviewed to investigate the possibility of adopting these recommendations.

Protocol

The evaluator conducted the following steps with each participant:

1. Evaluation appointment: first, participants were contacted to appoint a date for the evaluation session and to determine whether it would be a face to face or an audio-conference interview.
2. Pre-test introduction and questionnaire: at the interview, the objective of the evaluation was explained to the participant first, and then s/he was asked to provide some demographic information (see Appendix B for the complete questionnaire).
3. Choosing the expert role: the participant had to choose one of two tasks based on his/her experience, as follows:

- If the participant had the designer or developer role, s/he was asked to imagine designing a robot to perform a geriatric assessment through interaction with elderly people by asking them to answer questions or perform simple tasks such as walking for a few meters. The robot has a haptic display, microphone and RGB-D camera (s/he could add other necessary hardware components) in order to interact and collect data for later analysis by doctors. Additionally, s/he would design the robot following the accessibility guidelines to ensure that the robot can be used by people with different abilities.
- Otherwise, the participant was asked to watch three different videos of elderly people interacting with a socially assistive robot (CLARC) (Bandera et al., 2016) to perform a geriatric assessment at a hospital where the elderlies interacted with the robot through speech and haptic channels to answer questions about their daily life routine and perform some activities as well. The participant's task was to find all accessibility barriers during the HRI interaction in the videos based on the accessibility guidelines.

4. Guidelines' familiarity and performing the selected task: then, a summarized version of the proposed guidelines was presented to the participant. They were asked to read it carefully in order to achieve the objective set in step (2). The minimum recorded time to complete the task was (5) min and the maximum time was (12.19) min, while the mean was (8.12) min.

5. Post-test interview: thereafter, the participant was asked to answer the five-point Likert Scale and 6 open-ended questions. All responses were recorded for more accuracy while studying and analyzing participants' responses.

Evaluation Results

All questionnaires were checked to determine whether they were completely and properly filled with none of them being excluded from the study. The contents of interview records were transcribed as text on an excel sheet and responses to open-ended questions were analyzed according to thematic analysis of Braun and Clarke (2019). Figure 6.1 shows the summarized results of the nine 5-point Likert Scale questions answered by participants in the post-test questionnaire, including questions related to usability, user's experience, user's satisfaction and societal impact.

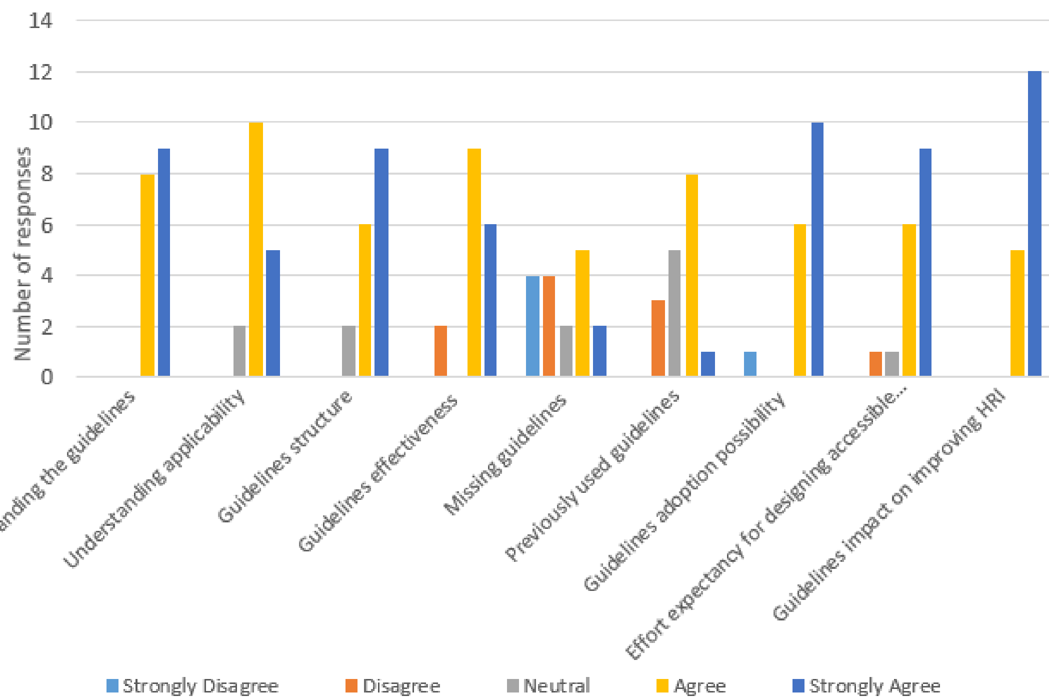

Figure 6.1 Number of responses assigned to scale point for each question.

The responses of participants to each evaluation factor were studied repetitively, descriptive codes were extracted and linked to themes, and then themes were grouped based on their relativity to one of the indicators of the studied factors as follows:

Usability factor: the study included four 5-point Likert Scale items (questions q1–q4 in table 6.2), one open-ended question (question q2.1 in table 6.2) and one objective question (question q5 at table 6.2) to assess the usability factor. The following indicators were measured:

1. Understanding: question 1 and question 2 were dedicated to evaluating understanding both the checkpoints (accessibility requirements) and the guidelines (techniques to achieve each accessibility requirement). All participants agreed that the checkpoints were fully understood with 15 of 17 participants understanding the guidelines completely. Two of 15 participants selected neutral. Careful analysis of their answers to the open-ended questions revealed that both participants think the guidelines should be accompanied with graphical examples. The participants also responded to an open-ended question (Question q2.1) to report some difficulties met in understanding the guidelines. They also gave recommendations to improve guidelines understanding. For instance, 7 participants recommended enhancing the guidelines with graphical practical examples.
2. Guidelines' structure: question 3 revealed participants' responses regarding the guidelines structure, where 15 of 17 participants agreed that the guidelines are structured in an order easy for them to use or apply. None of the participants disagreed with this assumption. Two of 17 participants chose neutral. After analyzing their answers to open-ended questions, it was found that both participants did not oppose the current guidelines' structure, but they preferred another structure or classification. These structures include targeted user' characteristics, where the guidelines are classified under three categories (visual, auditory and tactile) or to classify them into hardware and software guidelines.
3. Effectiveness: to evaluate the effectiveness of the proposed guidelines in helping the designers and developers design accessible robots or detect accessibility barriers, participants responded to question 4. Fifteen of 17 participants agreed that the guidelines will be helpful to design and develop accessible robots. Two of 17 disagreed with this assumption. Following the review of their answers to the open-ended questions, one participant thought applying all the guidelines is hard due to high cost; instead, the priority should be given to the guidelines that relate to the characteristics of the targeted user. The other participant thought that implementing all guidelines will slow robot's system and complicate interaction with users.
4. Efficiency: in question 5, the evaluators measured the time each participant spent to accomplish the task with the mean being (8.12 min). The evaluators found the required time to accomplish the task reasonably to fall between (5–12.19) min.

Table 6.2 Questions evaluating usability factor.

Question ID	Description	Mean	Standard deviation (SD)
q1	I could easily understand the checkpoints	4.53	0.52
q2	I could easily understand how to apply the technique for each checkpoint	4.18	0.64
q2.1	Difficulties in any checkpoint? Please, explain which one and how it could be improved	-	-
q3	The guidelines are structured in an order that is easy for me to use or apply	4.41	0.71
q4	I can easily design accessible robots or detect accessibility barriers by using the guidelines	4.12	0.93
q5	How much time did you spend to complete the task?	8.12	2.10

User's experience factor: the study dedicated two 5-point Likert Scale items (questions q6 and q7 in table 6.3) for the user experience factor. The following indicators were measured:

1. Missing guidelines: eight of 17 participants thought there were some accessibility aspects missing in the proposed guidelines (question 6). They highlighted some missing aspects such as appropriate distance for interaction between user and robot. Most of participants' recommendations in the open-ended questions were related to usability and user acceptance; for instance, guidelines for robot gender preferences.
2. Previously used guidelines: with the purpose of assessing participants' familiarity with the guidelines, participants responded about whether they considered these aspects in their previous designs or evaluations, even when they had not considered accessibility issues (question 7). None of the 17 participants had completely applied all the proposed guidelines in her/his designs or evaluations. One of 17 participants said that he had never applied any of them. A total of 72% of the proposed guidelines have been applied by less than or equal to 8 participants for each guideline. All the guidelines have been applied at least once due to participants' knowledge of HCI accessibility. Figure 6.2 shows the number of participants who previously applied each guideline.

Table 6.3 Questions evaluating user experience factor.

Question ID	Description	Mean	SD
q6	I think there are accessibility aspects missing in the guidelines	2.82	1.43
q7	I considered these aspects in my previous designs/evaluations, even when I had not taken into account accessibility issues.	3.41	0.87

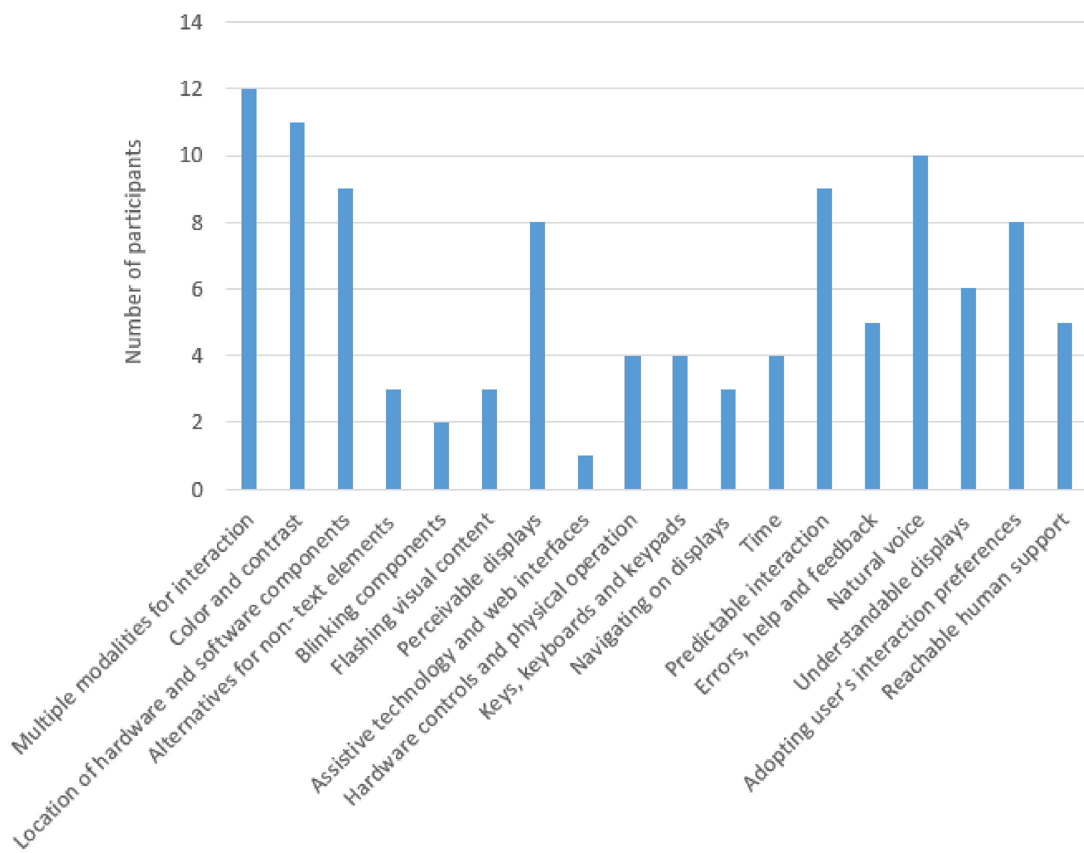

Figure 6.2 Number of participants who previously used each guideline.

User's satisfaction factor: the study dedicated two 5-point Likert Scale items (questions q8 and q9 at table 6.4) for user satisfaction. The following indicators were measured:

1. Guidelines' adoption possibility: responses on question 8 show that the majority (16 of 17 participants) would use the proposed guidelines in their future robot designs or evaluations. Only 1 of 17 participants would not use the proposed guidelines. However, analysis of his answers to the open-ended questions showed that the participant thought applying all the proposed guidelines contradicts with cost, business and users' expectations issues.

Table 6.4 Questions evaluating user satisfaction factor.

Question ID	Description	Mean	SD
q8	I would like to use these guidelines in my future robot design/ evaluation.	4.41	1.00
q9	I think the design of accessible robots for all will require more effort.	4.35	0.86

2. Effort expectancy: the majority (15 of 17 participants) agreed that they think the design of accessible robots for all will require more effort. One of 17 participants selected neutral, while 1 of 17 participants disagreed with this assumption. After studying their answers extensively, it was concluded that they thought the design

and implementation of an accessible robot can be achieved by considering business, user's expectations and cost for each robotic product separately, rather than complying with general accessibility guidelines (question 9).

Societal impact factor: the study dedicated one 5-point Likert Scale item (question q10 in table 6.5) for the societal impact factor. The following indicator was measured:

1. Quality of life/Importance: all participants agreed on the importance of considering accessibility guidelines in the inclusive design of robots (questions 10).

Table 6.5 Question evaluating societal impact factor.

Question ID	Description	Mean	SD
q10	I think the inclusive design of robots, taking into account the accessibility guidelines, is necessary to improve the robot's interaction success and adoption.	4.71	0.47

Participants' recommendations: in question 11, participants were asked to recommend any ideas to develop the proposed guidelines. Most of the recommendations provided by the participants were suggested to consider guidelines related to usability and user acceptance such as adding guidelines for psychological aspects along with proposed guidelines. Related recommendations were extracted from users' feedback to improve the proposed guidelines, where participants suggested different classifications of the proposed guidelines according to user characteristics, robot characteristics, and designer or developer characteristics. These include hardware and software guidelines, functional guidelines related to the accessibility requirements for navigation on display, software and hardware buttons, etc., and non-functional guidelines related to accessibility requirements for color and contrast of the display, natural voice, etc.

The recommendations related to applying new classifications could convert these guidelines to guidelines that can be configured according to targeted user's disabilities or robot's interfaces components, and that would help avoiding slowness, boresome and difficulty in the interaction process with the robot. The recommended classification will comply with the cost, business and user's expectations issues too.

Other recommendations addressed tagging each checkpoint with a level of priority and prioritizing safety requirements, adding graphical examples to enhance the clarification of checkpoints and guidelines, and defining all mentioned abbreviations. Additionally, the recommendations tackle enriching the proposed guidelines with guidelines related to hardware aspects, emotional aspects in case they can serve accessibility, appropriate distance for interaction, environment accessibility requirements and user adaptation or adapting the robot to the user issues.

Other recommendations suggest developing a design methodology document besides the proposed guidelines to allow more focus on the flow of interaction. Finally, the recommendations propose an interactive online version of the proposed guidelines and to revise the proposed guidelines by an English language expert.

Project data

- **Funding**: this work has been partially funded by the EU ECHORD++ project (FP7-ICT-601116), and the UMA18-FEDERJA-074, the AT17-5509-UMA and the CSO2017-86747-R Spanish projects.
- **Institutional Review Board Statement**: the study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Universidad Carlos III de Madrid (protocol code CEI21_03_IGLESIAS_Ana María/19 February 2021.
- **Informed Consent Statement**: informed consent was obtained from all subjects involved in the study.
- **Data Availability Statement**: the evaluation data is summarized in this document.
- **Acknowledgments**: the authors warmly thank the persons involved in the evaluation process for their participation in this research and their valuable feedback.
- **Conflicts of Interest**: the authors declare no conflict of interest.

6.2 Experts and Users' Accessibility Evaluation of Town Crier Application

In this section, the proposed guidelines were used to perform heuristic evaluations of the ROSI robot interfaces for two different applications: Town Crier and Telepresence.

For town crier application, the developers were informed about the necessity of design and implementing accessible interfaces for the ROSI robot, which would be at a residence home, where older persons with a great functional diversity would interact with it. The developers followed our proposed accessibility guidelines for HRI guidelines to design ROSI's interfaces. In Subsection (6.2.1), a heuristic evaluation was performed to evaluate the implemented interfaces following our proposed evaluation methodology (Section 4.1), where the results showed that some of our proposed guidelines were missed during the implementation process. Later, the developers implemented some of the missed guidelines (evaluators' recommendations). Part of these guidelines were not possible to be implemented due to the robot's characteristics or because the implementation could not be done, as the developers did not have enough time to do it. Then, a user evaluation was performed to evaluate town criers' interfaces with real users (Subsection 6.2.2).

Another heuristic evaluation was performed to evaluate telepresence application's interfaces (Subsection 6.3), using our proposed guidelines and evaluation methodology.

6.2.1 Experts' Accessibility Evaluation

A heuristic evaluation by two accessibility experts was conducted to extract the accessibility problems existing in ROSI's robot interfaces (*ROSI – Robotic assistants for nursing homes*, n.d.), where ROSI plays a role of an assistant who helps elderly residents at an elderly care home by reminding them with their daily schedule, the weather, their friends' birthdays, time and date, see figure 6.3.

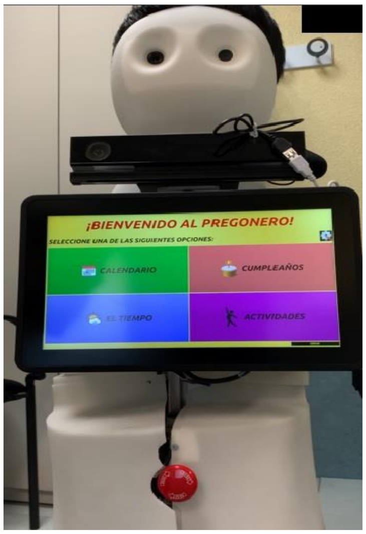

Figure 6.3 ROSI robot plays the role of Town Crier.

Evaluation Design

Objective

The objective of the evaluation is to extract existing accessibility problems from the interaction interfaces of ROSI robot, while performing the town crier task.

Participants

Two HRI and HCI accessibility experts performed the evaluation, both of them revised the robot's display interface and reported the existing accessibility problems.

Materials

An assistant robot (ROSI) (Bandera et al., 2016) and the software application (The Town Crier) that is integrated to robot's system to assist residents at the elderly care home by reminding them with their daily schedule and activities, the weather, time and date and their friends' birthdays. The robot is provided with a mobile base containing the battery and a number of sensors: safety bumper socket sensor, localization, navigation, and obstacle avoidance sensor and Microsoft Kinect V2. In addition, ROSI is equipped with a microphone, speaker, and webcam and a tablet (touch screen) (Bandera et al., 2016). Figure 6.4 shows the ROSI robot's prototype design.

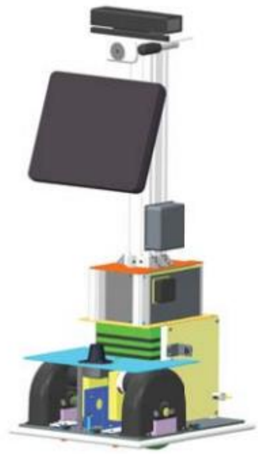

Figure 6.4 ROSI robot prototype design (Bandera et al., 2016).

In addition to a proposed accessibility guidelines for Human- Robot Interaction (Qbilat et al., 2021), see table 5.9 for the complete guidelines, and a website to manipulate the contrast ratio issue (*Contrast Finder, find correct color contrasts for web accessibility (WCAG)*, n.d.).

Protocol

Each evaluator revised all robot's display interfaces based on her expertise and the proposed accessibility guidelines for HRI. The proposed evaluation methodology in section (4.1) was applied as follows:

Step 1. Define the Evaluation Scope

The evaluators considered the entire application interfaces for the evaluation, the main software interface "Town Crier" that includes an option for voice configuration, besides four options for four tasks / processes: calendar, activities, friends' birthday and weather.

Step 2. Explore the Target Robotic Application (Software and Hardware)

In this step, all the common interfaces for each task are listed below in figure 6.5, the main interface is highlighted in blue:

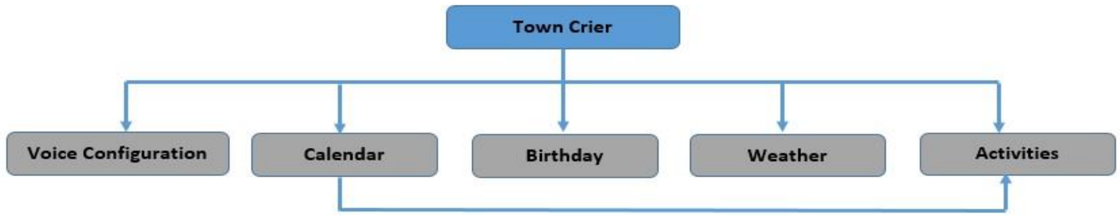

Figure 6.5 Main and common interfaces of ROSI robot's application (Town Crier).

The evaluated interfaces are related to four robot's tasks / processes: calendar, activities, friends' birthday, and weather, besides one interface for voice configuration (figure 6.5). All interfaces except the voice configuration interface have the same style, layout, structure, navigation and visual design. Interfaces vary in their content as they include buttons, headers, images and texts; the functional components are buttons, besides voice input as the robot has a voice recognition interface. The voice configuration interface has a non-colored visual design, and it includes sliders and buttons. Figures 6.6, 6.7 and 6.8 represent the main interface of ROSI robot's (town crier) voice recognition and calendar interfaces respectively. (The rest of the town crier's interfaces are available in Appendix C).

The developers used C++ (QT library) to implement the interfaces. Changing in the interface's appearance usually depends on the user's action or the context of the task.

The robot incorporates a haptic display, microphone, RGB-D sensor, speakers and Kinect v2 camera.

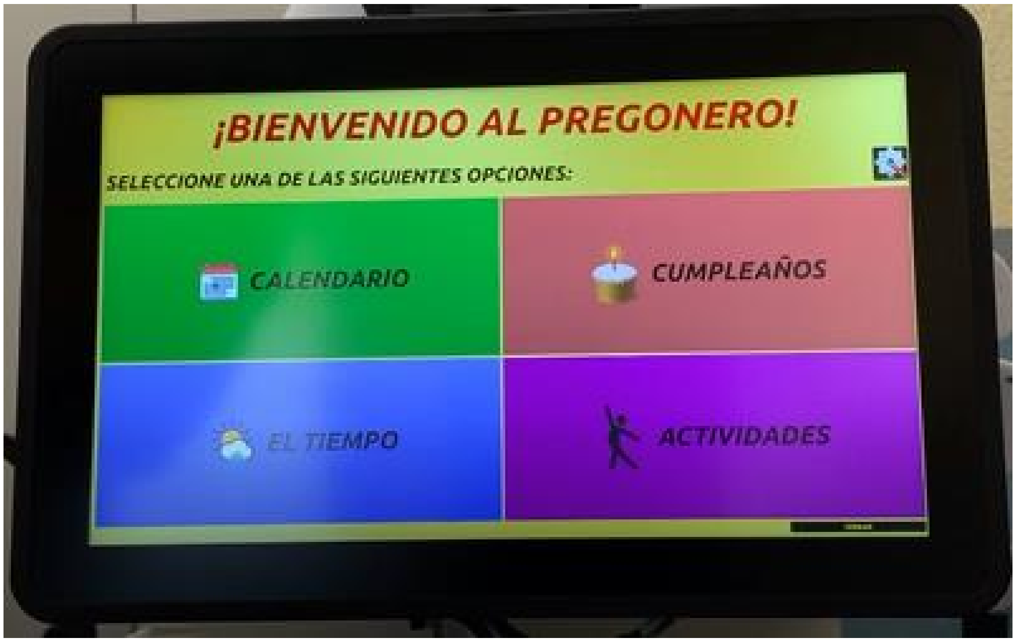

Figure 6.6 Main Interface of ROSI robot's application (Town Crier).

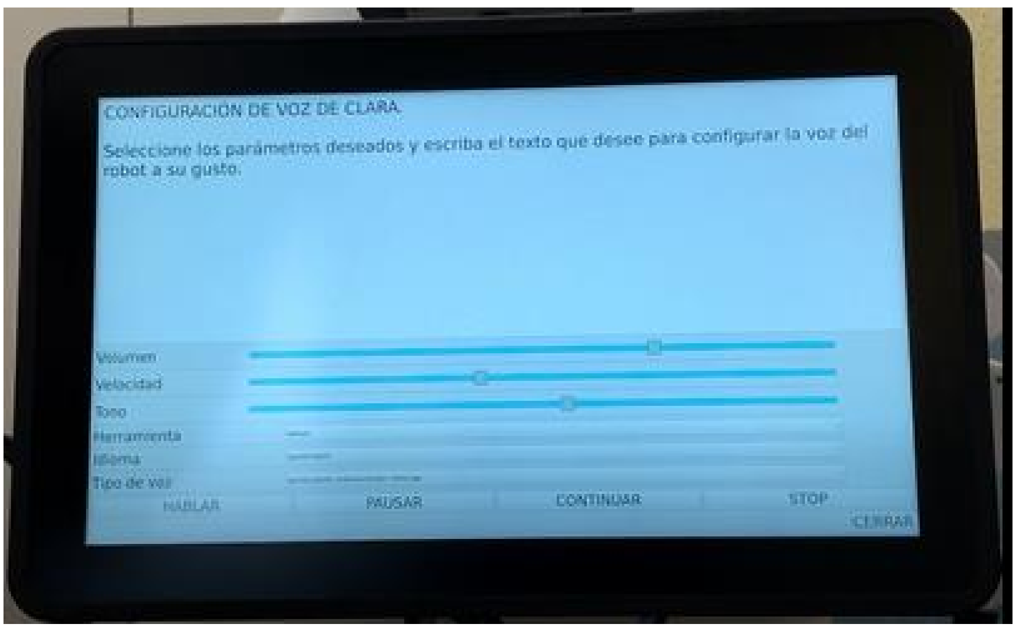

Figure 6.7 Voice recognition interface of ROSI robot's application (Town Crier).

Figure 6.8 Calendar interface of ROSI robot's application (Town Crier).

Step 3. Audit the Robotic Application

Check All Initial interaction components interfaces (hardware and software): the evaluators audited the interaction components of each interface without entering any inputs or performing tasks / functions.

Check All Complete Processes: the evaluators checked the complete task which includes the user's interaction with the different interfaces' components to perform functions, entering any data, or otherwise initiating a process.

Results

Each evaluator prepared a final report detailing the existing accessibility problems she found. A comparison was conducted to eliminate the repeated accessibility problems, and to agree on them and to combine them in one final report, see tables (6.6, 6.7 and 6.8) for the final results. To see the proposed guidelines used in this evaluation refer to table 5.9. The detected accessibility problems were linked with evaluators' recommendations and with the proper guideline that explain how to perform the recommendation in a practical way. Moreover, the conformed requirements were traced and listed according to the proposed guidelines for HRI. Eleven (11) accessibility problems were obtained regarding the software interface of ROSI, 1 accessibility problem was found in ROSI's hardware interfaces, besides 1 accessibility problems found during revising the complete process (going through the complete interaction for all robot's functions).

Table 6.6 Detected accessibility problems in software components of ROSI robot's interfaces / town crier application.

Software Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Town Crier	- The voice configuration button is located on the top of the interface, but it does not have a caption or label.	- Add caption or label for voice configuration button.	**(4.a)** **(7.1.c)**	**2.a** **2.b** **3.b** **3.c** **7.1.b** **15.a** **15.b** **15.c** **16**	**4.b** **5** **6**
	- We could not have access to the C++ code to evaluate this check.		**7.1.a**		
	- Calendar, Birthday, Weather, Activities and Voice configurations buttons' appearance is not clickable.	- Make all buttons with clickable appearance.	**(7.2)**		
	- There is no mechanism to control the contrast by user (dark text on a light background, and vice versa).	- Provide a setting for invert colors or contrast within the recommended luminosity ratio. The nurse can help the patient to adjust the contrast at the beginning of the session.	**(7.3)**		
	- The user cannot change font type and size, and zoom in or out on the interface.	- Provide a setting for changing font type and size within a minimum text size or for zoom, in the same way as voice configuration settings.	**(7.4)**		

Table 6.7 Detected accessibility problems in software components of ROSI robot's interfaces / town crier application

Software Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Voice Recognition	- Sliders are not very accessible UI components to people who have motor disabilities.	- In the absence of a keyboard or keypad in the robot's hardware, it would be useful to replace the sliders with a value field with two buttons, to increase and decrease any voice parameter value.	- This check is not available in the guidelines, but the developer may refer to this (link) for more explanation	**2** **3.c** **4** **7.1** **7.2** **15.a** **15.b** **15.c** **16**	**5** **6**
	- The general design of this interface is totally different from all other interfaces, especially in colors and the absence of the main menu which appears in all other interfaces.	- Please design consistently, and provide a main menu to this interface, where the user expects to have a main menu in all interfaces.	**(3.b)**		
	- For these checks, please refer to the recommendations of (Town Crier) and apply them to this interface (Voice Recognition).		**(7.3)** **(7.4)**		

Table 6.8 Detected accessibility problems in software components of ROSI robot's interfaces / town crier application

Software Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Calendar	- Time and main menu icons are without labels or captions	- Add labels or captions to the main menu icons and to the time too.	**(4.a)** **(7.1.c)**	**2.a** **3.b** **3.c** **4.b** **7.1.a** **7.1.b** **7.2** **15.c** **16**	**5** **6**
	- For these checks, please refer to the recommendations of (Town Crier) and apply them to this interface (Calendar).		**(7.3)** **(7.4)**		
Birthday	- Main menu icons are without labels or captions.	- Add labels or captions to the main menu icons.	**(4.a)** **(7.1.c)**	**2.a** **2.b** **3.b** **3.c** **4.b** **7.1.a** **7.1.b** **7.2** **15.a** **15.b** **15.c** **16**	**5** **6**
	For these checks, please refer to the recommendations of (Town Crier) and apply them to this interface (Birthday).		**(7.3)** **(7.4)**		
	- The appearance of arrow buttons which are on the left corner of each picture are not clickable.	- Make all arrow buttons with clickable appearance.	**(7.2)**		

Table 6.9 Detected accessibility problems in software components of ROSI robot's interfaces / town crier application

Software Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Weather	For these checks, please refer to the recommendations of (Town Crier) and apply them to this interface (Weather).		**(7.3)** **(7.4)**	**2.a** **2.b** **3.b** **3.c** **4.b** **7.1.a** **7.1.b** **7.2** **15.a** **15.b** **15.c** **16**	**5** **6**
	- Main menu icons are without labels or captions.	- Add labels or captions to the main menu icons.	**(4.a)** **(7.1.c)**		
Activities	- For these checks, please refer to the recommendations of (Town Crier) and apply them to this interface (Activities).		**(7.3)** **(7.4)**	**2.a** **2.b** **3.b** **3.c** **4.b** **7.1.a** **7.1.b** **7.2** **15.a** **15.b** **15.c** **16**	**5** **6**
	- Main menu icons are without labels or captions.	- Add labels or captions to the main menu icons.	**(4.a)** **(7.1.c)**		

Table 6.10 Detected accessibility problems in hardware components of ROSI robot's interfaces/town crier application.

Hardware Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Haptic display	- The display is placed in the middle of the robot's body, where the user might be in different positions (sitting on the bed or chair).	- Make sure the display is in a proper place, at least for a user who is sitting on a bed or chair (two positions at least), or provide the robot with an adaptable haptic display that can be adjusted manually or automatically.		**3.a**	**-**

Table 6.11 Detected accessibility problems in the complete processes of ROSI robot's interfaces/town crier application.

Complete process					
Process's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Town Crier	- We could not have access to the C++ code to evaluate this check.		**(8.a)** **(8.b)** **(8.c)**	**1** **8.d** **11** **13** **17**	**9** **10** **12** **14**
	- There is no reachable human support mean.	- Provide a button or any appropriate mean for reachable human support.	**(18)**		

Table 6.12 Detected accessibility problems in the complete processes of ROSI robot's interfaces/town crier application.

Complete process					
Process's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Voice recognition	- For this check, please refer to the recommendations of (Town Crier) and apply them to this interface (Voice recognition).		**(8.a) (8.b) (8.c) (18)**	**1 8.d 11 13 17**	**9 10 12 14**
Calendar	- For this check, please refer to the recommendations of (Town Crier) and apply them to this interface (Calendar).		**(8.a) (8.b) (8.c) (18)**	**1 8.d 11 13 14 17**	**9 10 12**
Birthday	- For this check, please refer to the recommendations of (Town Crier) and apply them to this interface (Birthday).		**(8.a) (8.b) (8.c) (18)**	**1 8.d 11 13 14 17**	**9 10 12**
Weather	- For this check, please refer to the recommendations of (Town Crier) and apply them to this interface (Weather).		**(8.a) (8.b) (8.c) (18)**	**1 8.d 11 13 14 17**	**9 10 12**

Table 6.13 Detected accessibility problems in the complete processes of ROSI robot's interfaces/town crier application.

<table>
<tr><th colspan="6">Complete process</th></tr>
<tr><th>Process's Name</th><th>Detected Problem</th><th>Evaluators' Recommendation</th><th>Not conformed guidelines</th><th>Conformed guidelines</th><th>Not applicable guidelines</th></tr>
<tr><td>Activities</td><td colspan="2">For this check, please refer to the recommendations of (Town Crier) and apply them to this interface (Activities).</td><td>(8.a)
(8.b)
(8.c)
(18)</td><td>1
8.d
11
13
14
17</td><td>9
10
12</td></tr>
</table>

6.2.2 Users' Accessibility Evaluation

In order to continue the investigation of finding an adequate answer to the following research question:

- **RQ7:** Are the proposed guidelines usable for the robot's developers and designers?

Evaluators' recommendations, which were made according to the proposed guidelines in Subsection (6.2.1), were implemented by the developers in the ROSI robot interfaces (town crier). It is important to clarify that it was not possible to implement all of them due to the robot's characteristics such as changing the fixed robot's display with an adaptable one. Also, some of the modifications were not easy to implement, as the developers did not have enough time to implement them such as implementing settings to invert display's colors or contrast.

In this subsection, a user evaluation was conducted to evaluate the accessibility of the ROSI robot's interfaces and to detect possible accessibility problems. And an explanation of possible accessibility problems that users may encounter due to not implementing some of evaluators' recommendations in the robot's interfaces.

Evaluation Design

Objective

This evaluation detects the accessibility problems found by real users during their interaction with the ROSI robot (Town Crier). This subsection presents the results of the first impression of the HRI with ROSI, but the robot's interfaces are being evaluated in a long-term evaluation in the residence home as part of the ROSI project. The results that include accessibility and usability evaluations will be published when the project finishes.

Environment

Evaluation sessions were conducted at the Vitalia Theatinos residence home (at Málaga, Spain) where participants reside. The participants were informed about the evaluation sessions on 29th of October of 2021 and signed the evaluation consent. Moreover, the information of the pre-test forms (related to socio-demographic, ability/disability and interaction characteristics, detailed in the following section) was collected on 3rd of November of 2021. Then, the first interaction session with the robot, which is detailed in this subsection, was done on 11th of November of 2021 until February 2022. We are planning to make a long-term evaluation of the interfaces at the residence home with the ROSI robot and another robot with other interaction components. The interaction with the robot starts with a greeting message, and then presenting information about the date, weather, ROSI robot, menu for lunch, agenda (activities) and birthdays. The interaction ends with a goodbye message.

The participants were not allowed to interact with the display; they just had to listen to the robot's information. The evaluation of the display interaction will be held in January 2022.

The sessions are conducted approximately every three-four days, according to the time available in the residence. Each session lasted for (2.14 min). Five sessions were conducted during this evaluation, with four participants attending the sessions. These were conducted in one of the common living rooms at the residence home. The robot was located in a suitable place near the group of participants to allow them to hear the robot's voice, see figure (6.9).

Figure 6.9 The participants with the ROSI robot during the users' evaluation.

Participants

Initially, 6 participants were enrolled, but for personal issues two of them could not participate in all the sessions with the robot and had to quit the evaluation. Four participants could continue the long-term evaluation at the residence home, all of them were volunteers: 1 female and 4 males. Also, they are Spanish and elderly who vary in the types of disabilities they have, as presented in figure 6.10, where severity of each disability is presented according to the 5-point Likert Scale questions with 1 being for example (I cannot hear, see, move, etc…) and 5 being (I can hear, see, move perfectly, etc…). The only exclusion criterion was the severity in cognitive disabilities, where persons with strict or moderate cognitive disabilities were not invited to participate in the study. They usually stay in a different room, doing different kinds of daily activities in the residence home.

Table 6.9 summarizes the socio-demographic information of participants, their abilities/disabilities, and their experience with technologies. Some descriptive statistics also were concluded. None of the participants had a disability severity over a moderate degree, in case of having hearing disability, visual disability or a problem in reading with agility. For motor disability, one participant presented a disability severity over a moderate degree.

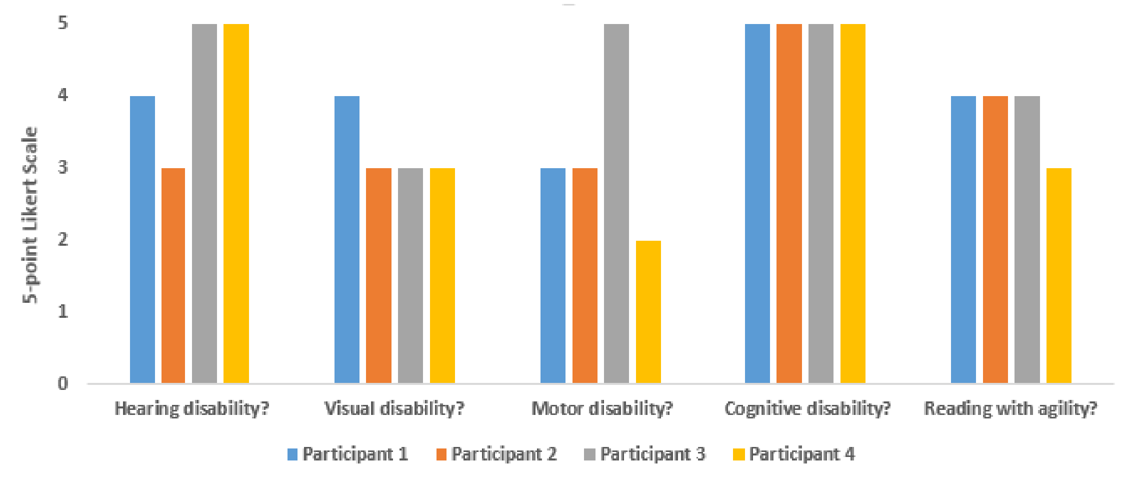

Figure 6.10 Participants' responses assigned to a scale point for each question.

The majority of the participants showed the knowledge of using the phone, while half of them have experienced using computers or tablets less often than they use the phone. The majority of them have never interacted with robots, only 1 out of 4 participants has interacted with a robot used for kitchen tasks. Half of them encourage the use of robots and ALL, while the rest showed lack of knowledge in robots and ALL and what they can do.

Table 6.14 Participants' characteristics.

Characteristics	Detailed characteristics	Percentages
Gender	(Male)	**75%**
	(Female)	**25 %**
Nationality	(Spanish)	**100%**
Experience in using electronic devices	Using mobile phone	(Fairly use) **50%,** (somewhat use) **25%** and (rarely use) **25%**
	Other uses of the phone besides calls	(None) **50%** and (Social media and surfing internet) **50%**
	Using computers or tablets	(somewhat use) **50%** and (rarely use) **50%**
	Using computer or tablet for	(Nothing specific) **25%**, (For work) **25%** and (reading news, playing music and store files) **50%**
Experience in interaction with robots	I have ever interacted with a robot	(Never) **75%** and (rarely) **25%**
	Type of used robot and what for	(Kitchen robot)
	Opinion about interacting with robots and preferred use cases of robots	(Do not know) **50%**, (robots should be used more) **25%** and (robots should be used more in hospitals, schools, center) **25%**
Experience in Ambient Assisted Living (ALL)	Knowing or hearing about AAL	(Never) **50%** and (rarely heard about ALL) **50%**
	Type of used ALL and what for	(Nothing specific but heard about All from TV)
	Preferred use cases of ALL	(Do not know) **50%**, (ALL should be used in hospitals and schools) **50%**
Type of disabilities (if any)	Hearing disabilities	(Hearing somewhat) **25**%, (hearing fairly) **50%** and (hearing perfectly) **25%**
	Used assistive tools in case of having hearing disabilities	(None) **100%**
	Visual disabilities	(Seeing somewhat) **75%** and (seeing fairly) **25%**
	Used assistive tools in case of having visual disabilities	(Glasses) **100%**
	Motor disabilities	(Moving somewhat) **50**%, (have moving difficulty) **25%** and (moving perfectly) **25%**
	Used assistive tools in case of having motor disabilities	(None) **25%** and (wheel chair) **75%**
	Cognitive disabilities	(No cognitive disabilities at all) **100%**
	Reading agility	(Reading fairly) **75%** and (reading somewhat) **25%**

Materials

The following evaluation methods and materials were used to run the evaluation:

- **ROSI robot**: which is described in detail in Subsection (6.2.1).
- **Questionnaire:** all participants were asked to answer the pre-test questionnaire to gather socio-demographic information of participants, besides their experience with technologies. Participants answered the post-test questionnaire after the first interaction session with the robot, which consists of seven open-ended questions,

and twenty-two 5-point Likert Scale questions with 1 being (strongly agree) and 5 being (strongly disagree), and two 5-point Likert Scale questions with 1 being (Never) and 5 being (Yes, at least 1 time every 6 months) (See Appendix G for the complete questionnaire). Questions in the post-test questionnaire focus on inspecting any accessibility problems that participants may have faced during the interaction with the robot and their User Experience (UX) and acceptance by measuring participants' responses on certain aspects, such as: previous knowledge of town crier as a human or as a robot, accessing robot's information, robot utility, participants' concentration, participants' emotions, robot's behavior and any recommendations or comments on the interaction with the robot.

- **Observation:** technicians were responsible for observing the participants' behavior and reactions during the test, and to write a report with all these observations. Also, the evaluators extracted some accessibility problems from the recorded videos. Later, when the whole evaluation project is completed, analysis of all videos of sessions will be analyzed in depth.

Protocol

The protocol followed with all participants was as follows:

1) Evaluation environment and duration: the sessions were held in one of the common living rooms at the facility where the users usually participated in activities such as watching TV, chatting, playing boarding games, etc. The duration for each session was (2.14 min) with five sessions held in this evaluation.
2) Introduction and pre-test questionnaire: participants were initially interviewed through a guided questionnaire. The purpose of this evaluation was explained to them and they were asked to sign consent forms to carry out this evaluation. Moreover, the participants were requested to answer the pre-test questionnaire for some socio-demographic information and to gather information about their experience with technology.
3) Evaluation sessions: for each session, the objective of the evaluation was explained to the participants before starting the session by one of the researchers. Then, the robot was teleported from its charge base to the common living room by the technician through a joystick / keyboard, and placed in a location where all participants could hear and see it. Once the robot was located, the interaction (events order) with the robot in the first session took place as follows:
    - First, the technician pressed a button on the control interface, where the robot made a trumpet sound as a wake-up call and launched a greeting message.
    - Then, the robot presented information about the date, weather, ROSI robot (only in the first time the robot interacted with the participants), menu for lunch, agenda (activities) and birthdays.

- The interaction ended with a goodbye message.

In subsequent sessions, interaction order (events) might change and the technician could choose one event or the complete list of events from the control interface to be announced by the robot. In case the participants were in two or more groups in the room, some on armchairs and others around the table for example, the robot announced the agenda (calendar, birthdays, weather, menu for lunch and / or activities) several times, once in each small group. If the technician noticed or heard that some participants did not hear the robot, he could make the robot repeat again and finally launch the farewell message. The robot was directed to leave the room to its charge base.

The technicians were also responsible to interfere if any technical error happened, besides taking notes and observing participants' behaviors and reactions towards interacting with the robot.

4) Post-test interview: when the evaluation session ended, the in-depth guided interview based on a post-test questionnaire was performed, the participants were invited to extend their answers with their own observations / recommendations. The post-test questionnaire consists of seven open-ended questions and twenty-four 5-point Likert Scale questions; these questions measured participants' responses on certain aspects: previous knowledge of town crier as a human or as a robot, accessing robot's information, robot utility, participants' concentration, participants' emotions, robot's behavior and any recommendations or comments on the whole test.

Evaluation Results

The results were obtained from the completed questionnaires, technical report and analyzed videos. The questionnaires were reviewed to check whether all of them were properly and completely filled. Hence, none of them were excluded. In addition, participants' responses on the six aspects (previous knowledge of town crier as a human or as a robot, access to robot's information, robot utility, participants' concentration, participants' emotions, and robot's behavior) were studied repeatedly, and concluded separately for each aspect, as follows:

Previous knowledge of a robot or human town crier: the study dedicated three 5-point Likert Scale questions (questions q1, q2 and q3 in table 6.10) and one open-ended question (question q4 in table 6.10) to assess participants' experience with a town crier robot or human. Following are the analysis of participants' responses on the three questions:

1) Experience with another robot town crier: participants' responses on q1 revealed that 3 of 4 have never known a robot or a machine similar to town crier robot, while 1 participant informed that he saw a robot similar to town crier in a movie.

2) Experience with a human town crier: half of the participants said they saw a human town crier oftentimes, while the rest have never seen it (question 2).
3) How similar is the town crier robot to the human one: one of 4 participants strongly disagreed that the town crier robot reminds him of the real town crier; the other participants selected Neutral (question 3). Analysis of their answers to the open-ended question (question 4) revealed that both participants think the robot should be more natural and have a personality like the human town crier.

Table 6.15 Questions evaluating previous knowledge of town crier concept.

Question ID	Description	Mean	SD
q1	Did you know of a similar town crier robot or machine?	1.8	1.5
q2	Have you ever seen a human town crier at work?	2.5	1.7
q3	The robot reminded you of a real town crier.	2	1.4
q4	Do you miss something about the town crier robot to make it behave just like a real town crier?	--	--

Accessing robot's information: five 5-point Likert Scale questions (questions q5- q7, q9 and q10 in table 6.11) and two open-ended questions (question q8 and q11 in table 6.11) were dedicated to assess how was accessing the robot's information during the evaluation. Following is the analysis of participants' responses on the three questions:

1) The start of interaction (trumpet sound): all participants strongly agree that the trumpet sound launched by the robot alerted them of starting the interaction with the robot (question 5).
2) Social distance of interaction: all participants strongly agreed that the distance of interaction with the robot helped them hear the robot properly (question 6).
3) Ability to hear robots' sound / sound volume fitting: all participants strongly agreed that they could hear the robot at all the times (question 7). Based on that, there was no necessity to ask the participants to answer (question 8).
4) Robots' information understandability: information proclaimed by the robots was understood for all the participants, where all of them chose strongly agreed (question 9).
5) Information presentation helps participants to remember it: all participants agreed that information presentation allowed them to remember it (question 10). Analysis of participants' responses on (question 11) showed that two of them think if the robot speaks slower, then it would make information remembering easier for them.

Table 6.16 Questions evaluating access to robot's information.

Question ID	Description	Mean	SD
q5	The trumpet call sound helps me to identify what new information is to be told next.	1	0
q6	The robot is located at a suitable distance to be able to hear you well	1	0
q7	I could hear what the town crier robot was saying at all times:	1	0
q8	If you couldn't hear well, what was it due to?	--	--
q9	The information proclaimed by the robot is clear and well understood.	1	0
q10	The way of giving the information allows me to remember it easily.	1.25	0.5
q11	How would it be easier for you to remember all the information provided by the robot?	--	---

Robot utility: two 5-point Likert Scale questions (q12 and q13 in table 6.12) and one open-ended question (q13 in table 6.12) were dedicated to evaluating robot utility, weather the participants found the robot proper for town crier tasks or not. The analysis of participants' responses is as follows:

1) The suitability of the robot to the task: all participants agreed that the robot was practical to perform the town crier tasks (question 12).
2) Willingness to interact with the robot in the future: all participants would like to interact with the robot daily (question 13), and they would like the robot to provide them with the same information: date, weather, daily activities and appointments (question 14).

Table 6.17 Questions evaluating robot utility.

Question ID	Description	Mean	SD
q12	I think the robot is practical to remember participants with events in the residence.	1	0
q13	I would like the robot-town crier to recall the events at the residence every day.	1	0
q14	What kind of information would you like the robot to provide?	--	--

Robot physical appearance: six 5-point Likert Scale questions (q15 – q20 in table 6.13) were assigned to evaluate how participants found robot physical appearance. Participants' responses were as follows:

1) Feeling safe in the robot's presence: all participants felt safe in the presence of the robot (question 15), while 3 of 4 participants found it easy to be with the robot and to predict its behavior and movement, while one participant chose Disagreed (questions 16 and 18). Careful review of this participant's characteristics revealed that he has a combination of two disabilities: visual and hearing, which means the robot's physical appearance has no relation to his answer. The interaction channels

(visual and audio modality) used in this robot might have made him find it difficult to be with the robot.

2) Robot appearance's effect on understanding: 3 of the participants felt comfortable and easily understood what the robot said, while one participant responded with Disagree (question 17). Again, this participant has visual and hearing disabilities, which affected his understanding of what the robot said, and again the robot's physical appearance has no relation to his answer.
3) Robot display size, colors and font: all participants disagreed that the robot display size was adequate (question 19), while all of them strongly agreed that display colors and fonts were suitable (question 20).

Table 6.18 Questions evaluating robot's physical appearance.

Question ID	Description	Mean	SD
q15	I was intimidated when I first saw the robot.	5	0
q16	I find it easy to be in the presence of the robot, whose physical appearance was not intimidating.	1.75	1.5
q17	The robot made me feel comfortable and it was easy to understand what it was saying.	1.75	1.5
q18	I felt safe, from a physical point of view, with the robot, whose behavior and movement were predictable.	1.75	1.5
q19	I think the display size is adequate (height and width).	4	0
q20	I think the colors used on the robot display and the font used were suitable.	1	0

Concentration / focus: participants responded to five 5-point Likert Scale questions (q21 – q25 in table 6.14), which were assigned to evaluate their concentration / focus during interaction with the robot. Participants' responses were as follows:

1) Focus during interaction: 3 of 4 participants strongly agreed that they were able to easily focus on what the robot was saying; the participant who has visual and hearing disabilities was not able to focus easily on what the robot was saying (question 21). In addition, all participants chose Neutral to answer question 22, and the analysis of their answers showed that two of them think there is no difference if a human or a robot performs this task. The other two participants said that they will be able to remember more if the interaction duration with the robot is longer and more frequent (question 22).
2) Recognizing when the interaction starts and when it ends: none of the participants faced a problem regarding recognizing when the interaction starts and ends (question 23 and question 24).
3) Interaction duration: 3 of the 4 participants agreed that the interaction duration was suitable to announce events and activities, while the participant with visual and hearing disabilities chose Neutral. Reviewing his answer in open ended questions, it is found that he found the interaction duration short and he needs more time to

hear and see the information announced by the robot in comparison to the rest of participants (question 25).

Table 6.19 Questions evaluating participants’ concentration during interaction with the robot.

Question ID	Description	Mean	SD
q21	It was easy for me to focus on what the robot was announcing.	1.75	1.5
q22	It is easier for me to retain information when told by the robot than when told by a person. Briefly explain your answer.	3	0
q23	It was clear to me at all times when the robot began to proclaim something.	1	0
q24	It was clear to me at all times when the robot had finished proclaiming something.	1	0
q25	The time the robot uses to announce the events seems adequate.	2	0.82

Emotions: one 5-point Likert Scale question (q26 in table 6.15) and one open-ended question (q27 in table 6.15) were designed to assess participants’ emotions during the interaction with the robot. participants’ responses showed that none of the participants felt afraid during the interaction with the robot (question 26), two of them were curious about what the robot can do, and one of them felt satisfied to see technology in their life.

Table 6.20 Questions evaluating participants’ emotions during interacting with the robot.

Question ID	Description	Mean	SD
q26	I'm afraid to touch the robot, in case it acts unpredictably or breaks something.	5	0
q27	Does it provoke any other emotion? Joy, sadness, anger, etc. When and why?	--	--

Robot behavior: two 5-point Likert Scale questions (q28 and q29 in table 6.16) were assigned to assess the robot’s behavior. Analyzing participants’ responses showed that all of them found the robot polite and sociable.

Table 6.21 Questions evaluating robot behavior.

Question ID	Description	Mean	SD
q28	Robot's way of talking was polite and I liked it.	1	0
q29	The robot was sociable at all times and made me feel good.	1	0

Participants’ comments: three open-ended questions (q30-q32 in table 6.17) were dedicated to collect participants’ comments on the interaction with the robot. Participants’ comments were thoroughly reviewed, and it was found that all their comments were about four main issues: enhancing the robot’s appearance to look more natural and close to the human appearance, especially the face and hair, increase robot display size and extend interaction duration with the robot.

Table 6.22 Questions relating to participants' comments.

Question ID	Description	Mean	SD
q30	The robot would improve if........ .	--	--
q31	I like the robot because........ .	--	--
q32	What I like least about the robot is........ .	--	--

Technicians' report: the report included a set of observations regarding participants' interaction with the robot. Observations were analyzed and concluded as follows:

- The participants reacted positively toward interacting with the robot, even after ending the interaction, where some of them tried to talk again to the robot. This reflects a positive acceptance of the robot. In addition, they wished the robot could do more tasks: reminding them of the meals they ate the day before, and delivering their requests and needs to the staff at the residence.
- All participants were able to hear the robot from a different location in the room.
- Participants were not satisfied about the robot's appearance and they wished it could look more natural or have a human appearance. Moreover, they all were happy with the name that other residents chose for the robot in a previous evaluation (Felipe), the Spanish King's name.
- In relation to the robot's voice, participants were not happy with the robot's voice as they found it somewhat robotic.
- Related to the initial town crier trumpet sound used to call the attention of the participants before starting the announcement, the participants preferred a more harmonic sound instead of trumpet.

In general, they were more concerned about the robot's appearance compared to the robot's voice or the initial trumpet sound.

Analysis of interaction videos

The evaluators observed some accessibility problems from the interaction videos. Following, potential accessibility problems that the participants did not address in their answers will be explained:

- **Non-interactive conversation**: the participants tried to talk to the robot, but the robot could not recognize and respond to them. Instead, the robot kept presenting the agenda (events).
- **Lack of emotion presentation**: the participants showed excitement and happiness expressions, some of them waved to the robot, but the robot did not show any emotion in return.

Summary on accessibility barriers found in ROSI robot

Following, we summarize the accessibility barriers found through this evaluation. Table 6.18 shows all the accessibility barriers addressed by the participants, explained in the technician report, or from the analysis of the videos.

Table 6.23 Accessibility barriers addressed by participants, technicians and evaluators.

#	Accessibility barrier
1	**The speech rate:** reducing the speech rate of the robot will help the users to better remember the information presented by the robot.
2	**Robot's display size**: increasing screen size will help the users to better recognize the presented information on the robot's display.
3	**The used modalities for interaction**: the audio and visual modalities, which were used for interaction, are not suitable for users who have a combination of hearing and visual disabilities.
4	**Robot's appearance**: enhancing the robot's appearance to be more natural and looks like a human will increase the users' acceptance of the robot.
5	**Robot's voice**: enhancing the robot's voice to be more natural instead of being mechanic will increase the users' acceptance of the robot. Including the importance of using harmonic music instead of the trumpet sound.
6	**Non- Interactive conversation**: enhancing the voice recognition and speech synthesis technologies used in the robot will increase the interaction quality and the sociality of the robot.
7	**Lack of emotion presentation:** implementing emotion representation in the robot such as facial expressions will increase the users' acceptance of the robot**.**

Furthermore, table 6.19 shows the potential accessibility barriers that users may encounter during the interaction with the robot due to not implementing some of the evaluator's recommendations.

Table 6.24 Potential accessibility barriers due to not implementing some of evaluators' recommendations.

#	Evaluators' recommendation	Potential accessibility barriers due to not implementing the recommendation.
1	Provide a setting for invert colors or contrast within the recommended luminosity ratio.	A group of users who have visual disabilities may face difficulty in recognizing the presented information on the robot's display.
2	Provide a setting for changing font type and size within a minimum text size or for zoom, in the same way as voice configuration settings.	A group of users who have visual disabilities may face difficulty in recognizing the presented information on the robot's display.

Table 6.25 Potential accessibility barriers due to not implementing some of evaluators' recommendations.

#	Evaluators’ recommendation	Potential accessibility barriers due to not implementing the recommendation.
3	For voice configuration, replace the sliders with a value field with two buttons to increase and decrease any voice parameter value.	A group of users who have motor disabilities may face difficulty in adjusting the robot’s voice volume.
4	Make sure the display is in a proper place for the users.	The fixed display may cause difficulty for users who are in different positions (sitting on the bed or chair) and they are trying to interact with the robot’s display.
5	Provide a button or any appropriate mean for reachable human support.	Not having implemented reachable human support may cause the interaction with the robot to be stopped completely in the event of an error, or to proceed in an undesirable manner for the users.

Project Data

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- **Institutional Review Board Statement**: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Universidad of Málaga.
- **Informed Consent Statement**: Informed consent was obtained from all subjects involved in the study.
- **Data Availability Statement**: The evaluation data is summarized in this document.

- **Acknowledgments**: The authors warmly thank the persons involved in the evaluation process for their participation in this research and their valuable feedback.

- **Conflicts of Interest**: The authors declare no conflict of interest.

6.3 Experts’ Accessibility Evaluation of Telepresence application.

A second heuristic evaluation was conducted using the proposed guidelines (see table 5.9 for the complete guidelines) to elicit accessibility problems from the ROSI robot’s interface (*ROSI – Robotic assistants for nursing homes*, n.d.). During the evaluation time, the robot (figure 6.11) was used as an assistant robot that helps patients reside at the hospital during the pandemic time because of the coronavirus spreading to make calls with their relatives via videoconferencing. The robot was used for the video conferencing task aligning with precautions. The evaluated interfaces were revised by the developers based on the experts’ recommendations for this evaluation, in preparation for a later user study for the proposed guidelines evaluation.

Figure 6.11 ROSI robot in telepresence robotic application.

Evaluation Design

Objective

The objective of evaluation is to report the existing accessibility barriers of the ROSI robot' interfaces, specifically for a videoconferencing task.

Participants

Two HRI and HCI accessibility experts performed the evaluation, both of them revised the robot's display interface and reported the existing accessibility problems.

Materials

Software application that is integrated to the ROSI robot's system (previously described in subsection (6.2.1) to help patients who reside at hospital during the pandemic time because of the coronavirus spreading to make calls with their relatives by video-conferencing, in addition to proposed accessibility guidelines for Human-Robot Interaction (see table 5.9 for the complete guidelines) and a website to manipulate the contrast ratio issue (*Contrast Finder, find correct color contrasts for web accessibility (WCAG)*, n.d.).

Protocol

The proposed evaluation methodology in section (4.1) was applied by the evaluators, as follows:

Step 1. Define the Evaluation Scope

Define the evaluation scope: The evaluators considered the entire interfaces and services of the telepresence application for the evaluation of three tasks / processes: disinfection and rest, open door and performing video calls.

Step 2. Explore the Target Robotic Application (Software and Hardware)

In this step all the common interfaces for each task are listed below (figure 6.12), where main interfaces are highlighted with blue:

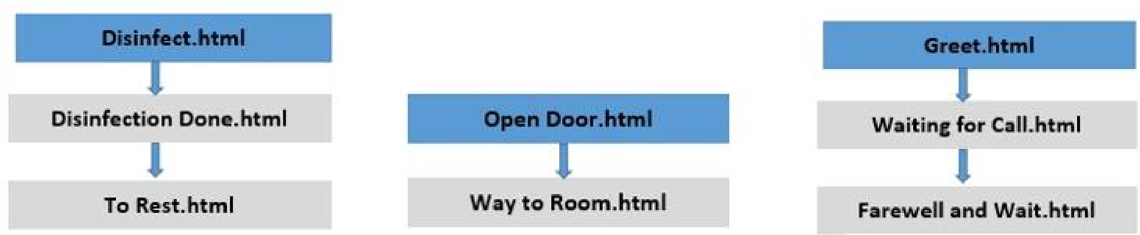

Figure 6.12 Main and common interfaces of ROSI robot's application (Telepresence).

The evaluated software interfaces are related to three robot's tasks / processes: disinfection of the robot and rest task, opening the door to allow the robot to enter the patient's room and performing the video call. All software interfaces have the same style, layout, structure, navigation and visual design. Software Interfaces vary in their content as they include buttons, headers, images, texts and toolbars; the functional components are buttons. Developers used HTML and CSS web technologies to implement the interfaces. Changing the interface's appearance usually depends on the user's action or the context of the task, in addition to dynamic content, error messages and notifications. Figures 6.13, 6.14 and 6.15 represent the main interface (Disinfect) of the ROSI robot's (telepresence application), (Disinfect Done) and (To Rest) interfaces respectively. (The rest of telepresence interfaces are available in Appendix D).

The robot incorporates a haptic display, microphone, RGB-D sensor, speakers, and Kinect camera.

Figure 6.13 Disinfect interface of ROSI robot's application (Telepresence).

Figure 6.14 Disinfect Done interface of ROSI robot's application (Telepresence).

Figure 6.15 To Rest interface of ROSI Robot's application (Telepresence).

Step 3. Audit the Robotic Application

Check All Initial interaction components' interfaces (hardware and software): the evaluators audited the components of each interface without entering any inputs or performing tasks / functions.

Check All Complete Processes: the evaluators checked the complete task, which included the user's interaction with the different interfaces' components to perform functions, entering any data, or otherwise initiating a process.

Results

Tables (6.20, 6.21 and 6.22) show the final list of existing accessibility problems in ROSI's interfaces; both evaluators agreed on them. Each accessibility problem is tied up with evaluators' recommendations and the required guideline to rectify it. In addition, all conformed and not applicable guidelines for ROSI's interface are traced and listed in the final list. 6 accessibility problems were obtained regarding the software interface of ROSI in telepresence application, 1 accessibility problem was found in ROSI's hardware interfaces, and besides 1 accessibility problem found during revising the complete process (going through the complete interaction for all robot's functions) for telepresence application

Table 6.26 Detected accessibility problems in software components of ROSI robot's interfaces/telepresence application.

Software Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Disinfect.html	- The blinking background keeps blinking till the nurse presses the "disinfected button".	- Specify blinking times for the background to be for a certain period and then stop automatically without any intervention by the user.	**(5)**	**2.a 3.b 3.c 4 6 7.1.a 7.1.b 15.a 15.b 15.c 16**	**-**
	- Home and doctor buttons on the right of the page header without labels.	- Label both buttons with words like "help" or "nurse station".	**(7.1.c)**		
	- Buttons (audio, help, home buttons etc. …) appearance is not clickable.	- Make all buttons with clickable appearance.	**(7.2)**		
	- There is no mechanism to control the contrast by user (dark text on a light background and vice versa). The contrast ratio for this page is (2.01) for (#ffafaf and #e65a5a) colors.)	- Provide a setting for inverting colors or contrast within the recommended luminosity ratio. The nurse can help the patient to adjust the contrast at the beginning of the session. - Please check the recommendations at this web (contrast finder) for buttons and text compared to their background.	**(7.3) (2.b)**		

Table 6.27 Detected accessibility problems in software components of ROSI robot's interfaces/telepresence application.

Software Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Disinfect.html	- The user cannot change font type and size and zoom in or out on the interface.	- Provide a setting for changing font type and size within a minimum text size or for zoom. The nurse can help the patient to adjust the contrast at the beginning of the session.	(7.4)	**2.a** **3.b** **3.c** **4** **6** **7.1.a** **7.1.b** **15.a** **15.b** **15.c** **16**	-
Disinfection Done.html	- Please apply all the recommendations for the previous interface (Disinfect.html) to this interface (Disinfection Done.html), and ignore requirement (5), as there are no blinking components in this interface.			**2.a** **3.b** **3.c** **4** **5** **6** **7.1.a** **7.1.b** **15.a** **15.b** **15.c** **16**	-

Table 6.28 Detected accessibility problems in software components of ROSI robot’s interfaces/telepresence application.

Software Components					
Interface’s Name	**Detected Problem**	**Evaluators’ Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
To Rest.html	- Please apply all the recommendations for the previous interface (Disinfect.html) to this interface (To Rest.html), and ignore requirement **(5)**, as there are no blinking components in this interface.			**2.a 3.b 3.c 4 5 6 7.1.a 7.1.b 15.a 15.b 15.c 16**	**-**
Open Door.html	- Please apply all the recommendations for the previous interface (Disinfect.html) to this interface (Open Door.html), and ignore requirement **(5)**, as there are no blinking components in this interface.			**2.a 3.b 3.c 4 5 6 7.1.a 7.1.b 15.a 15.b 15.c 16**	**-**

Table 6.29 Detected accessibility problems in software components of ROSI robot's interfaces/telepresence application.

Software Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Way to Room.html	- Please apply all the recommendations for the previous interface (Disinfect.html) to this interface (Way to Room.html), and ignore requirement **(5)**, as there are no blinking components in this interface.			**2.a** **3.b** **3.c** **4** **5** **6** **7.1.a** **7.1.b** **15.a** **15.b** **15.c** **16**	**-**
Greet.html	- Please apply all the recommendations for the previous interface (Disinfect.html) to this interface (Greet.html), and ignore requirement **(5)**, as there are no blinking components in this interface.			**2.a** **3.b** **3.c** **4** **5** **6** **7.1.a** **7.1.b** **15.a** **15.b** **15.c** **16**	**-**

Table 6.30 Detected accessibility problems in software components of ROSI robot's interfaces/telepresence application.

<table>
<tr><th colspan="6">Software Components</th></tr>
<tr><th>Interface's Name</th><th>Detected Problem</th><th>Evaluators' Recommendation</th><th>Not conformed guidelines</th><th>Conformed guidelines</th><th>Not applicable guidelines</th></tr>
<tr><td rowspan="2">Waiting for Call.html</td><td colspan="3">- Please apply all the recommendations for the previous interface (Disinfect.html) to this interface (Waiting for Call.html), and ignore requirement (5), as there are no blinking components in this interface.</td><td rowspan="2">2.a
3.b
3.c
4.a
5
6
7.1.a
7.1.b
15.a
15.b
15.c
16</td><td rowspan="2">-</td></tr>
<tr><td>- The live call interface does not contain the relative's name; some elderly people with cognitive problems may forget their relative's name.</td><td>- Add a description (relative name / caller name) to the live call interface close to their live screen / picture.</td><td>(4.b)</td></tr>
<tr><td>Farewell and Wait.html</td><td colspan="3">- Please apply all the recommendations for the previous interface (Disinfect.html) to this interface (Farewell and Wait.html), and ignore requirement (5), as there are no blinking components in this interface.</td><td>2.a
3.b
3.c
4
5
6
7.1.a
7.1.b
15.a
15.b
15.c
16</td><td>-</td></tr>
</table>

Table 6.31 Detected accessibility problems in hardware components of ROSI robot's interfaces/telepresence application.

Hardware Components					
Interface's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Haptic display	- The display is placed in the middle of the robot's body, where the patient might be in different positions (sitting in the bed or chair).	- Make sure the display is in a proper place, at least for the patient who is sitting on a bed or chair (two positions at least) or provide the robot with an adaptable display that can be adjusted manually or automatically after the robot defined and addressed the patient's position and height.	-	**3.a**	-

Table 6.32 Detected accessibility problems in the complete processes of ROSI robot's interfaces/telepresence application.

Complete process					
Process's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Disinfection and rest	- The widgets in the code are associated with "ID and alt" attributes, but their properties and states are not defined in HTML code. The keyboard navigation is not existing in the code either, which is necessary for assistive technology.	- Design accessible patterns and widgets based on WAI-ARIA, by defining (roles, properties and states of the widgets and keyboard navigation) in the code.	**(8.a)** **(8.c)**	**1** **8.b** **8.d** **11** **12** **13** **14** **18**	**9** **10**

Table 6.33 Detected accessibility problems in the complete processes of ROSI robot's interfaces/telepresence application.

Complete process					
Process's Name	**Detected Problem**	**Evaluators' Recommendation**	**Not conformed guidelines**	**Conformed guidelines**	**Not applicable guidelines**
Disinfection and rest	- Adopting users' interaction preferences like voice volume and font size.	-	(17)	1 8.b 8.d 11 12 13 14 18	9 10
Open door	- Please apply all the recommendations for the previous process (Disinfection and rest) to this process (Open door).			1 8.b 8.d 11 12 13 14 18	9 10
Performing video call	- Please apply all the recommendations for the previous process (Disinfection and rest) to this process (Performing video call). - In addition to programming the robot to announce the "telepresence mode" to the user, as it is important for their safety to not touch the screen.			1 8.b 8.d 11 12 13 14 18	9 10

6.4 Updating the Proposed Accessibility Guidelines for HRI

After carrying out the evaluations of the proposed accessibility guidelines for HRI, it became necessary to update the proposed guidelines according to the recommendations of the participants in the heuristic evaluation (Section 6.1). This is in addition to the fact that the release of the WCAG 2.1 (W3C, 2019) followed forming the proposed guidelines and the start of evaluating them, which makes it necessary to investigate the impact of WCAG 2.1 on the proposed guidelines and update them accordingly. Moreover, two accessibility guidelines which were previously excluded from the initial document of the proposed accessibility guidelines were added to the updated version of the proposed accessibility guidelines.

Updating the proposed guidelines came according to the following steps:

Step 1. Participants' recommendations have been concluded from the heuristic evaluation (Section 6.1) and studied to investigate the possibility of considering them in the proposed guidelines. Table 6.23 represents the included recommendations and modifications made to the proposed guidelines and exclusion justifications for some of participants' recommendations.

Table 6.34 Included and excluded participants' recommendations on the proposed guidelines.

#	Participants' recommendation	(✓) Included (X) Excluded	Justification in case of exclusion/ Modification made in case of inclusion
1	Adding guidelines for psychological and emotional aspects.	✓	- The following guidelines was added: "adopt emotions representation and recognition means, if it is essential for delivering robot's services"
2	Recommending different classifications for the proposed guidelines: - Targeted users' characteristics. - Robot characteristics (hardware and software guidelines). - Designer or developer characteristics. - Functional and non-functional guidelines.	✓	- Classification according to targeted users are going to be applied on the proposed guidelines, according to the targeted users' disabilities, which are specified in their original guidelines, or to propose targeted users' categories for the proposed guidelines). The rest of suggested classifications are going to be applied in future works.

Table 6.35 Included and excluded participants' recommendations on the proposed guidelines.

#	Participants' recommendation	(✓) Included (X) Excluded	Justification in case of exclusion/ Modification made in case of inclusion
3	Tagging each checkpoint with a level of priority.	✓	- Each guideline will be associated with a level of priority from A1 (the most necessary) to A3 (the least necessary). If the proposed guideline has a priority level in its original guidelines, such as WCAG, then it will be considered. Otherwise, WCAG guidelines' prioritizing (W3C, 2000) will be followed , where: - A1: the guideline must be implemented, or one group of users or more will not be able to access the information. - A2: the guideline should be implemented, or one group of users or more will encounter difficulty in accessing the information. - A3: the guideline may be implemented, where for one group of users or more it will make access to the information easier.
4	Prioritizing safety requirements.	✓	- A disclaimer was added to the beginning of the document of proposed guidelines in bold, to consider safety requirements first.
5	Adding graphical practical examples and making an online interactive version of the proposed guidelines.	X	- In future work, videos are going to be added to the proposed guidelines in its online version, besides the graphical examples to explain how to achieve the proposed guidelines.
6	Defining all mentioned abbreviations	✓	- All acronyms are defined at the end of the document of proposed guidelines.
7	Adding more guidelines related to hardware aspects.	X	- In future work, more SARs types will be studied to elicit more accessibility requirements related to their hardware components.
8	Adding guidelines related to appropriate distance for interaction.	✓	- The following guideline was added: "Design the robot that can always interact with the user according to the appropriate distance for interaction".

Table 6.36 Included and excluded participants' recommendations on the proposed guidelines.

#	Participants' recommendation	(✓) Included (X) Excluded	Justification in case of exclusion/ Modification made in case of inclusion
9	Adding environment accessibility requirements	✓	- The following guideline was added "Design the robot considering the environment accessibility requirements, for instance, waterproof exterior and proper type of camera for outdoor robot".
10	Adding guidelines related to adapting the robot to the user issues.	✓	- The following guideline was added to proposed guideline 17 "Design the robot to be able to adapt and learn user' preferences".
11	Developing design methodology document.	X	- In future work, a design methodology will be proposed and associated with the online version of the proposed guidelines.
12	Revising the proposed guidelines by an English language expert.	✓	- The proposed guidelines were revised to check and correct the language mistakes.

Step 2. In 2018, WCAG 2.1 (W3C, 2019) was published, which makes it necessary to investigate **the impact of the new release (WCAG 2.1)** on the proposed guidelines. Hence, the new added guidelines to WCAG 2.1 were checked if they were applicable to robotic technology, in case they do not exist in the proposed guidelines. Table 6.24 represents a checklist for included and excluded WCAG 2.1 guidelines, in preparation for adding the included ones to the proposed guideline.

Table 6.37 Included and excluded list of the new guidelines in WCAG 2.1.

#	The new guidelines in WCAG 2.1	(✓) Included (X) Excluded	Aspect category & requirements number where the new guideline will be added under	Justification in case of exclusion / summarizing guideline in case of inclusion
1	1.3.4 Orientation (W3C, 2019).	✓	**Perceivable** (7 Displays)	- Provide means to the user to control display orientation (portrait, landscape), unless a specific orientation is required.

Table 6.38 Included and excluded list of the new guidelines in WCAG 2.1.

#	The new guidelines in WCAG 2.1	(✓) Included (X) Excluded	Aspect category & requirements number where the new guideline will be added under	Justification in case of exclusion / summarizing guideline in case of inclusion
2	**1.3.5 Identify Input Purpose** (W3C, 2019)	✓	**Perceivable** (8 Assistive technology and web interfaces)	- Make sure that the purpose of all input fields which collect information about the user can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences.
3	**1.3.6 Identify Purpose** (W3C, 2019)	X	-	- This guideline is already in the proposed guidelines under requirements number (8.b)
4	**1.4.10 Reflow** (W3C, 2019)	✓	**Perceivable** (7 Displays)	- Make the content able to reflow within the windows boundaries, when the user zooms to enlarge content size.
5	**1.4.11: Non-text Contrast** (W3C, 2019)	✓	**Perceivable** (2 color & contrast)	- For all non-text or graphical objects (controls, icons, etc.), the contrast ratio for them against adjacent colors should be at least 3:1.
6	**1.4.12: Text Spacing** (W3C, 2019)	✓	**Perceivable** (7 Displays)	- Make the content capable to adapt the following spacing styles applied by users without losing content or functionality: line spacing up to 1.5 times the font size at least; paragraph spacing 2 times the font size at least; letter spacing up to 0.12 times the font size at least; word spacing up to 0.16 times the font size at least.

Table 6.39 Included and excluded list of the new guidelines in WCAG 2.1.

#	The new guidelines in WCAG 2.1	(✓) Included (X) Excluded	Aspect category & requirements number where the new guideline will be added under	Justification in case of exclusion / summarizing guideline in case of inclusion
7	**1.4.13: Content on Hover or Focus** (W3C, 2019)	✓	**Perceivable** (7 Displays)	- For additional content which appear and disappear by hovering or keyboard focus, such as, tooltip, sub-menus, etc., the interaction must be designed to allow the user to perceive the additional content and dismiss it without disturbing their current task.
8	**2.1.4: Character Key Shortcuts** (W3C, 2019)	✓	**Operable** (10 Keys, Keyboards and Keypads)	- For character key shortcuts, one of the following should be available or true: there is a mechanism to turn the shortcuts off; to associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt); shortcuts active only on focus.
9	**2.2.6: Timeouts** (W3C, 2019)	✓	**Operable** (12 Time)	- Warn the user about the duration of user inactivity at the start of a task, set task timeout to occur after 20 hours of inactivity or store user data for 20 hours following the inactivity at least.
10	**2.3.3: Animation from Interactions** (W3C, 2019)	✓	**Perceivable** (5 Blinking components)	- Any motion animation caused by interaction can be disabled, unless it is required for functionality or for information being conveyed.
11	**2.5.1: Pointer Gestures** (W3C, 2019)	✓	**Operable** (Assistive technology and web interfaces)	- Web content can be operated by a single pointer instead of multi- path pointer.

Table 6.40 Included and excluded list of the new guidelines in WCAG 2.1.

#	The new guidelines in WCAG 2.1	(✓) Included (X) Excluded	Aspect category & requirements number where the new guideline will be added under	Justification in case of exclusion / summarizing guideline in case of inclusion
12	**2.5.2 Pointer Cancellation** (W3C, 2019)	✓	**Operable** (Assistive technology and web interfaces)	- For interaction happening by single pointer, consider one of the following at least: Do not use down-event (mouse down) to execute any function; abort or undo is available using up- event (mouse up); up-event can reverse any action done by down-event; use down- event for completing the function.
13	**2.5.3 Label in Name** (W3C, 2019)	✓	**Operable** (Assistive technology and web interfaces)	- Make sure that the same visible label which is associated with any user interface component, is the same one that is associated with the component programmatically.
14	**2.5.4 Motion Actuation** (W3C, 2019)	X	-	- This guideline is already in the proposed guidelines under requirements number (1).
15	**2.5.5 Target Size** (W3C, 2019)	✓	**Operable** (11 Navigating on displays)	- Make sure target (content) size is large enough to activate it on small touch screen or by mouse, the minimum target size is (44 by 44 CSS pixels at least), except when: alternative for the target is available and with the minimum target size; the target (content) can be enlarged by reflow technique; target size is determined by user agent; a specific target size is required).
16	**2.5.6 Concurrent Input Mechanisms** (W3C, 2019)	X	**-**	- This guideline is already in the proposed guidelines under requirements number (1).

Table 6.41 Included and excluded list of the new guidelines in WCAG 2.1.

#	The new guidelines in WCAG 2.1	(✓) Included (X) Excluded	Aspect category & requirements number where the new guideline will be added under	Justification in case of exclusion / summarizing guideline in case of inclusion
17	**4.1.3 Status Messages** (W3C, 2019)	✓	**Perceivable** (8 Assistive technology and web interfaces)	- Make sure the role of status messages can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences.

Step. 3 Adding two Funka Nu accessibility guidelines which were excluded previously from the initial document of the proposed accessibility guidelines. After further investigations, the first heuristic evaluation in Section (6.1), it was found that these two accessibility guidelines could be applicable to robotic technology. Table 6.25 represents these two added guidelines.

Table 6.42 Added guidelines which were excluded from the initial document of the proposed guidelines.

#	Previously excluded accessibility guidelines	Aspect category & requirements number where the new guideline will be added under
1	Do not use frames in web interfaces because frames and (iframe) inline frames work poorly on mobile devices. (*Mobile guidelines - Funka*, n.d.)	**Operable** (11 Navigating on displays)
2	Minimize the use of scripts on the client page. (*Mobile guidelines - Funka*, n.d.)	**Understandable** (18 Displays)

Taking into account participants' recommendations, the impact of WCAG 2.1 and the added guidelines, the proposed guidelines were updated (see Appendix E for the updated version of the proposed guidelines). Another version of the updated proposed guidelines classified according to the targeted users' disabilities is available too in Appendix F.

6.5 Summary

The associated research question to this chapter is:

- **RQ7**: Are the proposed guidelines usable for the robot's developers and designers?

With the intention of evaluating the proposed accessibility guidelines, three heuristic evaluations and one user evaluation were performed. The first heuristic evaluation was conducted with the participation of HRI developers and designers. The second and third heuristic evaluations included the use of the proposed guidelines to evaluate two different robotic applications: town crier and telepresence. Evaluators' recommendations from the heuristic evaluation of town crier application were implemented in the robot's interfaces. Then a user evaluation was conducted, which included real users interacting with the ROSI robot.

In **the first heuristic evaluation**, **three experts performed the evaluation with the participation of seventeen HRI developers and designers**, in order to measure four different factors related to the **proposed guidelines: usability, user's experience, user's satisfaction and societal impact**. The evaluators used interview questionnaire, observations and their expertise as evaluation methods. There were two tasks in the evaluation assigned to the participants based on their role, HRI developer or designer. Then, they were asked to accomplish the task using our proposed guidelines. The participants provided demographic and background information in pre-test interviews, and they answered the questionnaire in post-test interviews. For our proposed guidelines' usability, it was found that **the majority (15 of 17 participants) agreed that the guidelines were helpful for them to design and implement accessible robot interfaces and applications**. The mean time required to read the guidelines and accomplish the task was (8.12 min), which is reasonable. While for the users' experience factor, **some of the participants had considered some ad hoc guidelines in their design practice, but none of them showed awareness of or had applied all the proposed guidelines in their design practice**. **72% of the proposed guidelines have been applied by less than or equal to 8 participants for each guideline**. Moreover, **16 of 17 participants would use the proposed guidelines in their future robot designs or evaluation**. The **participants recommended the importance of aligning the proposed guidelines with safety requirements, environment of interaction (indoor or outdoor), cost and users' expectations, and appropriate distance for interaction**.

In **the second heuristic evaluation**, **two evaluators used the proposed guidelines to elicit the accessibility problems in ROSI's robot interfaces in the town crier application**. ROSI is a robot that plays an assistance role in helping elderly people who reside at the elderly care home. ROSI reminds them with their daily schedule, the weather, their friends' birthdays, time and date. **The evaluators revised ROSI's interaction interfaces following the proposed evaluation methodology for HRI** (Section 4.1). **Elicited accessibility problems attached to evaluators' recommendations and with the proper guidelines to solve the accessibility problem were reported in tables (6.6, 6.7 and 6.8)**. The **elicited accessibility problems were: eleven accessibility problems regarding software interface of ROSI, 1 accessibility problem regarding ROSI's hardware interfaces, besides 1 accessibility problem regarding the complete process** (going through complete interaction for all robot's functions).

Evaluators' recommendations concluded from the heuristic evaluation of town crier application were implemented in the ROSI robot's interface. Then, a **users' evaluation was performed to elicit further accessibility problems from the robot's interface (table 6.18). In addition, to address any potential accessibility problem that could be faced by the users (table 6.19), due to not implementing some of the evaluator's recommendation**, the developers could not implement all of them due to the robot's characteristics or not having enough time to implement them. The COVID pandemic situation caused difficulty in entering the residence home to conduct the evaluation. In the future, users' evaluation will be pursued to involve more users and conduct more sessions. By conducting this evaluation we have tested that the proposed guidelines were useful for developers and designers to avoid accessibility barriers.

The **third heuristic evaluation** was for the ROSI robot too, but with a **different application (telepresence)**; ROSI was used for helping elderly residents to make calls (video conference) with their relatives during the pandemic time (coronavirus). **The same protocol, which was followed in revising and evaluating town crier application, was followed in the telepresence application evaluation too**. **Elicited accessibility problems linked to evaluators' recommendations and with the proper guidelines to solve the accessibility problem were reported in tables (6.20, 6.21 and 6.22)**: **6 accessibility problems regarding software interface of ROSI in telepresence application, one accessibility problem regarding ROSI's hardware interfaces, besides 1 accessibility problems regarding the complete process** (going through complete interaction for all robot's functions) for the telepresence application.

Finally, participants' recommendations concluded from the first heuristic evaluation and the impact of the new release of WCAG 2.1 were studied. Table 6.23 and table 6.24 shows included and excluded participants' recommendations and newly added WCAG 2.1 guidelines. The proposed guidelines were updated to consider these changes. At last, two versions of our proposed guidelines are presented in Appendix E and Appendix F for the updated proposed guidelines. The first one is according to the old classification (perceivable, understandable, operable and general) and the second one is classified according to the targeted users' disabilities.

Chapter 7: Conclusions and Future work

7.1 Conclusions

This thesis **aims** to study the accessibility problems that users may encounter while interacting with Social Assistive Robots (SARs), in addition to propose accessibility guidelines to help developers and designers of SARs to design and implement accessible hardware and software interfaces.

The **main contributions** made in this thesis are: first, the identification of SAR's hardware and software interfaces; second, a proposal of an evaluation methodology to assess accessibility as a main factor in HRI; third, the recognition of possible accessibility barriers in Human-Robot Interaction (HRI) for SARs; and fourth, a proposal and validation of accessibility guidelines for HRI for SARs. The proposed guidelines are presented in two versions: general classification (perceivable, understandable, operable, and general), and targeted users' disabilities classification.

The contributions of this thesis made in light of **some limitations**: first, taking into account the great diversity of existing and future Service Robotics (SR) types and platforms (with different software and hardware components, the scope of the Ph.D. has been limited to specific types of SARs, studied in detail in section (2.2). Another limitation to this thesis is the wide range of disability types, severity degree and combination of disabilities that the potential users could present. Hence, in this thesis we limit the scope of studied user's disabilities to include: visual, auditory, motor, cognitive and speech disabilities. Besides defining five personas for evaluating the interaction with SARs to elicit accessibility barriers, these personas present the studied users' disabilities. Moreover, the COVID pandemic had an impact on the final users' evaluation as it was difficult to enter the residence home, and evaluation sessions had to be rescheduled several times.

Further, we conclude with the work done to achieve the thesis's goals:

First, identification of SAR's hardware and software interfaces was made, where a classification of the interaction components / interfaces of SARs was proposed. The classification includes two categories: hardware and software components. 20 SARs were studied to identify the hardware and software interaction interfaces of SARs in Chapter 2. In addition to conducting a systematic review to find other classifications for interaction interfaces of SARs. The results from the systematic review were integrated with the proposed classification to present the final proposal for interaction interfaces of SARs which is presented in Chapter3.

Second, a proposal of an evaluation methodology to assess accessibility as a main factor in HRI was introduced in Chapter 4; **third**, the proposed evaluation methodology was used to recognize possible accessibility barriers in Human-Robot Interaction (HRI) for SARs, by eliciting accessibility problems from real users' cases and fictional users' cases. A set of accessibility problems from the two evaluations were extracted and identified in Chapter 4. Moreover, a proposal of mapping the interaction components to the affected disability type was presented in Chapter 4.

Fourth, a proposal and validation of accessibility guidelines for HRI for SARs were achieved. The proposed guidelines were presented in two versions: general classification (perceivable, understandable, operable, and general aspects), and targeted users' disabilities classification. Three heuristics evaluations and a user evaluation were conducted to evaluate our proposed guidelines; it was concluded that the proposed guidelines were helpful for; the evaluators in eliciting accessibility barriers; and for the developers and designers to design and implement accessible interfaces.

7.2 Future work

At last, our proposal of accessibility guidelines for HRI is the first attempt in this regard. These guidelines form a basis that can be developed by expanding in specific directions:

Initially, studying other interaction components by investigating the accessibility requirements of technologies such as BCI interfaces, virtually reality interface devices and implanted user interfaces. Then, propose the needed accessibility guidelines, and update the proposed evaluation methodology for HRI in line with the new studied interaction interfaces to ensure the compatibility of the proposed methodology for evaluating the accessibility of these interfaces.

Besides, extend the users' evaluation once the pandemic is over. The final users' evaluation of ROSI project reflects the first impression of the HRI with ROSI, robot's interfaces are being evaluated in a long-term evaluation in the residence home. The evaluation will involve more users and conduct more sessions, allowing the investigation of additional potential accessibility barriers. The upcoming users' evaluations could update our proposed guidelines with new guidelines or recommendations.

Moreover, the proposed guidelines are presented under two different classifications: general classification (perceivable, understandable, operable, and general aspects), and targeted users' disabilities classification. In the future, providing a different classification of the proposed guidelines based on interaction components can be useful for HRI designers and developers; allowing them to focus only on guidelines that may affect the accessibility of the interaction components they design or implement, rather than implementing all of the guidelines which may increase the cost and slow down the robot's system. This can be achieved by grouping the proposed guidelines relevant to each interaction component of SARs under one category, which must be named the same as the interaction component.

Finally, we published a conference paper on accessibility guidelines for tactile displays in HRI. In addition to a journal paper on the complete guidelines for HRI accessibility. In the future, we are planning to disseminate Ph.D. results from scientific and divulgative points of view, through channels such as fairs, conferences, journals, etc. The following are the contributions that we plan to publish in the journals:

- The evaluation results that are obtained and presented in this thesis, including (experts' and users' evaluation of ROSI robot's applications). And extending the evaluation in ROSI – DIH/HERO projects, and publish the obtained results.
- Accessibility guidelines for HRI which are classified according to targeted users' disabilities.
- The Ontology of software / hardware interaction components of robots mapped to the affected user's disabilities.
- The proposal of Evaluation Methodology for HRI.
- Secondary study (review) of the application domains of SARs in the society, along with classification of SAR's hardware and software interfaces.

Appendix A
Personas

This Appendix represents the details of other personas used to extract accessibility barriers through fictional users' cases (Section 4.6). The four personas detailed in this Appendix were involved in scenarios of interacting with NAOTherapist to get therapy; all personas were created to present fictional child users who have OBPP or CP. All personas' pictures were generated by Artificial Intelligence (Generated Photos, 2021).

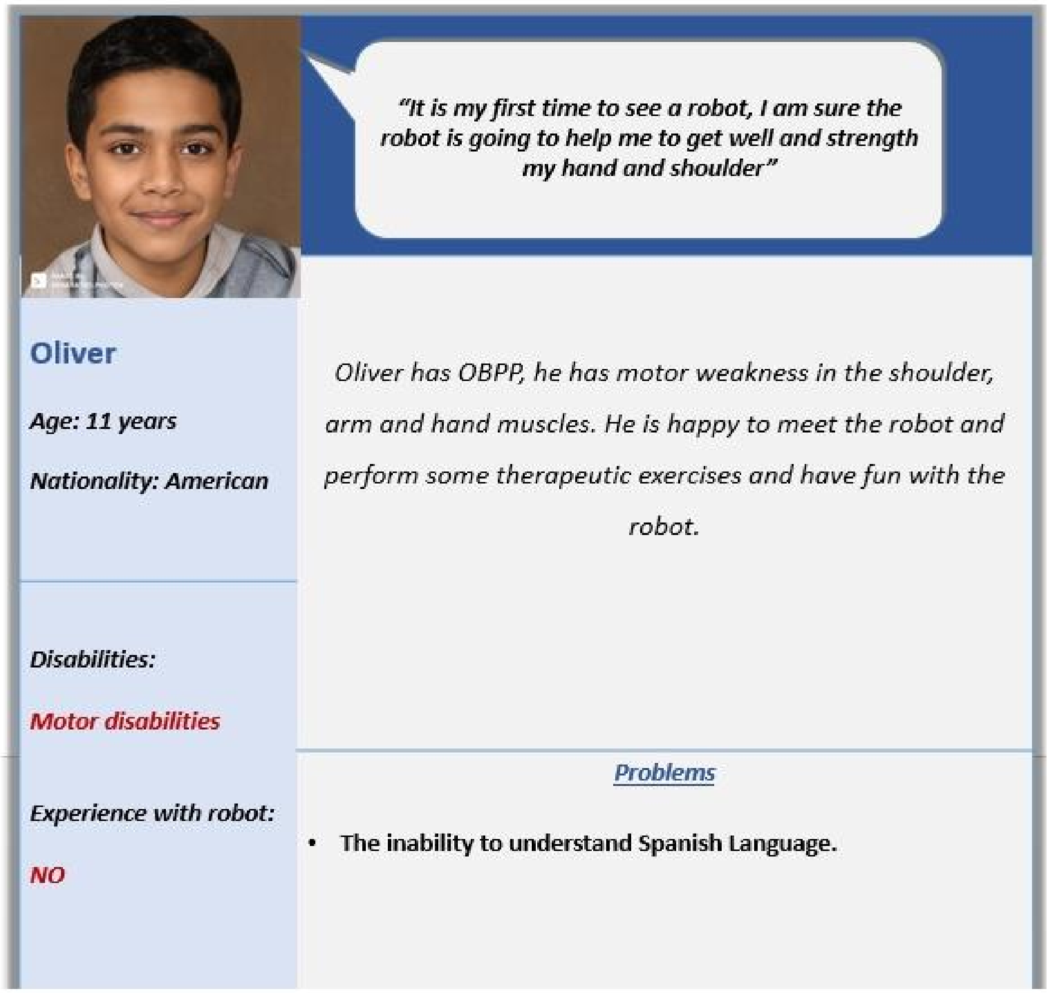

Figure A.1 Persona Oliver.

Figure (A.1) shows Oliver persona who has OBPP and consequently has motor disability. OBPP does not cause any other disabilities rather than motor disability. Oliver does not speak Spanish as he is American.

Figure A.2 Persona Maria.

Figure (A.2) details Maria persona, who has motor and vision disabilities due to CP.

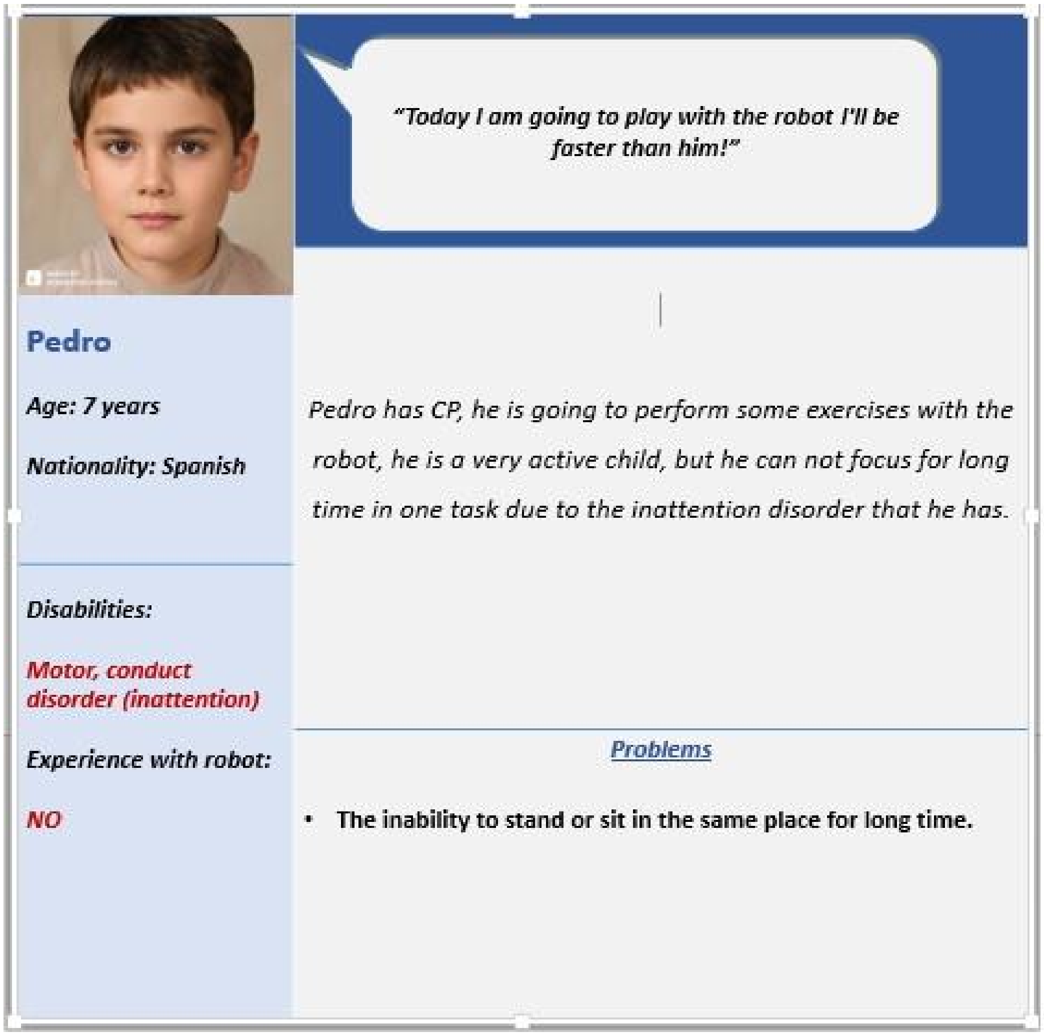

Figure A.3 Persona Pedro.

Pedro (figure A.3) is another persona who has been involved in the study, similar to the previous persona (Maria), Pedro has CP which caused a motor and conduct disorder to him.

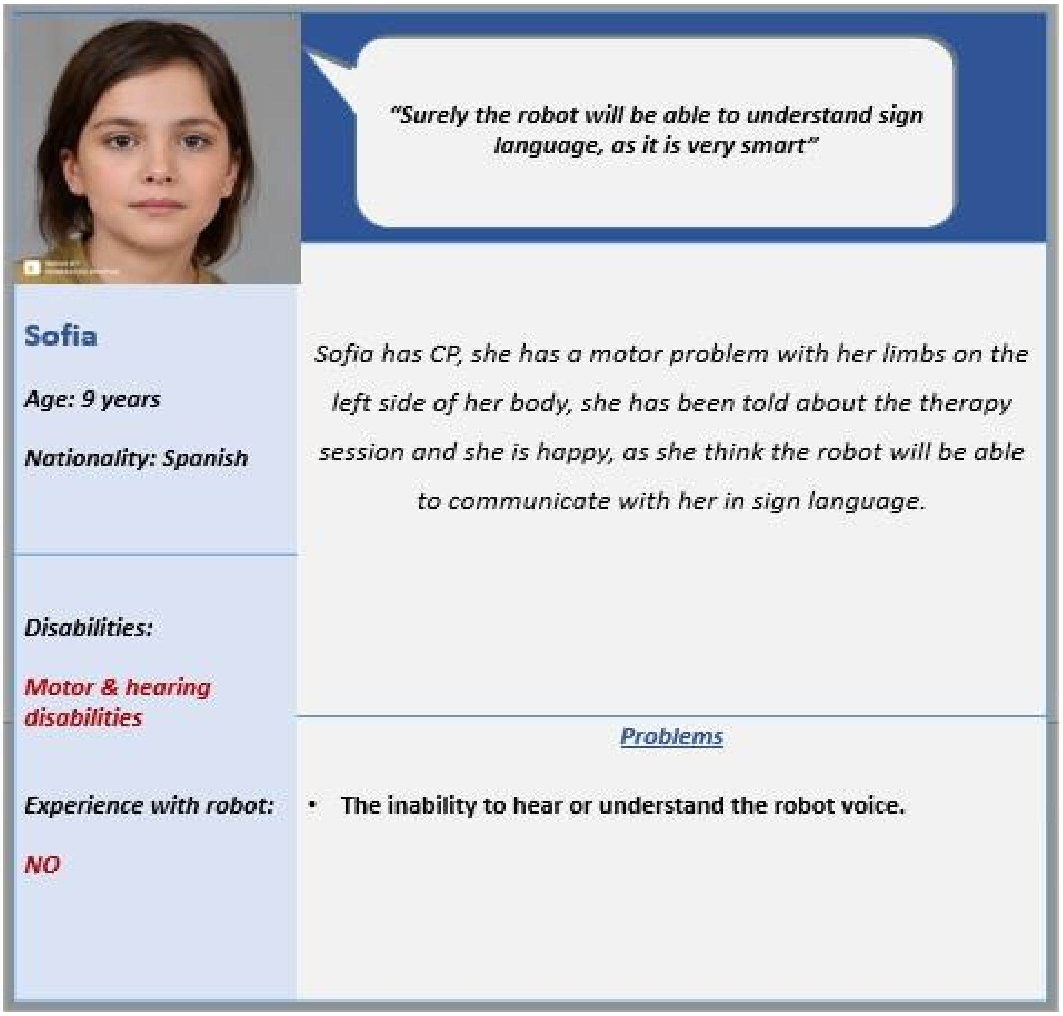

Figure A.4 Persona Sofia.

Sofia (figure A.4) is the last persona involved in the study; she has CP which caused motor and hearing disabilities to her.

Appendix B
Questionnaire for Accessibility Guidelines Evaluation

This appendix presents the questionnaire used in the heuristic evaluation (Section 6.1), which was performed with participation of HRI developers and designers. The below questionnaire assesses usability, user's experience, user's satisfaction and societal impact of the new proposed guidelines from developers' and designers' perspective.

A. Purpose of a questionnaire

This questionnaire is a part of evaluating a proposed guidelines for accessibility in Human-Robot Interaction, in order to verify if the guidelines are useful for the developer, designer, sociologist, etc.

B. Demographic Information

1. Please mark the age group that fits you:

-20	21-35	36-50	50-65	65+

Female	Male

2. Please mark the answer that describes the level of your proficiency in English language:

Not at all	With difficulty	Moderate	Fairly fluent	Fluent

3. What is your education level?

4. What is your job title?

5. How many years have you worked in this field?

Less than one year	*1-2*	*3-4*	*5-6*	*More than 6 years*

6. How familiar are you with the Inclusive Design, Design for All and Accessibility in Human-Robot Interaction?

Very familiar *Fairly familiar* *Somewhat familiar* *Not very familiar* *Not at all*

C. Instructions

If you have a robot/ computer designer or developer role, please read point 1, else read point 2.

1. Imagine you have to design a robot to perform a geriatric assessment through interaction with elderly people, by asking them to answer questions or perform simple tasks, such as, walking for a few meters. The robot has a haptic display, microphone and RGB-D Camera (you can add other necessary hardware components), in order to interact and collect data for later analysis by doctors. And you will design the robot following the accessibility guidelines, to ensure that the robot can be used by people with different abilities. Now please answer questions in Section D.
2. You will watch videos about a robot which performs a geriatric assessment for elderly people at a hospital, pay attention to the accessibility barriers that are exist during the interaction with the robot, and try to solve them using the accessibility guidelines. Then please answer the questions at Section D.

D. Questions related to the guidelines

Answer the following questions by circling the most appropriate answer:

1. (**Understand**) I could easily understand the checkpoints:

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

2. (**Understand how to apply**) I could easily understand how to apply the technique for each checkpoint:

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

2.1 (**Feeling of security**) difficulties in any checkpoint? Please, explain which one and how it could be improved:

____

3. The guidelines are structured in an order that is easy for me to use/apply:

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

3.1 Any ideas to improve the structure?

4. (**Effectiveness / self-efficacy**) I can easily design accessible robots or detect accessibility barriers by using the guidelines:

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

5. (**Efficiency**) How much time did you spend to complete the task?

____

6. I think there are accessibility aspects missing in the guidelines:

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

6.1 Which ones?

____

7. I considered these aspects in my previous designs/evaluations, even when I had not taken into account accessibility issues:

Strongly Disagree *Disagree* *Neutral* *Agree* *Strongly Agree*

Which ones (include just the numbers)?

____

8. (**Satisfaction /social acceptation**) I would like to use these guidelines in my future robot design/ evaluation:

Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*

9. (**Effort expectancy**) I think the design of accessible robots for all will require more effort:

Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*

10. (Quality of life / importance) I think the inclusive design of robots, taking into account the accessibility guidelines, is necessary to improve the robot's interaction success and adoption:

Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*

11. Any other recommendations?

Appendix C
Town Crier application's interfaces

This section presents the rest of the ROSI robot's interfaces (town crier), which are: birthday, weather and activities interfaces (figures C.1, C.2 and C.3) respectively.

Figure C.1 Birthday interfaces of ROSI robot's application (Town Crier).

Figure C.2 Weather interfaces of ROSI robot's application (Town Crier).

Figure C.3 Activities interfaces of ROSI robot's application (Town Crier).

Appendix D
Telepresence application's interfaces

This section presents the rest of ROSI robot's interfaces (telepresence), which are: Open Door, Way to Room, Greeting, Waiting for Call and Farewell and Wait interfaces (figures D.1, D.2, D.3, D.4 and D.5) respectively.

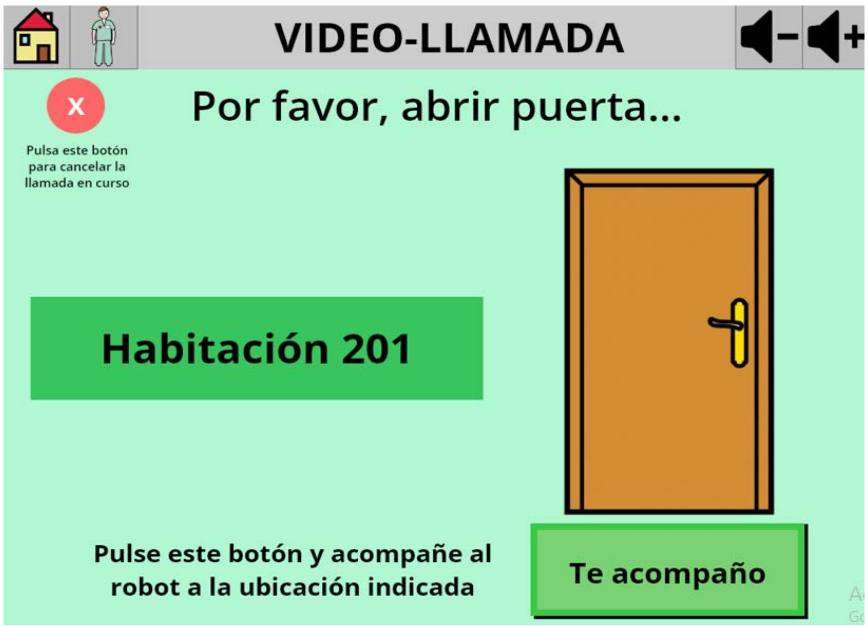

Figure D.1 Open Door interface of ROSI robot's application (Telepresence).

Figure D.2 Way to Room interface of ROSI robot's application (Telepresence).

Figure D.3 Greeting interface of ROSI robot's application (Telepresence).

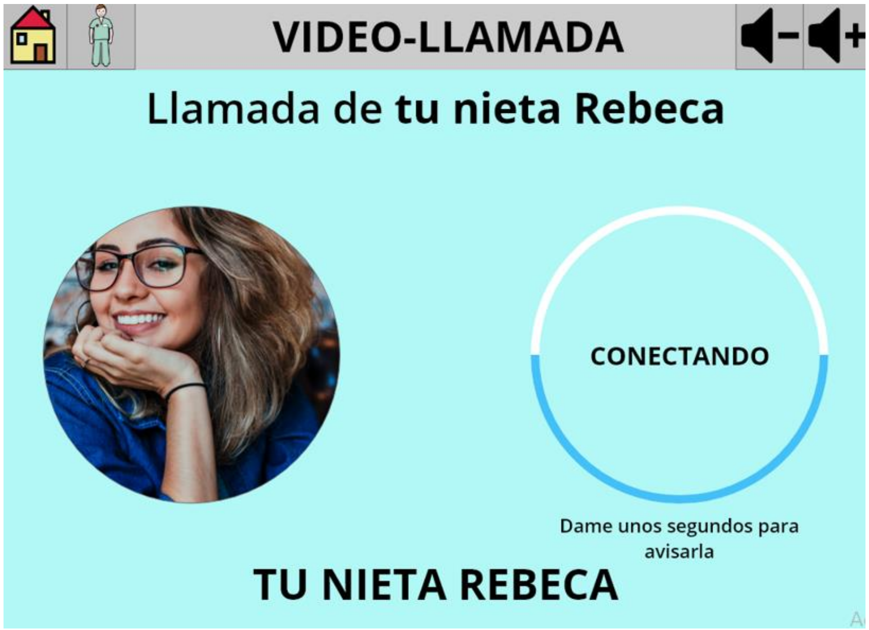

Figure D.4 Waiting for Call interface of ROSI robot's application (Telepresence).

Figure D.5 Farewell and Wait interface of ROSI robot's application (Telepresence).

Appendix E
Updated Guidelines

This appendix presents the updated version of our proposed accessibility guidelines for HRI (table E.1). These guidelines were updated according to the recommendations of the participants in the heuristic evaluation (Section 6.1), in addition to considering the impact of releasing WCAG 2.1 on the proposed guidelines and updating them accordingly.

Table E.1 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
1	**Multiple modalities for interaction**	The user can operate the robot using different channels for input and output.	a) Provide multiple modalities for interaction (**A1**). (For examples, see **annex 1**). b) Verify that all functions are accessible via keyboard, virtual keyboard, mouse, haptic displays, voice (Automatic Speech Recognition and Text to Speech techniques) or gestures (according the interaction modalities chosen) (**A1**).
2	**Color and Contrast**	Color is not the only way to distinguish keys, controls and labels or to convey information, and it is easy to distinguish foreground from the background.	a) Make sure that color is not the only way to indicate hardware controls, keys and labels of the robot. This also applies to software widgets (buttons, labels, etc.) or for information displayed on the robot (**A1**). (For examples, see **annex** 1). b) Careful use of luminosity, contrast, and background audio (**A2**). WCAG 2.0 (guideline 1.4) c) For all non-text or graphical objects (controls, icons, etc.), the contrast ratio for them against adjacent colors should be at least 3:1 (**A2**). WCAG (1.4.11)

Table E.2 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
3	**Location of hardware and software components.**	The user can easily perceive and access robot's interfaces (hardware and software) components.	a) Make sure the display of visual information is visible to people who are of short stature or seated in wheelchairs. Place interface components in a perceivable and accessible place, for example, place hardware buttons in the middle of the robot's body (**A1**). b) Design consistently and group related elements together. For example, place software buttons and links horizontally, vertically or on a grid, and important objects at the top of the interface and the less important objects at the bottom (**A2**). c) Avoid unnecessary information and objects. Use images only when necessary (**A3**). Funka Nu (43.content) and BBC guidelines (HTML Accessibility)
4	**Alternatives for non-text elements**	All non-text interface elements on the robot's display and all spoken information must have accompanying text or synchronized alternatives for multimedia elements.	a) Provide captions, description or labels for all non-text interface elements (**A1**). b) For prerecorded and live multimedia, provide captions, audio descriptions, or sign language. For robot voice, provide text or sign language (**A1**). WCAG 2.0 (guideline 1.1, 1.2).
5	**Blinking components**	For any blinking component on the robot's interface (lights, display contents, etc.) the blinking stops after a certain period, or can be switched off by the user.	- Provide a mechanism to allow the user to stop blinking or specify the blinking times for the content to be a fixed number (**A2**). WCAG 2.0 (guideline 2.2.2)
		User can disable any motion animation caused by interaction	- Any motion animation caused by interaction can be disabled unless it is required for functionality or for information being conveyed (**A3**). WCAG 2.1 (2.3.3)

Table E.3 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
6	**Flashing visual content**	Avoid flashing components on the robot's interface that are known to cause seizures.	- Any flashing component should not exceed three flashes in one second. Red flash should be avoided (**A1**). WCAG 2.0 (guideline 2.3)
7	**Displays**	Separation of content and presentation.	a) Make sure presentation and structure of the content is determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences (**A1**). WCAG 2.0 (guideline 1.3) b) The meaning of colored information should also be clear without color through the context for example (**A1**). c) Do not rely on shape, size, location or color to represent the meaning of user interaction elements. Add a text label as well (**A2**). WCAG 2.0 (guideline 1.3)
		Large clickable areas, icons and objects on the interface are familiar and should appear clickable.	- Use familiar icons and design objects with clickable appearance and large clickable areas (**A2**). Funka Nu (25. Layout and design)
		The user can invert the screen contrast (dark text on a light background and vice versa).	- Provide a setting for invert colors or contrast (**A2**).
		The user can change font type and size, interface orientation and zoom in or out on the interface and allow content to reflow without any content loss.	a) Provide a setting for changing font type and size within a minimum text size (**A1**). b) Make sure the user can zoom the interface up to 200% (**A2**). BBC guidelines (HTML accessibility) c) Provide means to the user to control display orientation (portrait, landscape), unless a specific orientation is required (**A2**). WCAG 2.1 (1.3.4) d) Make the content able to reflow within the windows boundaries, when the user zooms to enlarge content size (**A2**). WCAG 2.1 (1.4.10)

Table E.4 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
7	**Displays**	The user can apply different spacing styles on interface content without losing content or functionality.	- Make the content capable to adapt the following spacing styles applied by users without losing content or functionality: line spacing up to 1.5 times the font size at least; paragraph spacing 2 times the font size at least; letter spacing up to 0.12 times the font size at least; word spacing up to 0.16 times the font size at least (**A2**). WCAG 2.1 (1.4.12)
		The user can perceive the additional content (tooltip, sub-menus, etc.) and dismiss it without disturbing their current task.	- For additional content which appears and disappears by hovering or keyboard focus, such as, tooltip, sub-menus, etc., the interaction must be designed to allow the user to perceive the additional content and dismiss it without disturbing their current task (**A2**). WCAG 2.1 (1.4.13)

Table E.5 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
8	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	**For web interfaces :** a) Design accessible patterns and widgets based on WAI-ARIA, by defining roles, properties and states of the widgets in the code (**A1**). (for examples, see **annex 1**) b) Identify the organization and structure of a web page by using ARIA landmark roles in the code, such as headings and regions (**A1**). c) Provide keyboard navigation in the code based on WAI-ARIA for UI objects and events (**A1**). (for examples, see **annex 1**) WAI-ARIA best practices d) Make sure that the purpose of all input fields which collect information about the user can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences (**A2**). WCAG 2.1 (1.3.5) e) For interaction happening by single pointer, consider one of the following at least: Do not use down-event (mouse down) to execute any function; Abort or undo is available using up-event (mouse up); up-event can reverse any action done by down-event; use down-event for completing the function (**A1**). WCAG 2.1 (2.5.2) f) Make sure the role of status messages can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences (**A2**). WCAG 2.1 (4.1.3) **For hardware:** g) Provide industry standard ports for alternate input and output devices, e.g., assistive tools (**A1**).

Table E.6 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
9	**Hardware controls and physical operation**	User can operate all hardware and physical controls with one hand and minimum dexterity	- Design the input devices, such as, keyboards, remote controls (including the joysticks, buttons, etc.) so the user can operate them with one hand and minimum dexterity (**A1**). (for examples, see **annex 1**)
10	**Keys, Keyboards and Keypads**	The user can verify the status of locking or toggle keys visually, through touch or sound, or tactically.	- Provide visual, auditory or tactile feedback to verify the status of locking or toggle keys (**A1**). (for examples, see **annex 1**)
		The user can turn character key shortcuts off, associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt) or the shortcuts active only on focus.	- For character key shortcuts, make one of the following available or true: there is a mechanism to turn the shortcuts off; to associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt); shortcuts active only on focus (**A1**). WCAG 2.1 (2.1.4)
11	**Navigating on displays**	Facilitate navigation process while interacting with the robot's display.	- Provide methods that help the user to navigate, find content and determine where s/he is in a structure. Avoid using frames and inline frames (iframes) (**A2**). (for examples, see **annex** 1) - Make sure target (content) size is large enough to activate it on small touch screen or by mouse, the minimum target size is (44 by 44 CSS pixels at least), except when: alternative for the target is available and with the minimum target size; the target (content) can be enlarged by reflow technique; target size is determined by user agent; a specific target size is required) (**A3**). WCAG 2.1 (2.5.5)

Table E.7 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
12	**Time**	Time does not affect users' ability to finish any interactive task with the robot, s/he has started.	- Allow the user to control the time limits, turn off, adjust or extend the time limit, except when time is an essential part of activity or real-time event (**A1**). - Warn the user about the duration of user inactivity at the start of a task, set task timeout to occur after 20 hours of inactivity or store user data for at least 20 hours following the inactivity (**A3**). WCAG 2.1 (2.2.6)
13	**Appropriate distance for interaction**	The user can interact with the robot within appropriate distance.	- Design the robot so it can always interact with the user according to the appropriate distance for interaction (**A1**).
14	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	a) Make sure web content can be operated by a single pointer instead of multi-path pointer (**A1**). WCAG 2.1 (2.5.1) b) For interaction happening by single pointer, consider one of the following at least: Do not use down-event (mouse down) to execute any function; Abort or undo is available using up-event (mouse up); up-event can reverse any action done by down-event; use down-event for completing the function (**A1**). WCAG 2.1 (2.5.2)
Understandable			
15	**Predictable interaction**	Interaction with the robot is consistent and predictable.	a) Use a simple and familiar interaction and navigation mechanism (**A2**). b) A change in operation of the robot should preferably be initiated by the user (**A3**).

Table E.8 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Understandable			
#	**Requirement**	**Description**	**How to achieve it**
16	**Errors, help and feedback**	The user can review and correct interaction information before submitting, this can avoid errors. The user can at all times query what the robot is doing or processing.	a) Provide a clear mechanism controlling the robot and reviewing commands before execution (**A1**). (for examples, see **annex 1**) b) Design the robot's system to detect and explain errors to the user, and where possible explain how to correct them (**A1**). (for examples, see **annex** 1) c) Inform the user about progress status during their interaction with the robot (**A2**).
17	**Natural voice**	Robot's voice should be clear and natural, the user can choose the robot's voice s/he prefers, and adjust / set the voice volume.	a) Provide the robot with a set of different clear and appropriate voices and allow the user to choose the voice that matches his/her hearing abilities or preferences (**A3**). b) Where possible, allow the user to select a preferred voice accent (**A3**). c) Provide a mechanism to allow the user to adjust the robots' voice volume (**A1**).
18	**Displays**	Predictable UI components and functionality.	- Use familiar user interface components and widgets (**A2**). (for examples, see **annex** 1)
		(Readability) Text on the robot's display should be legible for the user.	a) Provide additional information for unusual words or phrases, avoid the use of abbreviations (**A3**). b) Make sure the line length does not exceed 70 characters. Generally, minimize the use of scripts on the client page (**A2**). c) If necessary, identify a specific pronunciation of words to give them the correct meaning (**A3**). d) Ensure the readability of all text (**A2**): (http://www.readabilityformulas.com/freereadability-formula-tests.php)

Table E.9 Proposed accessibility guidelines for HRI_Updated version.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
General			
#	**Requirement**	**Description**	**How to achieve it**
19	**Adopting user's interaction preferences**	User adjusts/sets the interaction settings of the robot; preferences are stored.	- Design the robot to adapt to and store the users' interaction abilities, preferences and settings (**A3**). (for examples, see **annex 1**) - Design the robot to be able to learn user' preferences and adapt it (**A3**).
20	**Reachable Human support**	The user can easily ask for human help or support.	- Design the robot with a mechanism for calling human support or help (**A2**). (for examples, see **annex 1**)
21	**Adopting emotions representation and recognition**	The user can interact with the robot though emotions representation and recognition.	- Adopt emotions representation and recognition means if it is essential for delivering robot's services (**A1**).
22	**Adopting environment accessibility requirements**	The user can interact with a robot that is designed considering the environment accessibility requirements.	- Design the robot considering the environment accessibility requirements, for instance, waterproof exterior and proper type of camera for outdoor robot (**A1**).

Acronyms

WCAG Web Content Accessibility Guidelines.

BBC British Broadcasting Corporation.

HTML Hypertext Markup Language.

WAI-ARIA Web Accessibility Initiative - Accessible Rich Internet Applications.

UI User Interface.

Appendix F
Targeted Users' Disabilities Guidelines

This appendix presents the updated version of our proposed accessibility guidelines for HRI according to the targeted users' disabilities. Tables F.1, F.2, F.3, F.4 and F.5 show our proposed accessibility guidelines for HRI for users with visual disabilities, users with motor disabilities, users with speech disabilities, users with auditory disabilities and users with cognitive disabilities.

Table F.1 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with visual disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
1.	**Proper modalities for interaction**	The user can operate the robot using proper channels for input and output.	a) Provide proper modalities for interaction. (for examples, see **annex 1**) b) Verify that all functions are accessible via the channel chosen such as keyboard, virtual keyboard, mouse, tactile displays, voice (Automatic Speech Recognition and Text To Speech techniques) or gestures.
2.	**Color and Contrast**	Color is not the only way to distinguish keys, controls and labels or to convey information, and it is easy to distinguish foreground from the background.	a) Make sure that color is not the only way to indicate hardware controls, keys and labels of the robot. This also applies to software widgets (buttons, labels, etc.) or for information displayed on the robot. (for examples, see **annex** 1) b) Careful use of luminosity, contrast, and background audio. WCAG 2.0 (guideline 1.4) c) For all non-text or graphical objects (controls, icons, etc.), the contrast ratio for them against adjacent colors should be at least 3:1. WCAG (1.4.11)
3.	**Alternatives for non- text elements**	All non-text interface elements on the robot's display and all spoken information must have accompanying text or synchronized alternatives for multimedia elements.	a) Provide captions, description or labels for all non- text interface elements. b) For prerecorded and live multimedia, provide captions, audio descriptions, or sign language. For robot voice, provide text or sign language. WCAG 2.0 (guideline 1.1, 1.2).

Table F.2 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

<table>
<tr><td colspan="4">PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!</td></tr>
<tr><td colspan="4">Users with visual disabilities</td></tr>
<tr><td colspan="4">Perceivable</td></tr>
<tr><td>#</td><td>Requirement</td><td>Description</td><td>How to achieve it</td></tr>
<tr><td>4.</td><td>Assistive Technology and web interfaces</td><td>The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.</td><td>For web interfaces :
a) Design accessible patterns and widgets based on WAI-ARIA, by defining roles, properties and states of the widgets in the code. (for examples, see annex 1)
b) Identify the organization and structure of a web page by using ARIA landmark roles in the code, such as headings and regions.
c) Provide keyboard navigation in the code based on WAI-ARIA for UI objects and events. (for examples, see annex 1) WAI-ARIA best Practices
d) Make sure that the purpose of all input fields which collect information about the user can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (1.3.5)
e) Make sure the role of status messages can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (4.1.3)
For hardware:
f) Provide industry standard ports for alternate input and output devices, e.g., assistive tools.</td></tr>
</table>

Table F.3 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with visual disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
5.	**Displays**	Separation of content and presentation.	a) Make sure presentation and structure of the content is determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.0 (guideline 1.3) b) The meaning of colored information should also be clear without color through the context for example. c) Do not rely on shape, size, location or color to represent the meaning of user interaction elements. Add a text label as well. WCAG 2.0 (guideline 1.3)
		Large clickable areas, icons and objects on the interface are familiar and should appear clickable.	- Use familiar icons, and design objects with clickable appearance and large clickable areas. Funka Nu (25. Layout and design)
		The user can invert the screen contrast (dark text on a light background, and vice versa).	- Provide a setting for invert colors or contrast.
		The user can change font type and size, interface orientation and zoom in or out on the interface and allow content to reflow without any content loss.	a) Provide a setting for changing font type and size within a minimum text size. b) Make sure the user can zoom the interface up to 200%. BBC guidelines (HTML accessibility) c) Provide means to the user to control display orientation (portrait, landscape), unless a specific orientation is required. WCAG 2.1 (1.3.4) d) Make the content able to reflow within the windows boundaries, when the user zoom to enlarge content size. WCAG 2.1 (1.4.10)

Table F.4 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with visual disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
5.	**Displays**	The user can apply different spacing styles on interface content without losing content or functionality.	- Make the content capable to adapt the following spacing styles applied by users without losing content or functionality: line spacing up to 1.5 times the font size at least; paragraph spacing 2 times the font size at least; letter spacing up to 0.12 times the font size at least; word spacing up to 0.16 times the font size at least. WCAG 2.1 (1.4.12)
		The user can perceive the additional content (tooltip, sub-menus, etc.) and dismiss it without disturbing their current task.	- For additional content which appear and disappear by hovering or keyboard focus, such as, tooltip, sub-menus, etc., the interaction must be designed to allow the user to perceive the additional content and dismiss it without disturbing their current task. WCAG 2.1 (1.4.13)
Operable			
6.	**Keys, Keyboards and Keypads**	The user can verify the status of locking or toggle keys visually, through touch or sound, or tactically.	- Provide visual, auditory or tactile feedback to verify the status of locking or toggle keys. (for examples, see **annex 1**)
		The user can turn character key shortcuts off, associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt) or the shortcuts active only on focus.	- For character key shortcuts, make one of the following available or true: there is a mechanism to turn the shortcuts off; to associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt); shortcuts active only on focus. WCAG 2.1 (2.1.4)

Table F.5 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with visual disabilities			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
7.	**Navigating on displays**	Facilitate navigation process while interacting with the robot's display.	- Provide methods that help the user to navigate, find content and determine where s/he is in a structure. Avoid using frames and inline frames (iframes). (for examples, see **annex** 1) - Make sure target (content) size is large enough to activate it on small touch screen or by mouse, the minimum target size is (44 by 44 CSS pixels at least), except when: alternative for the target is available and with the minimum target size; the target (content) can be enlarged by reflow technique; target size is determined by user agent; a specific target size is required). WCAG 2.1 (2.5.5)
8.	**Time**	Time does not affect users' ability to finish any interactive task with the robot, s/he has started.	- Allow the user to control the time limits, turn off, adjust or extend the time limit, except when time is an essential part of activity or real-time event. - Warn the user about the duration of user inactivity at the start of a task, set task timeout to occur after 20 hours of inactivity or store user data for 20 hours following the inactivity at least. WCAG 2.1 (2.2.6)
9.	**Appropriate distance for interaction**	The user can interact with the robot within appropriate distance.	- Design the robot that can always interact with the user according to the appropriate distance for interaction
Understandable			
10	**Predictable interaction**	Interaction with the robot is consistent and predictable.	a) Use a simple and familiar interaction and navigation mechanism. b) A change in operation of the robot should preferably be initiated by the user.

Table F.6 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with visual disabilities			
Understandable			
#	**Requirement**	**Description**	**How to achieve it**
11	**Errors, help and feedback**	The user can review and correct interaction information before submitting, this can avoid errors. The user can at all times query what the robot is doing or processing.	a) Provide a clear mechanism controlling the robot and reviewing commands before execution. (for examples, see **annex 1**) b) Design the robot's system to detect and explain errors to the user, and where possible explain how to correct them. (for examples, see **annex** 1) c) Inform the user about progress status during their interaction with the robot.
12	**Natural voice**	Robot's voice should be clear and natural, the user can choose the robot's voice s/he prefers and adjust/set the voice volume.	a) Provide the robot with a set of different clear and appropriate voices and allow the user to choose the voice that matches his/her hearing abilities or preferences. b) Where possible, allow the user to select a preferred voice accent. c) Provide a mechanism to allow the user to adjust the robots' voice volume.
13	**Displays**	Predictable UI components and functionality.	- Use familiar user interface components and widgets. (for examples, see **annex** 1)
		(Readability) Text on the robot's display should be legible for the user.	a) Provide additional information for unusual words or phrases, avoid the use of abbreviations. b) Make sure the line length does not exceed 70 characters. Generally, minimize the use of scripts on the client page. c) If necessary, identify a specific pronunciation of words to give them the correct meaning. d) Ensure the readability of all text: (http://www.readabilityformulas.com/freereadability-formula-tests.php)

Table F.7 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with visual disabilities			
Understandable			
#	**Requirement**	**Description**	**How to achieve it**
14	**Assistive technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	a) For interaction happening by single pointer, consider one of the following at least: Do not use down- event (mouse down) to execute any function; Abort or undo is available using up- event (mouse up); up- event can reverse any action done by down-event; use down- event for completing the function. WCAG 2.1 (2.5.2) b) Make sure that the same visible label which is associated with any user interface component, are the same one that is associated to the component programmatically. WCAG 2.1 (2.5.3)
General			
15	**Adopting user's interaction preferences**	The user adjusts/sets the interaction settings of the robot, preferences are stored.	- Design the robot to adapt to and store the users' interaction abilities, preferences and settings. (for examples, see **annex 1**) - Design the robot to be able to learn user' preferences and adapt it.
16	**Reachable Human support**	The user can easily ask for human help or support.	- Design the robot with a mechanism for calling human support or help. (for examples, see **annex 1**)
17	**Adopting emotions representation and recognition**	The user can interact with the robot through emotions representation and recognition.	- Adopt emotions representation and recognition means, if it is essential for delivering robot's services.

Table F.8 Proposed accessibility guidelines for HRI_ Users with visual disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with visual disabilities			
General			
#	**Requirement**	**Description**	**How to achieve it**
18	**Adopting environment accessibility requirements**	The user can interact with a robot that is designed considering the environment accessibility requirements.	- Design the robot considering the environment accessibility requirements, for instance, waterproof exterior and proper type of camera for outdoor robot.

Table F.9 Proposed accessibility guidelines for HRI_ Users with motor disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with motor disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
1.	**Proper modalities for interaction**	The user can operate the robot using proper channels for input and output.	a) Provide proper modalities for interaction. (for examples, see **annex 1**) b) Verify that all functions are accessible via the channel chosen such as keyboard, virtual keyboard, mouse, haptic displays, voice (Automatic Speech Recognition and Text To Speech techniques) or gestures.
2.	**Location of hardware and software components.**	The user can easily perceive and access robot's interfaces (hardware and software) components.	a) Make sure the display of visual information is visible to people who are of short stature or seated in wheelchairs. Place interface components in a perceivable and accessible place, for example, place hardware buttons in the middle of the robot's body. b) Design consistently, and group related elements together. For example, place software buttons and links horizontally, vertically or on a grid, and important objects at the top of the interface and the less important objects at the bottom.
3.	**Display**	Large clickable areas, icons and objects on the interface are familiar and should appear clickable.	- Use familiar icons, and design objects with clickable appearance and large clickable areas. Funka Nu (25. Layout and design)
		The user can change interface orientation.	- Provide means to the user to control display orientation (portrait, landscape), unless a specific orientation is required. WCAG 2.1 (1.3.4)
		The user can perceive the additional content (tooltip, sub-menus, etc.) and dismiss it without disturbing their current task.	- For additional content which appear and disappear by hovering or keyboard focus, such as, tooltip, sub-menus, etc., the interaction must be designed to allow the user to perceive the additional content and dismiss it without disturbing their current task. WCAG 2.1 (1.4.13)

Table F.10 Proposed accessibility guidelines for HRI_ Users with motor disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with motor disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
4.	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	**For web interfaces :** a) Design accessible patterns and widgets based on WAI-ARIA, by defining roles, properties and states of the widgets in the code. (for examples, see **annex 1**) b) Identify the organization and structure of a web page by using ARIA landmark roles in the code, such as headings and regions. c) Provide keyboard navigation in the code based on WAI-ARIA for UI objects and events. (for examples, see **annex 1**) WAI-ARIA best practices d) Make sure that the purpose of all input fields which collect information about the user can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (1.3.5) e) Make sure the role of status messages can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (4.1.3) **For hardware:** f) Provide industry standard ports for alternate input and output devices, e.g., assistive tools.
Operable			
5.	**Hardware controls and physical operation**	The user can operate all hardware and physical controls with one hand and minimum dexterity	- Design the input devices, such as, keyboards, remote controls (including the joysticks, buttons, etc.) so the user can operate them with one hand and minimum dexterity. (for examples, see **annex 1**)
6.	**Keys, Keyboards and Keypads**	The user can verify the status of locking or toggle keys visually, through touch or sound, or tactically.	- Provide visual, auditory or tactile feedback to verify the status of locking or toggle keys. (for examples, see **annex 1**)

Table F.11 Proposed accessibility guidelines for HRI_ Users with motor disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with motor disabilities			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
6.	**Keys, Keyboards and Keypads**	The user can turn character key shortcuts off, associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt) or the shortcuts active only on focus.	- For character key shortcuts, make one of the following available or true: there is a mechanism to turn the shortcuts off; to associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt); shortcuts active only on focus. WCAG 2.1 (2.1.4)
7.	**Time**	Time does not affect users' ability to finish any interactive task with the robot, s/he has started.	- Allow the user to control the time limits, turn off, adjust or extend the time limit, except when time is an essential part of activity or real-time event. - Warn the user about the duration of user inactivity at the start of a task, set task timeout to occur after 20 hours of inactivity or store user data for 20 hours following the inactivity at least. WCAG 2.1 (2.2.6)
8.	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	a) Make sure web content can be operated by single pointer instead of multi- path pointer. WCAG 2.1 (2.5.1) b) For interaction happening by a single pointer, consider one of the following at least: Do not use down- event (mouse down) to execute any function; Abort or undo is available using up- event (mouse up); up- event can reverse any action done by down-event; use down- event for completing the function. WCAG 2.1 (2.5.2)
9.	**Navigating on displays**	Facilitate navigation process while interacting with the robot's display.	- Provide methods that help the user to navigate, find content and determine where s/he is in a structure. Avoid using frames and inline frames (iframes). (for examples, see **annex** 1) - Make sure target (content) size is large enough to activate it on small touch screen or by mouse, the minimum target size is (44 by 44 CSS pixels at least), except when: alternative for the target is available and with the minimum target size; the target (content) can be enlarged by reflow technique; target size is determined by user agent; a specific target size is required). WCAG 2.1 (2.5.5)
10.	**Appropriate distance for interaction**	The user can interact with the robot within appropriate distance.	- Design the robot that can always interact with the user according to the appropriate distance for interaction

Table F.12 Proposed accessibility guidelines for HRI_ Users with motor disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with motor disabilities			
Understandable			
#	**Requirement**	**Description**	**How to achieve it**
11.	**Predictable interaction**	Interaction with the robot is consistent and predictable.	a) Use a simple and familiar interaction and navigation mechanism. b) A change in operation of the robot should preferably be initiated by the user.
12.	**Errors, help and feedback**	The user can review and correct interaction information before submitting, this can avoid errors. The user can at all times query what the robot is doing or processing.	a) Provide a clear mechanism controlling the robot and reviewing commands before execution. (for examples, see **annex 1**) b) Design the robot's system to detect and explain errors to the user, and where possible explain how to correct them. (for examples, see **annex** 1) c) Inform the user about progress status during their interaction with the robot.
13.	**Natural voice**	Robot's voice should be clear and natural, the user can choose the robot's voice s/he prefers, and adjust/ set the voice volume.	a) Provide the robot with a set of different clear and appropriate voices and allow the user to choose the voice that matches his/her hearing abilities or preferences. b) Where possible, allow the user to select a preferred voice accent. c) Provide a mechanism to allow the user to adjust the robots' voice volume.
14.	**Displays**	Predictable UI components and functionality.	- Use familiar user interface components and widgets. (for examples, see **annex** 1)
		(Readability) Text on the robot's display should be legible for the user.	a) Provide additional information for unusual words or phrases, avoid the use of abbreviations. b) Make sure the line length does not exceed 70 characters. Generally, minimize the use of scripts on the client page. c) If necessary, identify a specific pronunciation of words to give them the correct meaning. d) Ensure the readability of all text: (http://www.readabilityformulas.com/freereadability-formula-tests.php)
General			
15.	**Adopting user's interaction preferences**	The user adjusts/sets the interaction settings of the robot, preferences are stored.	- Design the robot to adapt to and store the users' interaction abilities, preferences and settings. (for examples, see **annex 1**) - Design the robot to be able to learn user' preferences and adapt it.
16.	**Reachable Human support**	The user can easily ask for human help or support.	- Design the robot with a mechanism for calling human support or help. (for examples, see **annex 1**)

Table F.13 Proposed accessibility guidelines for HRI_ Users with motor disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with motor disabilities			
General			
#	**Requirement**	**Description**	**How to achieve it**
17.	**Adopting emotions representation and recognition**	The user can interact with the robot though emotions representation and recognition.	- Adopt emotions representation and recognition means, if it is essential for delivering robot's services.
18.	**Adopting environment accessibility requirements**	The user can interact with a robot that is designed considering the environment accessibility requirements.	- Design the robot considering the environment accessibility requirements, for instance, waterproof exterior and proper type of camera for outdoor robot.

Table F.14 Proposed accessibility guidelines for HRI_ Users with speech disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with speech disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
1.	**Proper modalities for interaction**	The user can operate the robot using proper channels for input and output.	a) Provide proper modalities for interaction. (for examples, see **annex 1**) b) Verify that all functions are accessible via the channel chosen such as keyboard, virtual keyboard, mouse, haptic displays, voice (Automatic Speech Recognition and Text To Speech techniques) or gestures.
2.	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	**For web interfaces :** a) Design accessible patterns and widgets based on WAI-ARIA, by defining roles, properties and states of the widgets in the code. (for examples, see **annex 1**) b) Identify the organization and structure of a web page by using ARIA landmark roles in the code, such as headings and regions. c) Provide keyboard navigation in the code based on WAI-ARIA for UI objects and events. (for examples, see **annex 1**) WAI-ARIA best practices d) Make sure that the purpose of all input fields which collect information about user can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (1.3.5) e) Make sure the role of status messages can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (4.1.3) **For hardware:** f) Provide industry standard ports for alternate input and output devices, e.g., assistive tools.
Operable			
3.	**Keys, Keyboards and Keypads**	The user can verify the status of locking or toggle keys visually, through touch or sound, or tactically.	- Provide visual, auditory or haptic feedback to verify the status of locking or toggle keys. (for examples, see **annex 1**)

Table F.15 Proposed accessibility guidelines for HRI_ Users with speech disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with speech disabilities			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
4.	**Time**	Time does not affect users' ability to finish any interactive task with the robot, s/he has started.	- Allow the user to control the time limits, turn off, adjust or extend the time limit, except when time is an essential part of activity or real-time event. - Warn the user about the duration of user inactivity at the start of a task, set task timeout to occur after 20 hours of inactivity or store user data for 20 hours following the inactivity at least. WCAG 2.1 (2.2.6)
5.	**Navigating on displays**	Facilitate navigation process while interacting with the robot's display.	Provide methods that help the user to navigate, find content and determine where s/he is in a structure. Avoid using frames and inline frames (iframes). (for examples, see **annex** 1)
6.	**Appropriate distance for interaction**	The user can interact with the robot within appropriate distance.	- Design the robot that can always interact with the user according to the appropriate distance for interaction
Understandable			
7.	**Predictable interaction**	Interaction with the robot is consistent and predictable.	a) Use a simple and familiar interaction and navigation mechanism. b) A change in operation of the robot should preferably be initiated by the user.
8.	**Errors, help and feedback**	The user can review and correct interaction information before submitting, this can avoid errors. The user can at all times query what the robot is doing or processing.	a) Provide a clear mechanism controlling the robot and reviewing commands before execution. (for examples, see **annex 1**) b) Design the robot's system to detect and explain errors to the user, and where possible explain how to correct them. (for examples, see **annex** 1) c) Inform the user about progress status during their interaction with the robot.

Table F.16 Proposed accessibility guidelines for HRI_ Users with speech disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with speech disabilities			
Understandable			
#	**Requirement**	**Description**	**How to achieve it**
9.	**Natural voice**	Robot's voice should be clear and natural, the user can choose the robot's voice s/he prefers, and adjust/ set the voice volume.	a) Provide the robot with a set of different clear and appropriate voices and allow the user to choose the voice that matches his/her hearing abilities or preferences. b) Where possible, allow the user to select a preferred voice accent. c) Provide a mechanism to allow the user to adjust the robots' voice volume.
10.	**Displays**	Predictable UI components and functionality.	- Use familiar user interface components and widgets. (for examples, see **annex** 1)
		(Readability) Text on the robot's display should be legible for the user.	a) Provide additional information for unusual words or phrases, avoid the use of abbreviations. b) Make sure the line length does not exceed 70 characters. Generally, minimize the use of scripts on the client page. c) If necessary, identify a specific pronunciation of words to give them the correct meaning. d) Ensure the readability of all text: (http://www.readabilityformulas.com/freereadability-formula-tests.php)
General			
11.	**Adopting user's interaction preferences**	The user adjusts/sets the interaction settings of the robot, preferences are stored.	- Design the robot to adapt to and store the users' interaction abilities, preferences and settings. (for examples, see **annex 1**) - Design the robot to be able to learn user' preferences and adapt it.
12.	**Reachable Human support**	The user can easily ask for human help or support.	- Design the robot with a mechanism for calling human support or help. (for examples, see **annex 1**)

Table F.17 Proposed accessibility guidelines for HRI_ Users with speech disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with speech disabilities			
General			
#	**Requirement**	**Description**	**How to achieve it**
13.	**Adopting emotions representation and recognition**	The user can interact with the robot though emotions representation and recognition.	- Adopt emotions representation and recognition means, if it is essential for delivering robot's services.
14.	**Adopting environment accessibility requirements**	The user can interact with a robot that is designed considering the environment accessibility requirements.	- Design the robot considering the environment accessibility requirements, for instance, waterproof exterior and proper type of camera for outdoor robot.

Table F.18 Proposed accessibility guidelines for HRI_ Users with auditory disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with auditory disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
1.	**Proper modalities for interaction**	The user can operate the robot using proper channels for input and output.	a) Provide proper modalities for interaction. (for examples, see **annex 1**) b) Verify that all functions are accessible via the channel chosen such as keyboard, virtual keyboard, mouse, haptic displays, voice (Automatic Speech Recognition and Text To Speech techniques) or gestures.
2.	**Alternatives for non- text elements**	All non-text interface elements on the robot's display and all spoken information must have accompanying text or synchronized alternatives for multimedia elements.	a) Provide captions, description or labels for all non- text interface elements. b) For prerecorded and live multimedia, provide captions, audio descriptions, or sign language. For robot voice, provide text or sign language. WCAG 2.0 (guideline 1.1, 1.2).
3.	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	**For web interfaces :** a) Design accessible patterns and widgets based on WAI-ARIA, by defining roles, properties and states of the widgets in the code. (for examples, see **annex 1**) b) Identify the organization and structure of a web page by using ARIA landmark roles in the code, such as headings and regions. c) Provide keyboard navigation in the code based on WAI-ARIA for UI objects and events. (for examples, see **annex 1**) WAI-ARIA best practices d) Make sure that the purpose of all input fields which collect information about the user can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (1.3.5) e) Make sure the role of status messages can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (4.1.3) **For hardware:** f) Provide industry standard ports for alternate input and output devices, e.g., assistive tools.

Table F.19 Proposed accessibility guidelines for HRI_ Users with auditory disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with auditory disabilities			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
4.	**Keys, Keyboards and Keypads**	The user can verify the status of locking or toggle keys visually, through touch or sound, or tactically.	- Provide visual, auditory or tactile feedback to verify the status of locking or toggle keys. (for examples, see **annex 1**)
5.	**Navigating on displays**	Facilitate navigation process while interacting with the robot's display.	- Provide methods that help the user to navigate, find content and determine where s/he is in a structure. Avoid using frames and inline frames (iframes). (for examples, see **annex** 1)
6.	**Time**	Time does not affect users' ability to finish any interactive task with the robot, s/he has started.	- Allow the user to control the time limits, turn off, adjust or extend the time limit, except when time is an essential part of activity or real-time event. - Warn the user about the duration of user inactivity at the start of a task, set task timeout to occur after 20 hours of inactivity or store user data for 20 hours following the inactivity at least. WCAG 2.1 (2.2.6)
7.	**Appropriate distance for interaction**	The user can interact with the robot within appropriate distance.	- Design the robot that can always interact with the user according to the appropriate distance for interaction
Understandable			
8.	**Predictable interaction**	Interaction with the robot is consistent and predictable.	a) Use a simple and familiar interaction and navigation mechanism. b) A change in operation of the robot should preferably be initiated by the user.
9.	**Errors, help and feedback**	The user can review and correct interaction information before submitting, this can avoid errors. The user can at all times query what the robot is doing or processing.	a) Provide a clear mechanism controlling the robot and reviewing commands before execution. (for examples, see **annex 1**) b) Design the robot's system to detect and explain errors to the user, and where possible explain how to correct them. (for examples, see **annex** 1) c) Inform the user about progress status during their interacting with the robot.

Table F.20 Proposed accessibility guidelines for HRI_ Users with auditory disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with auditory disabilities			
Understandable			
#	**Requirement**	**Description**	**How to achieve it**
10.	**Natural voice**	Robot's voice should be clear and natural, the user can choose the robot's voice s/he prefers, and adjust/ set the voice volume.	a) Provide the robot with a set of different clear and appropriate voices and allow the user to choose the voice that matches his/her hearing abilities or preferences. b) Where possible, allow the user to select a preferred voice accent. c) Provide a mechanism to allow the user to adjust the robots' voice volume.
11.	**Displays**	Predictable UI components and functionality.	- Use familiar user interface components and widgets. (for examples, see **annex 1**)
		(Readability) Text on the robot's display should be legible for the user.	a) Provide additional information for unusual words or phrases, avoid the use of abbreviations. b) Make sure the line length does not exceed 70 characters. Generally, minimize the use of scripts on the client page. c) If necessary, identify a specific pronunciation of words to give them the correct meaning. d) Ensure the readability of all text: (http://www.readabilityformulas.com/freereadability-formula-tests.php)
General			
12.	**Adopting user's interaction preferences**	The user adjusts/sets the interaction settings of the robot, preferences are stored.	- Design the robot to adapt to and store the users' interaction abilities, preferences and settings. (for examples, see **annex 1**) - Design the robot to be able to learn user' preferences and adapt it.
13.	**Reachable Human support**	The user can easily ask for human help or support.	- Design the robot with a mechanism for calling human support or help. (for examples, see **annex 1**)

Table F.21 Proposed accessibility guidelines for HRI_ Users with auditory disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with auditory disabilities			
General			
#	**Requirement**	**Description**	**How to achieve it**
14.	**Adopting emotions representation and recognition**	The user can interact with the robot through emotions representation and recognition.	- Adopt emotions representation and recognition means, if it is essential for delivering robot's services.
15.	**Adopting environment accessibility requirements**	The user can interact with a robot that is designed considering the environment accessibility requirements.	- Design the robot considering the environment accessibility requirements, for instance, waterproof exterior and proper type of camera for outdoor robot.

Table F.22 Proposed accessibility guidelines for HRI_ Users with cognitive disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with cognitive disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
1.	**Proper modalities for interaction**	The user can operate the robot using proper channels for input and output.	a) Provide proper modalities for interaction. (for examples, see **annex 1**) b) Verify that all functions are accessible via the channel chosen such as keyboard, virtual keyboard, mouse, haptic displays, voice (Automatic Speech Recognition and Text To Speech techniques) or gestures.
2.	**Location of hardware and software components.**	The user can easily perceive and access robot's interfaces (hardware and software) components.	a) Design consistently, and group related elements together. For example, place software buttons and links horizontally, vertically or on a grid, and important objects at the top of the interface and the less important objects at the bottom. b) Avoid unnecessary information and objects. Use images only when necessary. Funka Nu (43.content) and BBC guidelines (HTML Accessibility)
3.	**Alternatives for non- text elements**	All non-text interface elements on the robot's display and all spoken information must have accompanying text or synchronized alternatives for multimedia elements.	a) Provide captions, description or labels for all non- text interface elements. b) For prerecorded and live multimedia, provide captions, audio descriptions, or sign language. For robot voice, provide text or sign language. WCAG 2.0 (guideline 1.1, 1.2).
4.	**Blinking components**	For any blinking component on the robot's interface (lights, display contents, etc.) the blinking stops after a certain period, or can be switched off by the user.	- Provide a mechanism to allow the user to stop blinking, or specified the blinking times for the content to be a fixed number. WCAG 2.0 (guideline 2.2.2)
		User can disabled any motion animation caused by interaction	- Any motion animation caused by interaction can be disabled, unless it is required for functionality or for information being conveyed. WCAG 2.1 (2.3.3)
5.	**Flashing visual content**	Avoid flashing components on the robot's interface that are known to cause seizures.	- Any flashing component should not exceed three flashes in one second. Red flash should be avoided. WCAG 2.0 (guideline 2.3)

Table F.23 Proposed accessibility guidelines for HRI_ Users with cognitive disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with cognitive disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
6.	**Display**	The user can apply different spacing styles on interface content without losing content or functionality.	- Make the content capable to adapt the following spacing styles applied by users without losing content or functionality: line spacing up to 1.5 times the font size at least; paragraph spacing 2 times the font size at least; letter spacing up to 0.12 times the font size at least; word spacing up to 0.16 times the font size at least. WCAG 2.1 (1.4.12)
		The user can perceive the additional content (tooltip, sub-menus, etc.) and dismiss it without disturbing their current task.	- For additional content which appear and disappear by hovering or keyboard focus, such as, tooltip, sub-menus, etc., the interaction must be designed to allow the user to perceive the additional content and dismiss it without disturbing their current task. WCAG 2.1 (1.4.13)

Table F.24 Proposed accessibility guidelines for HRI_ Users with cognitive disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with cognitive disabilities			
Perceivable			
#	**Requirement**	**Description**	**How to achieve it**
7.	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	**For web interfaces :** a) Design accessible patterns and widgets based on WAI-ARIA, by defining roles, properties and states of the widgets in the code. (for examples, see **annex 1**) b) Identify the organization and structure of a web page by using ARIA landmark roles in the code, such as headings and regions. c) Provide keyboard navigation in the code based on WAI-ARIA for UI objects and events. (for examples, see **annex 1**) WAI-ARIA best practices d) Make sure that the purpose of all input fields which collect information about user can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (1.3.5) e) Make sure the role of status messages can be determined programmatically in code, so it can be rendered appropriately on different devices and for different audiences. WCAG 2.1 (4.1.3) **For hardware:** f) Provide industry standard ports for alternate input and output devices, e.g., assistive tools.

Table F.25 Proposed accessibility guidelines for HRI_ Users with cognitive disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with cognitive disabilities			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
8.	**Keys, Keyboards and Keypads**	The user can verify the status of locking or toggle keys visually, through touch or sound, or tactically.	- Provide visual, auditory or tactile feedback to verify the status of locking or toggle keys. (for examples, see **annex 1**)
		The user can turn character key shortcuts off, associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt) or the shortcuts active only on focus.	- For character key shortcuts, make one of the following available or true: there is a mechanism to turn the shortcuts off; to associate the shortcut to include non-printable keyboard keys (e.g., Ctrl, Alt); shortcuts active only on focus. WCAG 2.1 (2.1.4)
9.	**Time**	Time does not affect users' ability to finish any interactive task with the robot, s/he has started.	- Allow the user to control the time limits, turn off, adjust or extend the time limit, except when time is an essential part of activity or real-time event. - Warn the user about the duration of user inactivity at the start of a task, set task timeout to occur after 20 hours of inactivity or store user data for 20 hours following the inactivity at least. WCAG 2.1 (2.2.6)
10.	**Assistive Technology and web interfaces**	The user can use assistive technology to interact with the robot, such as screen reader, braille keyboards, etc.	- Make sure web content can be operated by a single pointer instead of multi- path pointer. WCAG 2.1 (2.5.1) - For interaction happening by single pointer, consider one of the following at least: Do not use down- event (mouse down) to execute any function; Abort or undo is available using up- event (mouse up); up- event can reverse any action done by down-event; use down- event for completing the function. WCAG 2.1 (2.5.2)
11.	**Navigating on displays**	Facilitate navigation process while interacting with the robot's display.	Provide methods that help the user to navigate, find content and determine where s/he is in a structure. Avoid using frames and inline frames (iframes). (for examples, see **annex** 1)

Table F.26 Proposed accessibility guidelines for HRI_ Users with cognitive disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with cognitive disabilities			
Operable			
#	**Requirement**	**Description**	**How to achieve it**
12.	**Appropriate distance for interaction**	The user can interact with the robot within appropriate distance.	- Design the robot that can always interact with the user according to the appropriate distance for interaction
Understandable			
13.	**Predictable interaction**	Interaction with the robot is consistent and predictable.	a) Use a simple and familiar interaction and navigation mechanism. b) A change in operation of the robot should preferably be initiated by the user.
14.	**Errors, help and feedback**	The user can review and correct interaction information before submitting, this can avoid errors. The user can at all times query what the robot is doing or processing.	a) Provide a clear mechanism controlling the robot and reviewing commands before execution. (for examples, see annex 1) b) Design the robot's system to detect and explain errors to the user, and where possible explain how to correct them. (for examples, see annex 1) c) Inform the user about progress status during their interaction with the robot.
15.	**Natural voice**	Robot's voice should be clear and natural, the user can choose the robot's voice s/he prefers, and adjust/ set the voice volume.	a) Provide the robot with a set of different clear and appropriate voices and allow the user to choose the voice that matches his/her hearing abilities or preferences. b) Where possible, allow the user to select a preferred voice accent. c) Provide a mechanism to allow the user to adjust the robots' voice volume.
16.	**Displays**	Predictable UI components and functionality.	- Use familiar user interface components and widgets. (for examples, see **annex** 1)

Table F.27 Proposed accessibility guidelines for HRI_ Users with cognitive disabilities.

PLEASE CONSIDER SAFETY REQUIREMENTS FIRST!			
Users with cognitive disabilities			
Understandable			
#	**Requirement**	**Description**	**How to achieve it**
16.	**Displays**	**(Readability)** Text on the robot's display should be legible for the user.	a) Provide additional information for unusual words or phrases, avoid the use of abbreviations. b) Make sure the line length does not exceed 70 characters. Generally, minimize the use of scripts on the client page. c) If necessary, identify a specific pronunciation of words to give them the correct meaning. d) Ensure the readability of all text: (http://www.readabilityformulas.com/freereadability-formula-tests.php)
General			
17.	**Adopting user's interaction preferences**	The user adjusts/sets the interaction settings of the robot, preferences are stored.	- Design the robot to adapt to and store the users' interaction abilities, preferences and settings. (for examples, see **annex 1**) - Design the robot to be able to learn user' preferences and adapt it.
18.	**Reachable Human support**	The user can easily ask for human help or support.	- Design the robot with a mechanism for calling human support or help. (for examples, see **annex 1**)
19.	**Adopting emotions representation and recognition**	The user can interact with the robot though emotions representation and recognition.	- Adopt emotions representation and recognition means, if it is essential for delivering robot's services.
20.	**Adopting environment accessibility requirements**	The user can interact with a robot that is designed considering the environment accessibility requirements.	- Design the robot considering the environment accessibility requirements, for instance, waterproof exterior and proper type of camera for outdoor robot.

Acronyms

WCAG Web Content Accessibility Guidelines.

BBC British Broadcasting Corporation.

HTML Hypertext Markup Language.

WAI-ARIA Web Accessibility Initiative - Accessible Rich Internet Applications.

UI User Interface.

Appendix G
Questionnaire for Evaluating ROSI Robot Interfaces

This appendix presents a questionnaire used for evaluating the ROSI robot interfaces (town crier) to elicit accessibility problems that users faced during their interaction with the robot.

A. Purpose of a questionnaire

This questionnaire is a part of evaluating ROSI robot interfaces (town crier), the robot designed to help elderly people by reminding them with some important daily information such as, the date and time, activities, weather and birthdays. The evaluation aims to elicit accessibility problems that users may encounter during the interaction with the robot.

B. Pre Test Questionnaire:

1) Please mark your gender: ☐ *Male* ☐ *Female*

2) What is your Nationality?

***Use of Electronic Devices**

3) Please mark the answer that describes your use of mobile phone:

Continuously (at all hours) *Fairly use* *Sometimes* *Rarely use* *Never*

4) Any other use besides talking on the phone?

5) I use computers / tablets:

Continuously (at all hours) *Fairly use* *Sometimes* *Rarely use* *Never*

6) What do you usually use your computer / tablet for?

***Interaction with robots**

7. I have ever interacted with a robot

Continuously (at all hours) *Fairly use* *Sometimes* *Rarely use* *Never*

8. In the case of having interacted with robots, of what type? What kind of interaction?

9. What do you think about the idea of interacting with robots? Would you especially like it in a specific case (home, hospitals, educational centers, shopping, etc.)?

***Experience in Ambient Assisted Living (ALL)**

10. Every day there are more systems or environments with intelligent sensors that aim to make life more comfortable for people, for example, sending medical information or the location of the residents to the appropriate services. Have you heard of them / do you know them?

Always *Oftentimes* *Sometimes* *Rarely* *Never*

11. In case of knowing them (ALL) or having used them, of what type? With what objective? In what way did you use it?

12. In which cases would you like to be able to use ALL?

***User characteristics**

13. Do you have hearing disability?

I can't hear anything at all	*I have hearing difficulty*	*Hearing somewhat*	*Hearing fairly*	*I can hear perfectly*

14. In the case of having hearing disability, do you use a support/ assistive system or tool (hearing aid, cochlear implant, etc.)?

15. Do you have visual disability?

I can't see anything at all	*I have seeing difficulty*	*Seeing somewhat*	*Seeing fairly*	*I can hear perfectly*

16. If you have visual disability, do you use a support/ assistive system or tool (magnifying glass, glasses, etc.)?

17. Do you have motor disability?

I can't move at all	*I have moving difficulty*	*Moving somewhat*	*Moving fairly*	*I can move perfectly*

18. If you have a motor disability, do you use a support/ assistive system or tool (cane, walker, etc.)? Please explain what type of motor disability.

19. Do you have a cognitive disability?

I have a HIGH degree of cognitive disability (over 90)	*I have cognitive difficulty*	*somewhat*	*My cognitive abilities are fairly fine*	*I do not have cognitive disability (less than 10)*

20. Do you find it difficult to read with agility?

I read very slowly (syllable by syllable)	*I read slowly*	*somewhat*	*Reading quickly*	*I read very quickly (I can read subtitles in movies)*

C. Post Test Questionnaire:

***Previous knowledge of test**

1) Did you know of a similar town crier robot or machine? If yes, described it.

Never	*Rarely*	*Sometimes*	*Oftentimes*	*Yes, at least 1 time every 6 months*

2) Have you ever seen a human town crier at work:

Never	*Rarely*	*Sometimes*	*Oftentimes*	*Yes, at least 1 time every 6 months*

3) The robot reminded you of a real town crier:

Totally agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*

4) Do you miss something about the town crier robot to make it behave just like a real town crier?

***Access to town crier information**

5) The trumpet call sound helps me identify what new information is to be told next:

Totally agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*

6) The robot is located at a suitable distance to be able to hear you well:

Totally agree	Agree	Neutral	Disagree	Strongly disagree

7) I could hear what the town crier robot was saying at all times:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

8) If you couldn't hear well, what was it due to?

9) The information proclaimed by the robot is clear and well understood:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

10) The way of giving the information allows me to remember it (retain it in memory) easily:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

11) How would it be easier for you to remember all the information provided by the robot?

***Utility and Attitude to use**

12) I think the robot is practical to remember participants with events in the residence:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

13) I would like the robot-town crier to recall the events at the residence every day:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

14) What kind of information would you like the robot to provide?

***Robot physical appearance**

15) I was intimidated when I first saw the robot:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

16) I find it easy to be in the presence of the robot, whose physical appearance was not intimidating:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

17) The robot made me feel comfortable and it was easy to understand what it was saying:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

18) I felt safe, from a physical point of view, with the robot, whose behavior and movement were predictable:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

19) I think display size is adequate (height and width):

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

20) I think the colors used on the robot display and the font used were suitable:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

***Concentration**

21) It was easy for me to focus on what the robot was announcing:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

22) It is easier for me to retain information when told by the robot than when told by a person:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

Briefly explain your answer.

23) It was clear to me at all times when the robot began to proclaim something:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

24) It was clear to me at all times when the robot had finished proclaiming something

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

25) The time the robot uses to announce the events seems adequate:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

***Emotions**

26) I'm afraid to touch the robot, in case it acts unpredictable or breaks something:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

27) Does it provoke any other emotion? Joy, sadness, anger, etc. When and why?

***Robot perception**

28) Robot's way of talking was polite and I like it:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

29) The robot was sociable at all times and made me feel good:

Totally agree *Agree* *Neutral* *Disagree* *Strongly disagree*

***Other comments and THANK YOU FOR PARTICIPATING**

30) The robot would improve if...
31) I like the robot because...
32) What I like least about the robot is...

GLOSSARY

Accessibility Accessibility in HRI means that people with disabilities can use robots' interaction components/ interfaces.

Disability That the person has a visual, hearing, speech, motor, or/ and cognitive impairment.

Guidelines A set of rules to guarantee the success of a certain goal or process.

Human-Computer Interaction That when the user applies means to communicate via interaction interfaces to send data/ commands or to receive information/ service from computer.

Human-Robot Interaction That when the user applies means to communicate via interaction interfaces to send data/ commands or to receive information/ service from robot.

Inclusive design That when designers work on their products or services to consider the needs of all users, despite their age, ability, culture, geographic place or economic level.

Usability The ease of use a certain product or service to accomplish a specified task or goal with effectiveness, efficiency and satisfaction.

Robot Programmable machine that can perform complex tasks, it can be autonomous or semi-autonomous, with at least two axes for actuation.

Socially Assistive Robots A type of robots which use its physical embodiment and social interaction to present services/ assistance to users.

ACRONYMS

AAL Ambient Assisted Living.

AI Artificial Intelligence.

ANEMONE Action and Intention Recognition in Human Robot Interaction.

ASD Autism Spectrum Disorder.

AT Assistive Technologies.

ATAG Authoring Tool Accessibility Guidelines.

AUSUS Accessibility, Usability, Social acceptance, User experience and societal impact.

BBC British Broadcasting Corporation.

BCI Brain Computer Interaction.

CEN European Committee for Standardization.

CENELEC European Committee for Electrotechnical Standardization.

CP Cerebral Palsy.

CSCW Computer Supported Cooperative Work.

CSS Cascading Style Sheet.

DOF Degree of freedom.

ETSI European Telecommunications Standards Institute.

EU European Union.

HCI Human-Computer Interaction.

HRI Human-Computer Interaction.

HTML Hypertext Markup Language.

IBM International Business Machines Corporation.

ICT Information Communication Technology.

IFR International Federation of Robotics.

IMU Inertial Measurement Unit.

IQ Intelligence Quotient.

IR Infrared.

ISO International Organization for Standardization.

LED Light Emitting Diode.

MR Mental Retardation.

OBPP Obstetrical Brachial Plexus Palsy.

OLED Organic Light-Emitting Diode.

PC Personal Computer.

PICO Population, Intervention, Comparison and Outcomes.

PUX Personal User Experience.

RGB-D Red Green Blue-Depth.

RISC Reduced Instruction Set Computer.

RIZE Robot Interfaces from Zero Experience.

SAR Socially Assistive Robots.

SCPE Surveillance of Cerebral Palsy in Europe.

SD Standard Deviation.

SE Software Engineering.

SR Services Robots.

SS Social Sciences.

TV Television.

UAAG User Agent Accessibility Guidelines.

UCD User-Centered Design.

UEM European University of Madrid.

UI User Interface.

UK United Kingdome.

UN United Nations.

USA United States of America.

USUS Usability, Social acceptance, User experience and societal impact.

UTAUT Unified Theory of Acceptance and Use of Technology.

UX User Experience.

VCR video cassette recorder.

WAI-ARIA Web Accessibility Initiative-Accessible Rich Internet Applications.

WCAG Web Content Accessibility Guidelines.

WHO World Health Organization.

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