Mobile Interaction for Augmentative and Alternative Communication: a Systematic Mapping

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***Abstract*—Verbal communication is essential for socialization, meaning construction and knowledge sharing in a society. When verbal communication does not occur naturally because of constraints in people's and environments capabilities, it is necessary to design alternative means. Augmentative and Alternative Communication (AAC) aims to complement or replace speech to compensate difficulties of verbal expression. AAC systems can provide technological support for people with speech disorders, assisting in the inclusion, learning and sharing of experiences. This paper presents a systematic mapping of the literature to identify research initiatives regarding the use of mobile devices and AAC solutions. The search identified 1366 potentially eligible scientific articles published between 2006 and 2016, indexed by ACM, IEEE, Science Direct, and Springer databases and by the SBC Journal on Interactive Systems. From the retrieved papers, 99 were selected and categorized into themes of research interest: games, autism, usability, assistive technology, AAC, computer interfaces, interaction in mobile devices, education, among others. Most of papers (57 out of 99) presented some form of interaction via mobile devices, and 46 papers were related to assistive technology, from which 14 were related to AAC. The results offer an overview on the applied research on mobile devices for AAC, pointing out to opportunities and challenges in this research domain, with emphasis on the need to promoting the use and effective adoption of assistive technology.**

***Index Terms*—Augmentative and Alternative Communication, systematic mapping, mobile devices, interaction.**

I. Introduction

Verbal language is the most commonly used medium for people to communicate, yet communication between people can be much more comprehensive. Human beings use non-verbal behavior in order to complete their interpersonal interaction [1]. Communication between people is complemented by several communicative elements (e.g., emotional states, gestures, facial expressions) that allow people to understand each other.

Communication is essential for socialization. When people experience difficulties to express verbally what they intend to communicate, interaction problems arise, hampering learning, family living, social activities, professional practices etc., leading to emotional, social, and cognitive problems [2]. Therefore, alternatives for individuals to communicate to each other and with the world around them are demanded, and computing technology has potential to contribute with interactive and low cost solutions.

Augmentative and Alternative Communication (AAC) aims to complement or replace speech to compensate difficulties of expression by using non-verbal communication systems and intervention strategies [3]. The practice of AAC mediated by computational applications represents a very attractive alternative, mainly by means of mobile devices. Learning opportunities are numerous, and considering the reality of people already connected via smartphones and other mobile devices, creating means to enable everyone's access, anywhere, anytime, can be particularly interesting. AAC can serve as an alternative and effective way to promote social interactions towards a more inclusive and active participation of people in society [4].

The possibilities of using mobile devices for supporting AAC are diverse, interesting and challenging in terms of devices, interface, interaction, social and economic issues. In this article, we present a systematic mapping of the literature to identify research initiatives regarding the use of mobile devices as a tool to improve or facilitate the communication of people with some type of communication disability.

II. Augmentative and Alternative Communication

Augmentative and Alternative Communication refers to all forms of communication that can complement or replace speech. AAC covers the needs of reception, understanding and verbal expression, increasing the communicative interaction of individuals without orality. ”Augmentative” communication systems complement oral language when it is not possible to communicate effectively with other people and the environment. ”Alternative” communication systems replace oral language when it cannot be understood or has been lost. Both types of systems support people with communication problems to interact with other people, expressing their opinions, feelings and making personal decisions to lead and control their lives [5].

Non-speakers usually use AAC technology to enhance their communication (non-verbal gestures and non-lexical sounds, such as laughter) as well as an alternative to oral discourse [6].

ISSN: 2236-3297

The very aim of AAC is to enable all people to communicate, by strengthening ties with the environment in which they are inserted, with their families and with their peers.

AAC devices range from low-tech devices, such as photo cards and communication boards, to high-tech versions such as electronic communication boards, computerized voice synthesizers and specific software. For people with expressive language impairment (e.g., resulting from autism, cerebral palsy), these devices provide tools that allow the selection of words, symbols and images to communicate their thoughts, intentions and conversation with others by means of digitized or synthesized voice [6].

In the past, there may have been criticism about the effective usefulness of AAC solutions. Some argued that AAC affects learning negatively as an individual could prefer to use it than developing the necessary capabilities [7]. Currently, it is generally agreed that AAC is essential for the development of individuals with communication difficulties, assisting individuals with intellectual disabilities in their learning process [8].

A. AAC and Mobile Computing

In some contexts, devices with touch screens are more effective than pointers (e.g., a mouse) to allow interaction with computers. Computer games are becoming more and more mediated by means of devices like tablets, smartphones and sensors. Mobile computing applications have been often presented as assistive technology for children with special needs. These applications seek to assist children in different contexts, such as learning, reading and developing everyday skills [9].

The developments in mobile computing and advancements in electronic communication aids for nonspeaking individuals are inherently intertwined through the history of their research, development, commercialization, use, and reuse [6]. Individuals with various disabilities need to be recovered from and rewritten into the history of how communication technology are designed, marketed, and adopted [6].

As the use of mobile devices has gained popularity, there are applications being developed to promote learning in several areas of knowledge, such as: mobile applications to assist people with visual impairment to communicate and control an Android mobile phone via speech recognition [10]; serious game to teach first aid for individuals with autism spectrum disorder (ASD) [11]; collaborative games, such as the ComFiM (communication through the exchange of figures for multi-touch devices), a game to generate communicative situations among children with autism in a collaborative environment [12]; alternative communication systems for web and mobile devices to support alternative communication for inclusion processes to autism [13], to cite a few.

AAC supported by mobile devices can increase the autonomy of people with special communication needs. Because mobiles are well-disseminated, have high processing and memory capacity, and are relatively easy to acquire, such devices become an interesting alternative compared to computers or other equipment dedicated to provide the use of an AAC system.

III. Systematic Mapping

A systematic mapping review allows to identify, analyze and work on available research relevant to a particular research question, a topic area, or a phenomenon of interest [14]. In a systematic review, the search process is conducted according to a well-defined sequence of steps, following a previously planned study protocol [15].

Systematic mappings are a particular type of systematic review with a broader scope, designed to cover and give an overview of a research area by classifying and counting contributions according to pre-defined categories [16] [17]. A systematic mapping studies the literature to identify what topics are being covered and how, where research have been published and by whom, what are the most common practices and tools, the gaps and opportunities and so on.

While systematic literature reviews focus on gathering and synthesizing evidence, considering the evidence strength, systematic literature mapping are primarily used to structure a research area [17]. This article presents a systematic mapping of literature on studies related to AAC, mapping studies that investigate mobile devices as assistive technology solutions to enable or improve the communication capacities of people who have some type of expression or interaction difficulty. The mapping considered scientific articles/papers indexed by ACM, IEEE, Science Direct, Springer databases and by the SBC Journal on Interactive Systems, published between 2006 and 2016.

The plan for the systematic mapping was developed according to the guidelines from Munzlinger et al. [15] and Petersen et al. [17]. The first step was to plan and formalize the study protocol, specifying the research problem, its objective, the research questions and the keywords. Tab. I presents details about the study protocol.

TABLE I
Study Plan

Research problem: To investigate modalities of interaction on mobile devices able to be applied as assistive technology for AAC.
Objective: To map research possibilities in assistive technology in mobile devices for supporting AAC.
General question: What are the recent theoretical solutions or practical tools for supporting AAC via mobile devices, and what modalities of interaction have been employed?
Research questions: 1) What are the recent modalities of interaction used on mobile devices? 2) What are the interactive limitations of existing studies aimed at the practice of AAC via mobile devices? 3) Are there specific methodologies to stimulate AAC practice in mobile devices? What modes of interaction do they employ? 4) What kind of user interfaces are used to facilitate interaction via mobile devices? 5) What are the aspects of Human-Computer Interaction being considered? How? 6) What applications are used as assistive technology for AAC in mobile devices?

For the study protocol, selection criteria were defined and applied as a first filter for retrieved studies. Selection criteria were divided into inclusion and exclusion criteria and applied to classify the studies according to their metadata (title, abstract and keywords). Studies that met at least one of the inclusion criteria were included, and studies that felt in at least one of the exclusion criteria were excluded. Tab. II presents the inclusion and exclusion criteria of the first filter.

TABLE II
INCLUSION AND EXCLUSION CRITERIA FOR THE 1ST FILTER

1st Filter	
Inclusion Criteria	**Exclusion Criteria**
IC1: The study defines or presents instruments for AAC in mobile devices.	**EC1**: The study presents no evaluation or analysis of applications for AAC.
IC2: The study investigates, compares or evaluates AAC applications for mobile devices.	**EC2**: The study mentions AAC via mobile devices only as proposal for future research.
IC3: The study defines or presents different modalities of interaction via mobile devices.	**EC3**: The study was not related to AAC or modalities of interaction via mobile devices.
IC4: The study presents the application of a methodology for practicing AAC or employing assistive technology in mobile devices.	**EC4**: The study was published before 2006.

The selection criteria for the second filter were defined and applied on the complete reading of studies resulting from the first filter. Tab. III describes the criteria.

In the second step of the mapping process search expressions were defined, calibrated and adaptation for each selected database. The searches were carried out in November 2016, returning 1366 studies: 1217 were excluded by the first filter, and 50 were excluded by the second filter, resulting in a set of 99 studies. Tab. IV presents an overview of the selection process.

TABLE III
SELECTION CRITERIA FOR THE 2ND FILTER

2nd Filter - Selection Criteria
MOB: Application running on mobile devices or related theme.
AAC: Application for AAC or related topic.
ASS: Informations about accessibility or assistive technology.
INT: Informations about computational interfaces or interaction in mobile devices.
HCI: Information on topics from Human-Computer Interaction in mobile devices.

Tab. V shows the data extraction form used to standardize the data extracted from the publications read, aiming to reduce the bias of the results and the informality of the process. The extraction was performed by the first author and reviewed by the second author by tracing back the information in the extraction form to the statements in each paper, and checking their correctness. Categories were created dynamically as data were extracted in order to reflect the data set resulting from the extraction process itself. A dynamic scheme was adopted instead of a predefined scheme in order to reflect the extracted content. On the one hand, a predefined categorization can represent a more structured categorization; on the other hand, it prevents the identification of other relevant categories to represent the selected set. Because the nature of this study is an open and comprehensive mapping, we opted for this more flexible form of classification, generated from the data extraction form used.

TABLE IV
SEARCH EXPRESSION AND RESULTS OBTAINED

Example of search expression			
TITLE(mobile OR ”alternative communication” OR ”augmentative and alternative communication” OR ”AAC”) AND (interact OR touch OR gyroscope OR accelerometer OR vibracall OR tablet OR iPad OR phone) AND (ABSTRACT(mobile AND communication AND interact) OR ABSTRACT(mobile AND communication AND disability)).			
Database	**Number of studies**	**1st filter**	**2nd filter**
ACM	405	57	37
IEEE	835	62	37
Science Direct	108	13	10
Springer	16	15	13
SBC Journal on Interactive Systems	2	2	2
Total of selected studies	**1366**	**149**	**99**

TABLE V
DATA EXTRACTION FORM

Attributes
Article title
Year of publication
Name (s) of the author (s)
Author’s institution country (s)
Source of publication
Involved technology
Brief description
Contribution area (mobile interaction, mobile computing interface, AAC, assistive technology, autism, games, usability, education or other).
Type of contribution (theoretical, systematic review of literature, systematic mapping, survey, application, model, method, technique, comparison).
Database used in the search: name, public / private.

A. Threats to the validity of the study

This section discusses the threats to validity that might have affected the results of this systematic mapping. The review protocol was validated to ensure that the research was as correct, complete and objective as possible. However, possible limitations in two moments of the review process were identified: in the publication selection and in the data extraction.

Different threats to validity can be pointed out in this study. One of the threats is missing relevant studies in the area. In fact, we cannot guarantee that all related papers published are included in this mapping. The search for publications was performed only on a limited set of journals and databases, assuming that these search engines tend to contain the majority of the relevant studies. The terms used in search strings may have many synonyms and the search string itself narrows the possible results. Although we mitigate this threat as much as possible by following the references in the primary studies, we recognize that relevant papers are not included because of divergence in the use of terms and expressions.

As another threat, it is possible that some kind of inaccuracy or misclassification has occurred in the data extraction performed in this systematic mapping, mainly because the data extraction was done individually by a researcher. The coherence of our classification scheme can also introduce bias to the data analysis, and other researchers may possibly come up with different classification schemes. To reduce these threats, data extraction and classification were conducted by the first author and validated by the second. Disagreements were resolved by means of discussions or led to the refinement of the classification scheme, leading sometimes, to the reclassification and new validation of previously classified publications. This procedure was repeated until there were no disagreements.

Petersen et al. [17] reviewed existing validity classification schemes and discussed their applicability to software engineering. Based on the study of these authors, the following types of validity where taken into account to minimize the threats to the validity of the study: descriptive validity, theoretical validity, generalizability, interpretive validity.

Descriptive validity is the extent to which observations are described accurately and objectively [17]. To reduce this threat, a data extraction form has been designed to support the recording of data. The form objectified the data extraction process and could always be revisited. Hence, this threat is considered as being under control.

Theoretical validity is determined by our ability of being able to capture what we intend to capture [17]. To reduce this threat, the set of research questions was evaluated by the first author and later by the second and third author. The first and second filters were applied, and the remaining articles were read in full, making possible the extraction of answers to these questions.

Generalizability refers to how much it is possible to do a research and generalize the results to come from the proposed research process. Petersen et al. [17] presented a distinction between external generalizability (generalizability between groups or organizations) and internal generalizability (generalization within a group). To avoid the threat of external generalizability an own and theoretically advocated protocol [17] was used, and to avoid internal generalizability were defined research questions and own inclusion / exclusion criteria that allow the expansion or reproduction of the research in a different period, guaranteeing the generalizability of the study.

Interpretive validity is achieved when the conclusions drawn are reasonable given the data, and hence maps to conclusion validity [17]. A threat in interpreting the data is researcher bias, which is minimized through the review process carried out by the authors.

The repeatability requires detailed reporting of the research process [17]. We reported the systematic mapping process followed, and also elaborated on actions taken to reduce possible threats to validity.

IV. RESULTS

After selecting and reading, studies were categorized by publication year (Fig. 1). The majority of studies (57 of 99) was published in the last 4 years, suggesting the research topic has received attention from the academy and evolved.

Considering the authors' institutions and their respective countries (Fig. 2), most of studies have been published by authors working in institutions from the United States, Korea, China and Germany.

Selected studies were categorized into themes of research interest: games, autism, usability, assistive technology, AAC, computer interfaces, interaction in mobile devices, education, or others. Some studies have been categorized into more than one theme. Results are presented in Fig. 3. Although studies on varied themes related to mobile technology were found, studies focused on assistive technology, education, AAC, computational interfaces and interaction associated with mobile devices were quite representative, and are strongly related to the main objective of this study.

The categorization scheme was created and reviewed while data extraction took place. When extracting data from a specific paper, the first author tried to categorize the paper into an existing category. If the paper did not fit into any existing category, then a new category was created. Naturally, categories evolved during all the extraction process (e.g., categories were merged and refined as needed). Once data was extracted, the categorization scheme was reviewed by the other authors and eventual adjustments were made.

The categorization of the selected studies and their corresponding references are available in Tab. VI. Some selected studies are detailed below according to the categorization scheme developed in this study.

TABLE VI
STUDIES CATEGORIZED BY SUBJECT

Subject	Studies
AAC	[6] [11] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] [29]
Assistive technology	[6] [9] [10] [11] [13] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42] [43] [44] [45] [46] [47] [48] [49] [50] [51] [52] [53] [54] [55] [56] [57] [58]
Autism	[10] [23] [24] [28] [44] [53]
Computer Interfaces	[13] [36] [37] [38] [41] [42] [43] [59] [60] [61] [62] [63] [64] [65] [66] [67] [68]
Education, teaching and learning	[23] [28] [29] [35] [37] [44] [46] [47] [58] [64] [69] [70] [71] [72]
Games	[51] [59] [70] [71] [73] [74] [75]
Mobile Interaction	[12] [13] [18] [19] [20] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42] [59] [60] [61] [62] [63] [64] [69] [70] [73] [74] [76] [77] [78] [79] [80] [81] [82] [83] [84] [85] [86] [87] [88] [89] [90] [91] [92] [93] [94] [95] [96] [97] [98] [99] [100] [101] [102] [103] [104] [105] [106] [107]
Usability	[12] [38] [42] [60] [93] [105] [108] [109]

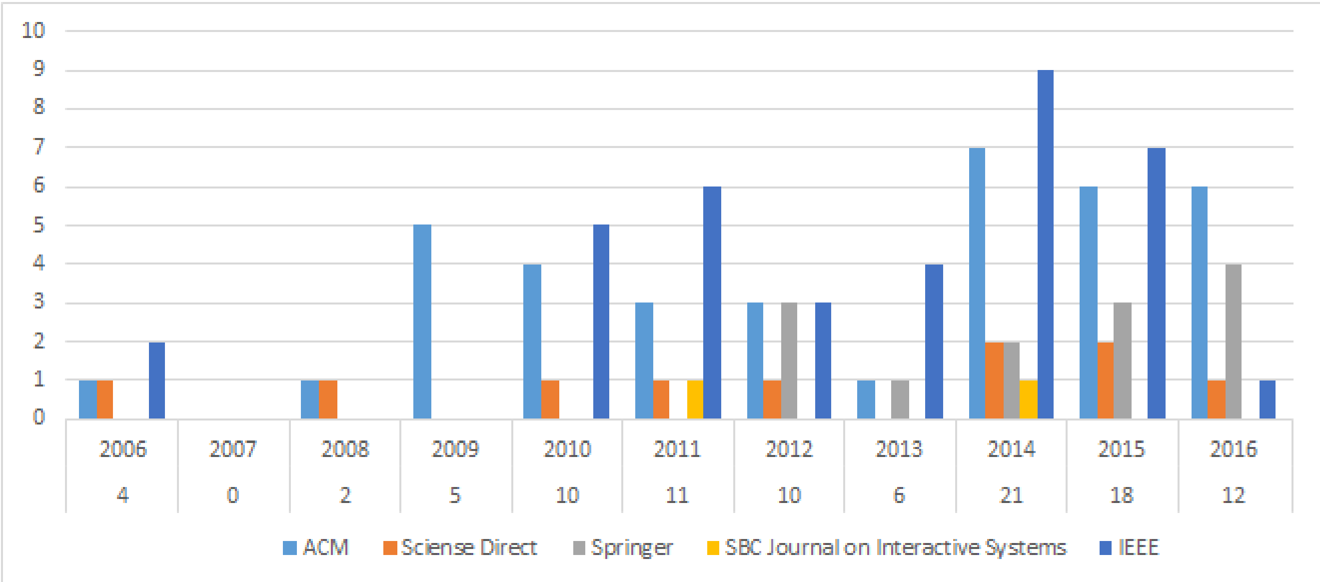

Fig. 1. Publications categorized by year.

A. Assistive technology

From the studies categorized as assistive technology, some were related to communication or interaction disorders. Studies in this area generally present initiatives to assist or investigate a specific target audience. Some examples are children with severe speech and physical impairment; people with motor difficulties; quadriplegic people; people with intellectual and development disabilities; elderly people with varying degrees of dementia or suffering from chronic diseases; people with speech, hearing or visual impairment; children with learning difficulties (dyslexia); children with cognitive and spastic disabilities; children with Autistic Spectrum Disorder; people with various communication difficulties caused by cerebral palsy, Parkinson disease, Down syndrome, among others. Other examples are students with disability; individuals with aphasia (disruption of the formulation and understanding of the language); and people with deficit of prosody (relative to the good pronunciation of the words).

B. AAC

The mapped studies investigate assistive technology via mobile devices and present challenges to be overcome. For instance, Moffatt et al. [11] cite as future study to: keep focus on communication, not technology; develop innovative approaches to service delivery for AAC; ensure easy access for individuals requiring AAC; and to improve AAC solutions to support a wide variety of communication functions.

Tab. VII presents some examples of studies that deal specifically with applications for AAC, whether proposing a new application or evaluating existing applications.

The cited studies present solutions aimed at supporting people with communication difficulties to express themselves, to be understood and to perform routine activities in a more facilitated way. Habitually AAC systems such as cited in Babic

TABLE VII
EXAMPLES OF PAPERS FOCUSING ON AAC

1	Development and evaluation of a mobile application for a personal narrative system to children with severe speech and physical impairment. [21]
2	Application for deaf people, people with language disorders, or non-native language users to report emergencies by means of icons or pictograms. [22]
3	Design and implementation of a mobile interface using an input device via Morse code. [19]
4	Application to support tutors who employ applied behavior analysis in people with Autistic Spectrum Disorder, based on AAC and discrete trial training (method of teaching in simplified and structured steps). [23]
5	Study about assistive technology and how they can provide greater independence and integration of their users with the community. [24]
6	Application that allows direct communication via voice and SMS, allowing control of smartphones and home appliances using NFC (Near Field communication), a wireless technology that allows the exchange of information between compatible devices close of each other. [18]
7	Evaluation of high technology AAC devices and their use by individuals with aphasia. [11]
8	Application that allows to create sentences from (i) embedded predefined symbols in the application or (ii) new user generated symbols added manually to the application using a symbol editor. [29]
9	Device designed to assist deaf-blind individuals to communicate by means of an intelligent glove that translates the Braille alphabet into text, and vice versa, and communicates the message via SMS to a remote contact. [37]
10	Project for developing an AAC cloud system, adopted in classroom for teaching and learning for children with ASD in Hong Kong. [28]
11	A software development process model for implementing AAC applications, which suggests some specific principles to be followed to successfully implement accessibility features. [11]
12	Mobile application for children between 3 and 12 years with alternative communication function and reading tool that shows the spelling of the word being heard. [25]

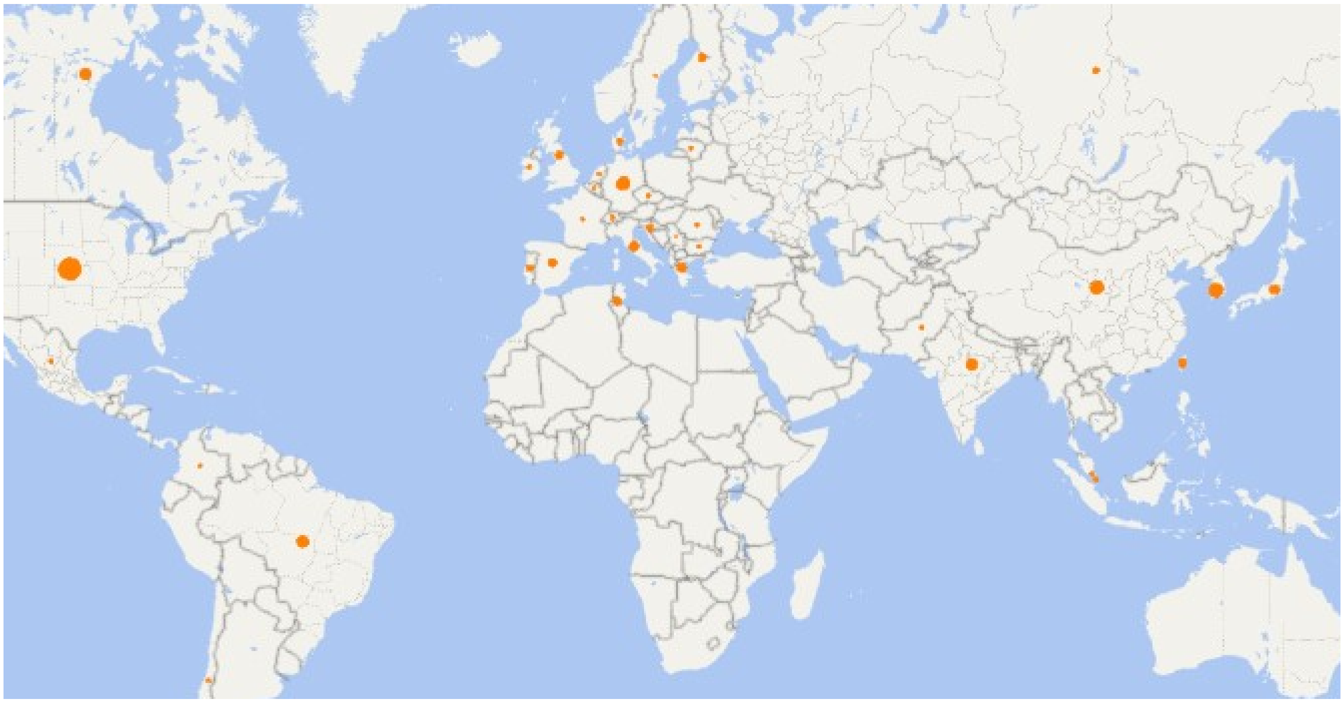

Fig. 2. Publications categorized according to the country of author's institution.

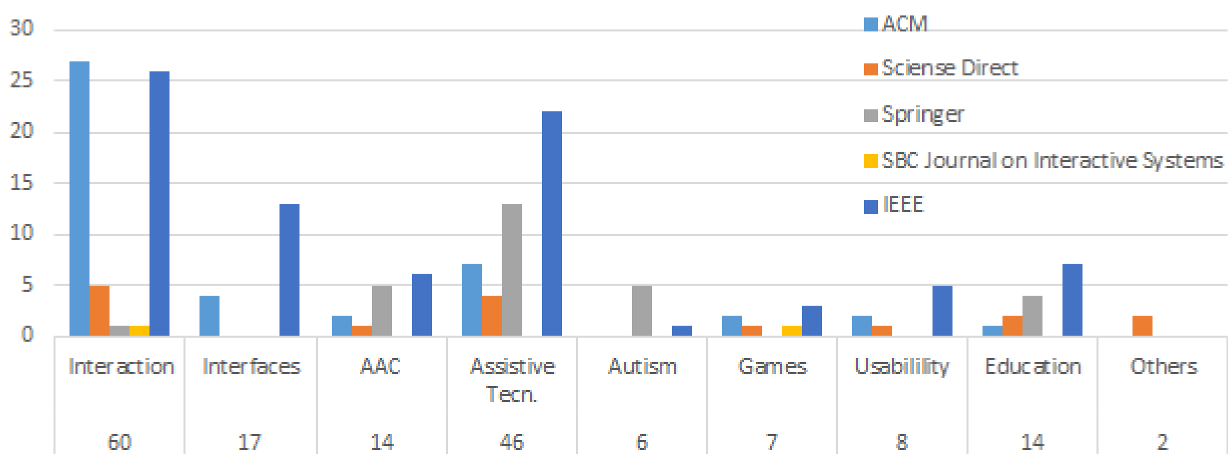

Fig. 3. Publications categorized by subject.

et al. [29], are based on the use of symbols, represented in the form of user-created icons, or in the form of pictograms used in traditional AAC systems. Voice output communication aids and speech generating devices have also been combined with new technology to generate more efficient systems.

Tab. VIII presents some devices and applications for AAC cited in the publications read, followed by some characteristics obtained directly from the publications and on websites of suppliers or manufacturers.

C. Mobile computing interfaces

Tab. IX presents some interfaces for use in mobile devices. The described studies are intend to increase user experience on mobile devices by moving from traditional touch interaction to more accessible and easier to use interfaces.

D. Education, teaching and learning

Individuals with communication / interaction disorders may present learning difficulties and / or interaction problems in the school environment. Although not the main focus of the mapping, it was possible to identify in the read studies, some research that approach this subject (Tab. X), even if they are not directly related to the AAC theme.

AAC can improve communication and increase children vocabulary knowledge [110]. It has also shown positive effects and can improve interactions with typically developing

TABLE VIII
EXAMPLES OF APPLICATIONS AND DEVICES FOR AAC

PhotoTalk (Cited in [11])	Application that allows people with aphasia to capture and manage digital photographs to support face-to-face communication.
Komunikator + (Cited in [29])	Application that allows to combine phrases and sentences using symbols that can be captured by an integrated camera, device image gallery, or symbols from three non-commercial galleries (ARAASAC, Mulberry, and Scler).
GoTalk (Cited in [23])	Introductory recording communication device which is useful for beginning augmentative communicators.
Activity Pad (Cited in [23])	Communication aid with a microchip so different layouts can be personalised for different contexts. Uses voice output, visual stimulation and tactile activation.
Dynavox (Cited in [23])	Speech generating device that creates a spoken message from a picture that is tapped by the user or a message that is typed into the keyboard, but can also track eye movement and puffs of air.
Proloquo2Go (Cited in [11] [21] [24])	Application that provides natural sounding text-to-speech voices, high resolution up-to-date symbols, automatic conjugations, a default vocabulary, word prediction, full expandability.
TapToTalk (Cited in [25] [47])	Application that renders smartphones and tablets into AAC devices. It helps these children communicate and interact with their mobile gadgets by tapping pictures and repeating what is said.
Lingraphica (Cited in [11] [28])	Speech-generating device that exploring familiar scenes to practice words and build functional communication messages. Use of symbols in storyboarding.
Tango (Cited in [23])	Communication aid that allows you to record the actual voice and actions through video to be relayed to the communication partner. It helps in understanding the emotional context of a message.
AutisMate (Cited in [24])	Application that enables the user to personalize the content, applying it to relevant skills and life experiences that users need to learn. Uses a hybrid approach of grid-based and visual scene display technology.
DynaVoxXpress (Cited in [18])	Handheld augmentative communication device, it delivers a full range of communication capabilities and offers optional web capabilities for surfing the Internet, copying images from web pages and sending email.
Gateway (Cited in [18])	Research-based core word vocabulary designed for users of AAC systems. It includes both text and symbol-based vocabularies that are combined with spelling and word prediction to accommodate the needs of both literate and non-literate users.
MinSpeak (Cited in [18])	Semantic compaction system in that pictures take on multiple meanings, which when linked together in short sequences, create words, phrases and sentences.
Tellus Smart (Cited in [11])	PDA with pre loaded Communication Aid software.
Vantage (Cited in [11])	Is a touch screen for access, and can compose message through combining icons and use of the keyboard. It is a medium weight device, but portable.
Gus Communicator (Cited in [11])	Device that offer a broad range of tablet based speech packages.
TalkRocketGo (Cited in [11])	A mobile AAC device for iOS and Android that helps people with Autism, Crebral Palsy, Stroke, Traumatic Brain Injury, Parkinson's (and others) speak out loud.
SmallTalk (Cited in [11])	Application that provides a vocabulary of pictures and videos that talk in a natural human voice. It allows to personalize and expand the vocabulary by using Lingraphica. Also contains mouth-position videos for practice and self-cuing.
VocaBeans (Cited in [11])	Helps people with speech conditions to communicate. Each VocaBean is a picture and sound representing a word or phrase.
SentenceShaper (Cited in [11])	Communication system designed to allow people with aphasia to create sentences and even narratives in their own voices. It can be used for both communication assistance and language therapy.
TalksBac (Cited in [11])	AAC system word-based and exploits the ability of some nonfluent individuals with aphasia to recognize familiar words and short sentences.
PROSE (Cited in [11])	A gesture to speech AAC app based on a social construct of conversation. Supported interactive storytelling, allowing users to control the narration of a story instead of delivering a monologue.
XTag (Cited in [11])	Supports the retelling of past experiences via a tagging and sharing application that couples picture taking with extra information such as mood and location.
Camelandar (Cited in [11])	Provides a structure for organizing and sharing these daily life stories.
Storytelling application (Cited in [11])	For individuals with expressive aphasia, application that supported social exchanges through a multi-modal tablet-based interface that supported taking photographs, making drawings and annotations, and recording sounds.

peers and consequently social communication [111]. However, practitioners still face challenges in deploying new technology in the classroom [112]. AAC requires a multidisciplinary approach [113]. According to Light et al. [114], to truly harness the power of technology, rehabilitation and education professionals must ensure that AAC intervention is directed not by the devices but by the individual's communication needs.

E. Mobile interaction

Most of studies resulting from the map presented some form of interaction in mobile devices: 57 publications were categorized according to the main theme and are presented in Fig. 4. These interaction modalities represent possible ways of interacting with mobile devices and can be combined to explore the concept of multimodal interaction in AAC systems.

It has been found that interactive, multi-sensory interaction and the integration of different technology present great potential to improve the user experience on mobile devices.

F. Games, Autism and Usability

It was noticed that multimodal interaction on mobile devices can be explored in several ways as assistive technology: Cakic et al. [36] developed a device that can be used for data

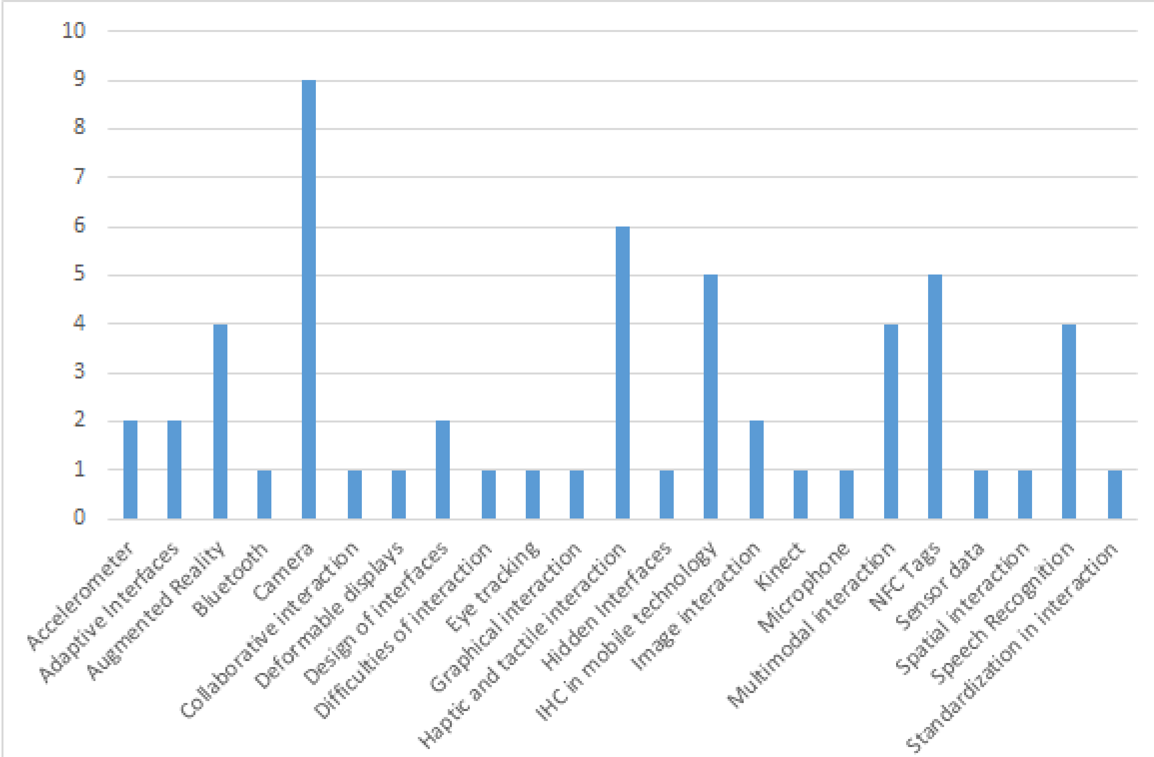

Fig. 4. Publications focused on interaction categorized by topic.

TABLE IX
EXAMPLES OF MOBILE COMPUTING INTERFACES

1	Portable physical feedback system that employs Bluetooth communication and OSC (Open Sound Control), allowing mouth-shape recognition and sound-level analysis to generate and deliver the act of blow as a sense of touch to the other party, generating an expanded mode of interaction. [65]
2	Virtual interface trackpad that tracks user input on any surface near the mobile device and extends the reach of the interaction over the touchscreen, uses the sound source localization technique and adopts the acoustic signal as the main means for interaction. [66]
3	Development of intelligent jewelry, which removes the disconnect between the wearable and the screen and focuses on the positive psychological, tactile and performative aspects. [67]
4	Design of an eye tracker to reduce the need for eye tracking detecting and computing, estimating the look by using a small subset of pixels per frame. [68]
5	Interface for mobile phone devices using Morse code by means of a unique key as an adapted access communication tool, allowing users with physical disabilities to be able to make / respond to phone calls or send / receive SMS messages. [19]

acquisition during movement to estimate kinematics in humans with motor impairment; Jeet et al. [41] proposed a prototype system that can provide a hands-free remote control for people with quadriplegia who do not have to send verbal commands for the selection of home appliances; Kostikis et al. [55] describes a smartphone-based method for detecting and quantifying hand tremor associated with movement disorders using accelerometer signals and gyroscope embedded in the users's phone; Xia et al. [74] proposed the concept of multimodal vocal interaction "Voz-TouchVision" based on multi-touch interaction and corresponding visual graphics; Yamamoto et al. [63] has developed a speech-input-driven embodied interaction mobile phone with a Narikiri-headset to reflect users' head movements and actions directly in InterActor (character) by an acceleration sensor and a gyro sensor.

In this context, to manipulate data from several sensors used in mobile devices requires a structure for storing, merging and processing this data. Billen [78] proposed a structure like this considering GPS, light, accelerometer, gyroscope and orientation of mobile device. Some papers explored the use of sensors of devices for mobile interaction: accelerometer [69] [106] [26]; microphone [88]; camera [79] [98] [100] [60] [39] [40] [103]; Kinect depth sensor [61].

Some papers employed augmented reality on mobile devices, to design a serious game [70], to generate a new architecture [99], and to provide immersive experiences [97] [73]. This technology can be used to motivate and stimulate the use of AAC, or to aid in the learning of important concepts related to this theme merging virtual objects with real-world images. In addition, computer vision technology can recognize hands-free gestures from live images to allow intuitive interactions, such presented in Yang et al. [64].

Collaborative interaction, such as proposed in Kambona et al. [83] can also be explored to aid the knowledge acquisition or to stimulate the practice of AAC.

Interesting study opportunities have been identified, such as deformable displays [77] that can physically mutates to better

TABLE X
STUDIES RELATED TO EDUCATION, TEACHING AND LEARNING

Skiada et al. [71]	presents a mobile application to promote learning and help children to improve some fundamental skills, such as reading comprehension, spelling, short term memory and solving mathematical problems.
Bereznak et al. [44]	analyzes the acquisition of day-to-day skills of students with ASD by using prompting video.
Epp [46]	presents a tool to support mobile assisted language learning.
Guerrero et al. [72]	presents a collaborative learning activity and a mobile software tool to support grammar teaching for primary school students.
Basit et al. [35]	talk about learning of Quran and related subjects on mobile devices, discussing the problems faced by blind individuals in using such applications.
Ismaili et al. [47]	investigates the potential of using smartphones and tablets as alternative learning tools for assistive technology devices in formal and informal learning environments.
Mehigan [69]	talk about mobile learning system for assist in the learning of blind and visually impaired people.
Salazar et al. [70]	presents a serious game designed to teaching concepts about cybersecurity using augmented reality.
Yang et al. [64]	talk about gesture interaction for learning.
Villamarin et al. [58]	talk about learning of gesture language by deaf people.
Jung et al. [20]	uses a focus group with dyslexia and other specific learning difficulties to design sets of user-defined gestures to invoke commands on a smartphone device.
Kouroupetroglou et al. [48] [49]	presents research in the field of universal design for learning, showing that mobile assistive technology applications should involve all students, including those with disabilities, in collaborative learning, reasoning, and problem-solving activities.
Schoen et al. [53]	evaluates the feasibility and acceptability of the SpeechPrompts mobile application, developed to aid in the treatment of prosody deficits in children with ASD and other speech disorders.
Recha et al. [57]	describes an initiative to support children with ASD to learn how to speech, and propose a machine translation device for sign language.
Dekelver et al. [45]	analyzes intellectual and development disabilities categories and describes particularities of mobile software design for each category.

represent the on-screen content; haptic and tactile Interaction [82] [91] [92] [33] [34] [62] with the aim of improving and enriching user interactions when the visual channel is blocked or restricted (for example, for blind or mentally disabled users) or helping to reduce the visual demand associated with the use of mobile applications, allowing the transmission of important information while users' hands and eyes are otherwise occupied; use of NFC tags for classification of NFC-based interaction techniques [76] [59], self-reporting for patients [42], or to controle a smart-home [18] [32] [22]; hidden Interfaces [87]; adaptive interfaces [84] [93]; speech recognition [102] [12] [74]; eye tracking [13].

Some papers presented studies related to design of interfaces for mobile devices, such as a study proposing six rules that should be considered in the design of mobile interfaces [80], and a study describing how to design applications for different cultures [101]. As mobile design exists in a global networked culture, it is important to adopt a cross-cultural perspective when designing technology in these contexts,understanding the shared psychology of mobile users.

Regarding the difficulty of interaction with mobile devices, a study evaluates and reports the difficulties of interaction of quadriplegic people with the touchscreen [31].

In order to standardize the interaction in mobile devices, one of the papers presents a concept of mobile-gesture, platform-independent notation, called Monox (MObile NOtation - eXtensible), which provides a common basis for collaborative design and interaction analysis mobile [81].

V. DISCUSSION

Based on the mapped studies, the research questions defined for this systematic mapping study were answered.

The main question in this study aimed at identifying the recent instruments available for practicing AAC via mobile devices and the possible modalities of interaction was answered. The mapping presented instruments that are used as assistive technology, either in AAC applications or for other purposes, as shown in Tab. V. Likewise, with respect to modalities of interaction and computational interfaces, it was possible to verify the wide variety of possibilities which are already being used, as shown in Fig. 4 and Tab. IX.

For each question presented in Table 1, an answer was elaborated based on the information extracted from the mapped studies. As regards to Question 1) What are the recent modalities of interaction used on mobile devices? There are currently many options for mobile interaction offering different degrees of accessibility. Among the interaction modalities identified are: augmented reality, multimodal interaction, speech recognition, look tracking, mobile device sensors, adaptive interfaces and attention/standardization in interface design. The human interaction with the world is inherently multimodal [115]. Thus, there is a growing effort by the scientific community to leverage human communication skills by means of speech, gestures, touch, facial expression and other modes of communication with interactive systems [116].

Considering that humans interact with the world mainly by means of their main senses (sight, hearing, touch, taste and smell), the goal of research in this area is to develop technology, interaction methods and interfaces to eliminate existing limitations by using these together for a more intuitive user interaction. The development of multimodal interaction between humans and computers tries to address problems such as the selection of gestures or emblems that have similar meaning in a world audience (due to the existence of several cultures), proposing a reduction in the number of misinterpretations by means of the integration of types of interaction. As reported by Fernandes et al. [117], multimodal interaction area gained special relevance with the appearance of low-cost body and gesture recognition / detection devices associated with video game consoles such as: EyeToy1 (Playstation), Wii Remote or Microsoft Kinect (Xbox). More recently, a diversity of console-independent devices are becoming readily available, which can be acquired by end users and connected to multiple processing devices, more independently of manufacturers, but also more specialized in certain aspects of interaction and reduced cost. Examples of such devices are presented in Fernandes et al. [117] and include Leap Motion or Parallax Si1143 which allow the identification of finger gestures using images taken by infrared cameras and the Myo bracelet, which identifies gestures by detecting electrical activity in the user arm muscles, a technique known as electromyography. Parallel to low-cost gesture interaction, virtual reality and augmented reality have experienced a resurgence by means of low-cost immersion monitors and augmented reality glasses. Very little is known about how students with special needs can use mobile devices with augmented reality, for example. According to Fecich [118] this is a fundamental research topic to be explored, because it brings awareness not only to the field of special education but also considers the development of the field of educational technology in research and in the elaboration of a study with this student population.

Considering the Question 2) What are the limitations of the existing studies aimed at practicing AAC by means of mobile devices in terms of interaction? People with disabilities often need support tools for AAC purposes in their daily lives and often the interaction with mobile devices is a big challenge. Most commercially available technology AAC is primarily designed to support transactional communication such as voice needs and desires (”I am thirsty”), and computing power is primarily used to allow physical access (e.g., control by the look) or to improve the voice (by means of the technology Text-to-Speech). There is little use of computing power to improve access to words and phrases for personal narrative, an essential part of social interaction. Word selection and phrase building, content storage and retrieval with all of their associated cognitive requirements are still left out. Although there are many digital products available for AAC, they are often expensive, inflexible, and difficult to use: training is required to configure and customize, making it difficult for responsible or caretakers to do so. It was identified that many options are currently available, but these are not used; even the application considered as an industrial leader is used by less than 5% of the people who could benefit from it [11]. The question remains unanswered: why, despite decades of development, these devices do not meet the needs of their target audience?

Concerning Question 3) Are there specific methodologies to stimulate AAC practice in mobile devices? What modes of interaction are employed? No study presenting a methodology for the practice of AAC in mobile devices was found. This result suggests a gap in literature and a demand of studies for this purpose, or even that the ”methodology” nomenclature has not been used to define studies related to the definition of ways to conduct practices of AAC. Some studies focused on participatory design methods, such as the papers of Borges et al. [119] [120] [121] are related to this question, but were not included in this mapping because of differences in the keywords used by the authors. Such studies focus on the inclusion of stakeholders with disabilities in participatory design practices to conceive customized assistive technology. As the papers suggest, participatory activities are promising for designing solutions to the practice of AAC.

Regarding Question 4) What types of computer interface are currently available to facilitate the interaction of users with mobile devices? Devices and alternative input methods are used to make computers accessible to users with compromised movements or other difficulties. Among the types of computational interfaces identified in the mapping are interfaces used to simulate the act of blowing, to extend the reach of the interaction on the touchscreen, intelligent jewelry, unique key to use Morse code, among others. Selecting an assistive interface requires maximizing the flow of information and minimizing the effort (physical and mental) to use it [122]. Current alternatives include non-invasive brain-computer interfaces, eye tracking, electromyography, sip-and-puff (blowing), voice commands, chin control, head control, mouth joystick and tongue control [123].

A possible perspective for the concept of accessibility is strongly related to the idea of Universal Design, which refers to making things as accessible as possible for a group of people as broad as possible. Regarding question 5) Are aspects of Human-Computer Interaction considered? How? Studies recognize that the development of systems and interfaces for assistive technology is particularly challenging from the IHC point of view. What would functionate for a general population cannot be assumed for some intended user groups [90]. It is particularly important to consider perspectives of users and their caregivers to develop something that functionate for them. Two of the most important requirements of a system to support the interaction between a disabled user and a mobile device are: flexibility and configurability to allow a fine personalization depending on the needs and conditions of the user. In addition, one of the main problems of smartphones is represented by their complex user interfaces, composed of many small icons and input methods that depend increasingly on keyboards via software, multi-touch or gestures. These mechanisms are particularly heavy for users with perceptual, motor, or cognitive impairment who may not be able to select an area of the screen with sufficient accuracy or with the requested time. 8 of the mapped studies cite the application of specific HCI techniques, such as user-centered design methods; and user-centered communication (puts human nature and its needs at the center of the design, implementation, and evaluation of communication systems and technology). Usability is also cited in these publications, and some studies focus exclusively on this theme associated with mobile technology.

Finally, as regards to Question 6) What applications have been used as assistive technology to help people with communication difficulties? In addition to the AAC applications presented as a result of the publications read, there are some applications and devices used for AAC, cited in these publications, presented in Tab. VIII.

The mapping shows some points need to be better explored for the benefits of AAC, which can be useful in the context of universally accessible learning. For example: 1. investigating pervasive computation associated with AAC; 2. identify the reason why existing applications are not being used by people with disabilities; 3. generate a methodology to help developers design effectively accessible AAC solutions; 4. Generate a methodology that stimulates the practice of communication construction considering the user with communication problems or their relatives as central stakeholders; 5. employ computer vision techniques to make the use of communication boards more attractive. All of these actions can help people with communication disorders exercise their communicative abilities, influencing affective, emotional aspects and, consequently, contributing to their education and learning.

Based on the mapped studies, it was noticed that most of the existing solutions are employed and focused on specific situations and offer little flexibility and adaptability, essential characteristics for accessibility. The use of mobile devices carries less stigma than traditional AAC devices, but in return, demands greater care with interface design and forms of interaction. Thus, the multimodal interaction in adaptive interfaces, informed by IHC theories and good practices, seems to be a promising option for AAC applications to provide their users independence and competence in their communicative functions.

With respect to adaptability, an important point to be studied and that requires continuous improvement is related to the use of AAC systems by people who have, besides communication disorders, motor difficulties. Regardless of the origin of the motor problem, it is common these users to present abnormal postures and involuntary movements that sometimes may be uncontrollable, making the use of various interfaces unfeasible. Several studies have been developed to generate alternatives for these users to interact with computer systems. From the results of the mapping, it is possible to highlight the studies of Cakic et al. [36] and Kostikis et al. [55], which in different ways seek to analyze the movements made by people with motor disabilities. Other approaches use a combination of different technology, but it is still difficult to find interfaces that can be controlled by people with pathological movements, such as spasms or tremors. Since users with motor difficulties have involuntary movements, it is necessary to design processing algorithms to separate voluntary movements from involuntary movements. This means that it is essential to define the particularities of these users because they will not be able to control interfaces in any other way, even if the technology are very sophisticated.

VI. Conclusion

This paper presented a systematic mapping on modalities of interaction in mobile devices associated with AAC, which resulted in the reading and categorization of 99 publications. The main objective was to provide an overview of what has been investigated in the context of this area. The results of this mapping can be useful in conducting research in the area of AAC, exploring the potentialities of mobile devices based on the theoretical and practical tools reported in the publications described. In this way, the aim is to help the AAC to effectively serve people with communication or interaction difficulties, whether in the school environment or in the performance of their daily activities, taking into account their individual needs. Among the main conclusions of the mapping, it has been identified that it may be useful develop a methodology or process to perform the practice of AAC in mobile devices exploring different modalities of interaction. There is a great potential in current technology to provide flexibility and adaptability in mobile devices, enabling information sharing and continuous learning. By strengthening human interactions, their capacities and cognitive abilities are expanded, allowing new and more elaborate learning, contributing to their social inclusion.

Acknowledgment

The authors acknowledge the financial support of CNPq by means of the so-called MCTI-SECIS / CNPq N 84/2013 - Assistive Technology.

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ISSN: 2236-3297