Systematic Literature Review of Internet of Things Solutions Oriented to People with Physical and Intellectual Disabilities

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Abstract: The Internet of Things (IoT) has become a revolutionary technology. It allows hundreds of devices to connect and collect information, send and receive data over the internet, and other activities. The IoT has been applied in various fields; one of them is to support people with disabilities. The interconnection of devices has allowed people to develop activities autonomously, improving their quality of life. Although it is an emerging technology and there are several secondary studies about the collection of evidence on IoT devices, very few are applied to people with disabilities. Based on the systematic review results, taxonomies related to the addressed topic determine research gaps for scientific progress and non-duplication of existing solutions. Thus, this article present the planning stage of a future study presenting IoT solutions applied to people with disabilities, aiming to answer the following research question: *What Internet of Things solutions exist for people with disabilities?* The results are presented, and the discussion describes the principal features of the IoT solutions oriented to people with physical and intellectual disabilities.

1 INTRODUCTION

Worldwide, more than 1000 million people suffer some kind of disability, of which between 110 and 190 million have affections that limit their daily tasks. Unfortunately, these numbers rise due to the aging population and the increase in chronic diseases globally (OMS, 2017). In Ecuador, there are 418.392 people registered with some kind of disability, from which 46,34% represents the people with a physical disability, 22,60% with intellectual, 14,05% auditory, 11,60% visual, and 5,41% psychosocial problems (CONADIS, 2020). These numbers indicate a fairly wide percentage of people who need assistive technologies to preserve their independence as much as possible and support health personnel during their activities. Moreover, according to Holloway and Dawes, people with disabilities can be helped by assistive technology to improve their well-being (Holloway & Dawes, 2016).

In this context, the IoT solutions could provide assistive technology based on connecting everyday objects to the internet. IoT devices and components exchange and process information collected through sensors and provide value added services to end-users (Barrio, 2018). Therefore, people with disabilities and health personnel can be supported by IoT technology, which can solve problems in several areas.

Health is one of the most popular fields supported by IoT, it plays a very important role in improving the precision, reliability and productivity of the electronic elements used in this area (Joyia et al., 2017). Also, in the disabilities scope it has also provided support and improved the quality of life of people with visual, hearing and physical problems, among others, since it has proven to be a powerful tool that contributes to the independence and participation of people (Domingo, 2012). In the context of the mIoT (medical Internet of Things) and disabilities, several technological solutions for people have emerged, which have been oriented towards the design of assistive technologies and improved rehabilitation practices (Holloway & Dawes, 2016). There are a wide variety of tools created using IoT technology. Thus, it is necessary to condensate their existence in a study that evidences the existing solutions into a

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secondary contribution, which provides insights for engineers, researchers, and health personnel.

This study aims to carry out a systematic literature review that addresses the information and answers the following research question: "*What Internet of Things solutions exist for people with disabilities?*". This question will be answered by focusing on the extraction criteria and the final discussion on how IoT solutions support, enable or improve various problems whether they are minor, moderate or severe. Also, defining how the IoT technology benefits children, adolescents, adults, older adults, among other actors from the health area. All of this emphasizes the kind of support, the type of instruments created, and the patient's characteristics.

Finally, this paper is structured as follows: Section 2 presents the related work, where it has been explained the existence of secondary studies related to IoT devices to disabilities. Then, in Section 3, the systematic literature review is presented, its protocol, execution and results; finally, Section 4 presents the conclusions and further work.

2 RELATED WORK

Over the years, systematic reviews have addressed IoT-related topics in various fields. On the one hand, some reviews emphasized general aspects of IoT technology; for example, Madakam, Ramaswamy & Tripathi (2015) provided an overview of IoT architectures and their use in people's daily lives; however, they do not emphasize solutions for people with disabilities. Other reviews, such as the one presented by Aqeel (2020) and Tiwari (2017) presented a complete overview of the components of IoT and various security problems typical of emerging technologies. These studies represent a significant contribution because they are focused on determining the high degree of trust in IoT applications. However, similar to previous authors, those studies do not address IoT solutions for people with disabilities.

On the other hand, there are studies focused on the use of technology for disabilities, such as the study by Colpani & Homem (2015) in which they perform a systematic review related to the treatment of disabilities with technology, gather virtual reality solutions and augmented reality for the treatment of people with cognitive impairment. Also, Cedillo, Sanchez, Campos & Bermeo (2018) proposed a secondary study on Ambient Assisted Living (AAL), which seeks to establish hardware and software relationships that solve specific disabilities. Although there are secondary studies that collect health-oriented IoT solutions; the existing literature on IoT solutions for people with disabilities has not been addressed, nor has any classification been presented to guide the healthcare professional in selecting the best IoT device to support their clinical activities.

3 THE SYSTEMATIC LITERATURE REVIEW

A systematic review of the literature seeks to follow a scientific, repeatable, and replicable method to collect information on a specific topic. It is necessary to follow a set of tasks to get a solid foundation and potential gaps in the field of study. For this specific case, the topic is related to IoT solutions focused on solving problems for people with disabilities. This study follows the Kitchenham & Charters (2007) methodology, which covers the three phases: (i) planning the review, (ii) conducting the review, and (iii) the review report.

Finally, this paper is structured as follows: Section 2 presents the related work, where it has been explained the existence of secondary studies related to IoT devices to disabilities. Then, in Section 3, the systematic literature review is

3.1 Planning the Review

The following sub-tasks or activities make up the planning stage: 1) defining the research questions, 2) the strategy to be followed for the search of primary studies, 3) establishing the criteria for the selection of primary studies, 4) assessing the quality of the studies, 5) establishing the data extraction strategy, 6) defining the synthesis strategy.

3.1.1 Research Question

Here is stated the question that covers the entire research. For this study, the main research question is: "Which Internet of Things solutions exist for people with disabilities?" In order to answer this question, the following sub-questions are also defined:

- RQ1. Which disabilities have been supported by IoT technology?
- RQ2. What kind of IoT devices and applications are the most used in the IoT area for health care?
- RQ3. How have studies of disabilities that rely on IoT technologies been addressed?

3.1.2 Data Sources and Search Strategy

The search strategy will be performed in two different ways: automatic search and manual search. Automatic searches require a combination of words based on the research questions, and manual searches are applied in relevant conferences, journals, and books.

For the automatic search the following digital libraries have been selected: IEEE Xplore Digital Library because it is a research database on Computer Science, Electrical and Electronic Engineering applied to various areas; ACM Digital Library, which has a complete collection of articles that cover fields of computer science and information technology: and, lastly, PubMed featuring biomedical and life science literature. The search string defined to retrieve the articles from the mentioned libraries is: *(Disability OR Handicap) AND (Internet of Things OR IoT)*. In order to obtain a more significant number of existing solutions and to be able to evaluate them later, it will be carried out according to the methodology of Kitchenham (B. Kitchenham, 2007), which proposes that the search be performed considering coincidences in the title, abstract and keywords and if the library allows it in the complete text. This string will be adapted to each digital library.

For this systematic review, all scientific articles were considered regardless of their year of publication, this for two reasons, on the one hand, IoT technology is emerging and, on the other, being an exploratory study, it seeks to find the development milestone of IoT suitable for disabilities.

Additionally, the journals were the manual search was performed were Disability and Rehabilitation: Assistive Technology Journal (Q2), Technology and Disability (Q4), for the conferences the selected ones were VAAT, i-CREATe, W4A'18 and ICSC . They provide relevant studies on technology and disabilities. This search was performed to complement the automated search to cover the cases in which the conference proceedings or journals did not appear in the digital libraries.

3.1.3 Extraction Criteria

This strategy will attempt to answer each sub-question raised in the research. The strategy will ensure that data extraction criteria are met and will also facilitate classification. The complete list of extraction criteria is presented in Table A at the following URL: https://n9.cl/dis3.

Selection of Primary Studies. The articles must go through a selection process, there they will be evaluated by different established inclusion and exclusion criteria. All the excluded articles will be considered to verify the inclusion and exclusion criteria among the research group's people.

Inclusion criteria: Studies that meet any of the following criteria will be included in the research:

- Studies dealing with related topics on the Internet of Things for health intervention to people with any disability.
- Studies containing Internet of Things technology architectures and solutions for people with disabilities.

Exclusion criteria: The articles that will not be considered in this study are:

- Articles dealing with disability and technology but not oriented to the Internet of Things.
- Duplicate studies, in which case the complete study will be chosen.
- Short papers (less than five pages)
- Studies that are written in a different language than English.

Quality Assessment. Two aspects have been considered to evaluate each study's quality: i) The relevance of the conference or journal in which the article is published. In this case, the articles have been classified into three categories, as shown in the web annex, Table B. ii) The number of citations the article has. The classification is also done in 3 categories: high, medium, and low. Citations are considered, according to Google's academic citation count. To not penalize potentially useful papers, they have been classified according to the year, as shown in the web annex on Table C and Table D. The URL to access the web annex is: https://n9.cl/dis3.

3.2 Conducting the Review

Preliminary results are presented in Fig 1. Selected studies were chosen after applying the inclusion and exclusion criteria. In total, 104 articles were obtained, of which 19 were selected. Of these, 12 are from IEEEXplore, four from PubMed, two from ACM, and one from manual search.

3.2.1 Methods of Analysis and Synthesis

The analysis methods and synthesis show the systematic review results; the statistical tables show individual results of each criterion concerning the number of studies that speak or are related to that subject, which can be seen in this link:

https://n9.cl/g82cj. The bubbles presented on Fig. 2 and Fig. 3 are generalized results.

Synthesis and Results. Results are presented in Fig.2 and Fig. 3. These figures are represented by a pair of coordinates (X, Y). Fig. 2 shows the axis of the ordinates represented by EC3: Population, in the axis of the abscissa, is represented by EC 7: Use of IoT. Then in Fig.3. EC1 represents ordinates axis: Type of disability, and EC7: Use of IoT; besides, on the axis of the abscissa EC5: Hardware or devices and EC6: Software.

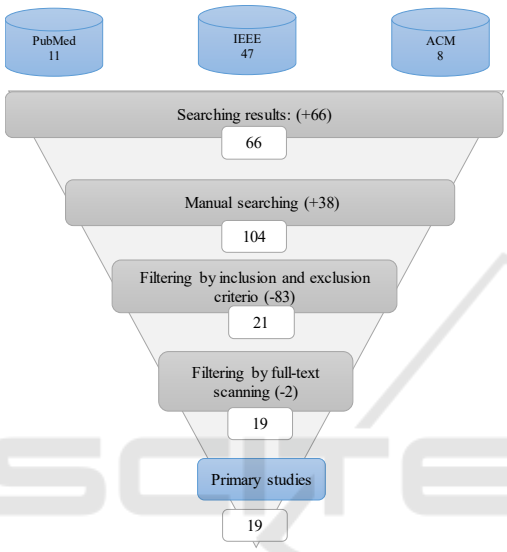

Figure 1: Found papers.

Discussion Criteria per Criteria.

EC1. Type of Disability. Most of the solutions are aimed at people with physical or motor disabilities. Some of them combine with mental or cognitive rehabilitation systems (Alapetite & Hansen, 2017; Brik et al., 2018; Iyswariya et al., 2020; Li et al., 2019). Others emphasize their intervention in disabilities associated with speech difficulties; for example, Malavasi et al. (2017) developed low-cost experimental systems for environmental control through simplified and accessible user interfaces, and many of the activities focus on automatic speech recognition.

While others develop solutions aimed at people with visual disabilities, for example, combine the benefits of the IoT and existing devices such as mobile phones, Husing & Lim (2020) proposed a system called InWalker to extend the typical white cane's functionality. They introduced several new features that improve security and trust among blind people.

Finally, other solutions are geared towards rehabilitation, either at home (Agyeman et al., 2019; Agyeman & Al-Mahmood, 2019) or in clinical environments (Errobidart et al., 2017; G. Postolache et al., 2019).

EC2. Degree of Disability. Regarding the degree of disability, it was found that very few solutions precisely specify this attribute of the population. Two of the nineteen articles indicate that the IoT devices they present are aimed at people with moderate disabilities. Errobidart et al. (2017) offer a prototype that has been installed in a Public Rehabilitation Center. Moreover, Bissoli et al. (2019) point out instead that people with motor disabilities can be supported by employing an eye-tracking solution so that they can control and monitor a smart home; which has a positive effect on their independence; particularly this type of solution is suitable for this degree of disability as it involves the constant need for supervision.

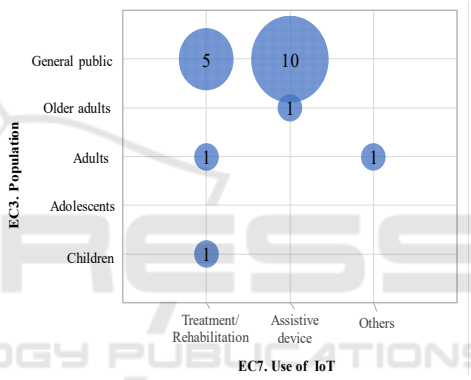

Figure 2: Comparison between EC3: Population and EC7: Use of IoT.

EC3. Age Group. The majority of the research involved in this systematic review is not directed at a specific population group. Aljahdali et al. (2018) directed their study to older adults, in which designed a smart walking assist device for frail and visually impaired people to reduce the risk of falls and costly emergency interventions and hospitalizations; the proposed device is based on the Internet of Things (IoT) concept to determine and communicate the location and path of the person for possible action in emergencies.

Although the study found that the IoT device is aimed at older adults who require particular care, the IoT principle can be used to help the same age group in their daily activities, not necessarily in emergencies. For example, with reminder services, such as taking medicine, turning off the kitchen, closing the window when leaving the apartment, location coordinates of things and people. Other types of monitoring services, such as chronic disease status;

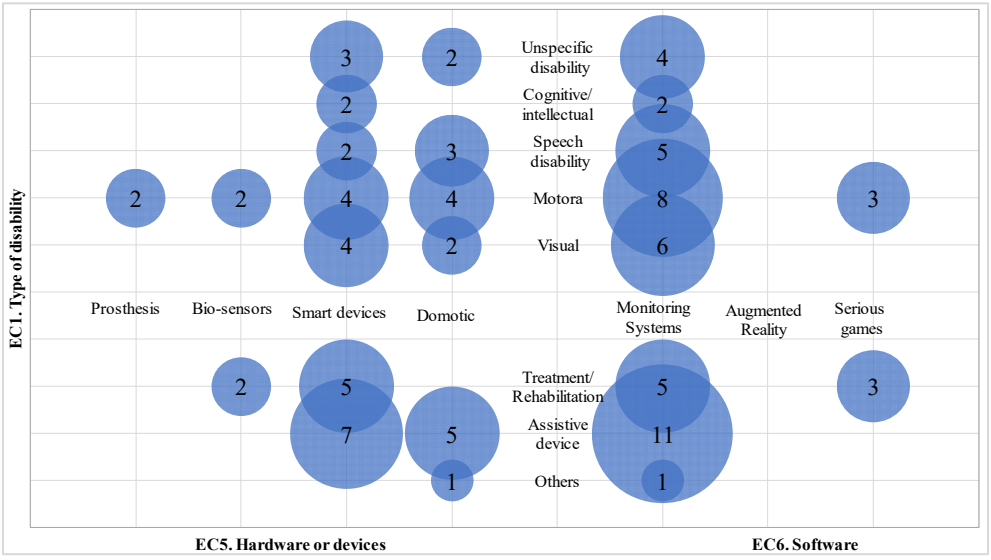

Figure 3: Comparison between EC1: Type of disability, EC5: Hardware or devices, and EC6: Software.

or social services, help maintain contact with other people (Sharma et al., 2013).

Other studies propose solutions-oriented to adults (Li et al., 2019; Postolache et al., 2020). Li et al. (2019) propose *Riobot,* a design tool for generating mechanisms that can connect, motorize, and actuate static objects to perform simple physical tasks; users only need to take a short video to manipulate an object to demonstrate intended physical behavior.

Furthermore, Postolache et al. (2020) develop an IoT device whose objective is to monitor physical rehabilitation. It combines strategies of serious games of virtual reality and wearable sensor network to improve the patient's commitment during physical rehabilitation and evaluate its evolution.

EC4. Type of Solution. In this extraction criteria, it can be seen that it is essential to have software to manage the IoT hardware. That is why all the selected roles have coincided in the same.

EC5. Hardware or Devices. In this extraction criteria, it is showed that most of the solutions have been oriented to the use of smart devices (Agyeman et al., 2019; Agyeman & Al-Mahmood, 2019; Alapetite & Hansen, 2017; Aljahdali et al., 2018; Amiri et al., 2017; Hung et al., 2019; Husin & Lim, 2020; Iyswariya et al., 2020; Mulfari et al., 2014; O. Postolache et al., 2020; Ranjan et al., 2020; Singh et al., 2015).

Alapetite & Hansen (2017) develop devices that can interact with the user through voice and gaze recognition. Other solutions implement wearable technologies with game aids to rehabilitate people with disabilities in the upper extremities (Agyeman & Al-Mahmood, 2019; G. Postolache et al., 2019). Also, daily use objects oriented to people with disabilities has been presented. An example is a smart walking device that helps users walk by themselves (Aljahdali et al., 2018).

The hardware technology that is also widely applied for people with disabilities is home automation, which allows users to function efficiently in their daily activities (Bissoli et al., 2019; Brik et al., 2018; Errobidart et al., 2017; Li et al., 2019; Malavasi et al., 2017; Singh et al., 2015).

Finally, the use of biosensors is a rarely used hardware technology, since, as can be seen in the research carried out, only 3 of the studies are focused on its use (Grigoriadis et al., 2016; G. Postolache et al., 2019).

EC6. Software. Regarding the software, in general, IoT is composed of monitoring systems (Alapetite & Hansen, 2017; Aljahdali et al., 2018; Brik et al., 2018; Errobidart et al., 2017; Grigoriadis et al., 2016; Hung et al., 2019; Mulfari et al., 2014; G. Postolache et al., 2019; Singh et al., 2015). This reality is understandable because biosensors, home automation, and smart devices generate information that needs to be operated from a specific system.

Other articles refer to the use of serious games to treat certain types of disabilities (Agyeman et al., 2019; Agyeman & Al-Mahmood, 2019; O. Postolache et al., 2020).

EC7. Use of the IoT. In this extraction criteria, it is presented that most of the IoT solutions are used as assistive devices. The vast majority of which belong to home automation solutions and smart devices

(Alapetite & Hansen, 2017; Aljahdali et al., 2018; Bissoli et al., 2019; Brik et al., 2018; Chand et al., 2019; Errobidart et al., 2017; Husin & Lim, 2020; Iyswariya et al., 2020; Malavasi et al., 2017; Mulfari et al., 2014; Singh et al., 2015). Moreover, some solutions are oriented to the use of devices for treatment and rehabilitation (Agyeman & Al-Mahmood, 2019; Agyeman et al., 2019; Amiri et al., 2017; Grigoriadis et al., 2016; Hung et al., 2019a; G. Postolache et al., 2019), and, finally, one of the articles was classified as "other", it is because it is a device that allows generating IoT devices for people with disabilities (Li et al., 2019).

EC8. Phase(s) in Which the Studies are based. In the case of the phases of the studies analyzed, the vast majority have gone through the analysis, design, and implementation, but very few have been able to be tested. Some of the articles whose implementation has been tested are those that include home automation solutions or use smart devices (Amiri et al., 2017; Bissoli et al., 2019; Errobidart et al., 2017; Husin & Lim, 2020; Iyswariya et al., 2020; Li et al., 2019; O. Postolache et al., 2020).

EC9. Type of Validation. As for the type of validation, the vast majority have used prototypes, the same ranging from domotics houses to automate and facilitate access to certain features of the houses (Bissoli et al., 2019; Errobidart et al., 2017; Li et al., 2019) to prototypes that include the development of smart devices (Agyeman et al., 2019; Agyeman & Al-Mahmood, 2019; Alapetite & Hansen, 2017; Aljahdali et al., 2018; Amiri et al., 2017; Husin & Lim, 2020; Iyswariya et al., 2020; Mulfari et al., 2014; O. Postolache et al., 2020; Ranjan et al., 2020). Into this minority, the revised articles have been written to deepen the concepts or develop experiments.

EC10. Approach Scope. Even though IoT devices are of great interest to the industry, such as hospitals or are designed for direct users; most of the articles that are part of this work are oriented to the academy This be due to the fact that being emerging technologies, they are not yet in commercial distribution; or, failing that, it is still exclusive for particular sectors, as is the case of smart bulbs by Philips (2020).

Moreover, the solution presented by Grigoriadis et al. (2016) shows an IoT solution-oriented to people diagnosed with multiple sclerosis.

EC11. Methodology. Of the 19 articles reviewed, only one paper is the extension of previous research. Malavasi et al. (2017) develop a solution that is the continuation of an existing project called cloudCAST (Clinical Applications of Speech Technology); the authors present the development of low-cost experimental systems through the use of automatic speech recognition systems, while the other articles reviewed propose their methodologies starting from the design and architecture of their solutions.

EC12. Area of Study. The articles that were part of this systematic review belong to computing and electronics, and they complement the developments with extensive knowledge of the health area, particularly medicine.

EC13. Country. The demographic results show that most studies were originated in India. Iraq, Italy, Portugal, and the USA. Latin American countries like Argentina and Brazil also presents solutions. In this context, this study provides insights into the relationship between a country and the use and study of IoT technology-oriented to people with disability.

EC14. Year. The studies reviewed are on the time range from 2014 to 2020. After it, the year 2014 represents a milestone for developing these devices; this article presents the use of integrated systems for multiple devices in intelligent environments that allow care and support to people with disabilities (Mulfari et al., 2014).

4 CONCLUSIONS AND FURTHER WORK

In this study, the systematic review of the literature on IoT solutions for people with disabilities was presented. It was developed based on the Kitchenham methodology; and, three sub-research questions were raised, which allow to answer the question of *What Internet of Things solutions exist for people with disabilities?*

Among the results, we can highlight that all the solutions found include hardware and software together. Similarly, researchers have focused on the development of home automation solutions to provide greater accessibility to the various elements that homes have. In addition, smart devices have also been developed to make life activities easier for people with specific disabilities, such as mobility or reduced visibility.

The use of IoT technology in treatment and rehabilitation is essential, since this has been achieved by implementing smart devices and biosensors in order to obtain more effective results; primary studies have relevant information. However,

in an extended version of the article, new extraction criteria must be added to better segment the results, such as the term disability, which can be treated as limitations in carrying out activities or restrictions on participation in normal environments; All this so that the information can be classified in a formal taxonomy so that health professionals can use it, so it is necessary to complete these activities in later work.

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