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Technological solutions for the inclusion of visually impaired individuals in urban: a literature review

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Abstract*– In the context of improving quality of life and inclusion, the development and implementation of technologies aimed at assisting people with visual impairment has emerged as an area of interest and is constantly evolving. The objective of this article is to review the technologies implemented worldwide that facilitate the mobility of individuals with visual impairment in outdoor environments. To achieve this objective, the PRISMA methodology was employed, and variables such as the study environment, platform/device utilized, sensors and components, services and APIs, among others, were established. The analysis of the selected research revealed a trend towards the use of assisted technologies, image processing, and machine learning. Furthermore, it was recommended that future work include the implementation of artificial intelligence and the creation of open-source environments to encourage greater community involvement in the development process. It was determined that the majority of the proposals analyzed are oriented towards the individual, rather than the social level. Consequently, the necessity to adapt these solutions to the specific social context of Colombia is emphasized.

***Keywords*-- Smart cities, inclusion, visually impaired, technological solutions.**

I. INTRODUCTION

The sense of sight is key to perceiving the world in all its richness of light and color. Nevertheless, it is of concern that, by the year 2022, it is estimated that approximately 1 billion people will have a moderate or severe type of visual impairment [1] and another 43 million will be completely blind [2]

It is worrying to think about the scale of this problem and its implications for the quality of life of people. As the world moves forward, this number is expected to increase significantly by the year 2050, with an increase of 41% which translates to approximately 61 million blind people in the world [3]. This number becomes even more impressive when talking about the correlation between poverty and disability where it is estimated that at least for 2009 the relationship between disability and poverty was 20% [3] [4].

In Colombia, the percentage of people with disabilities is 7.1% [5]. A general analysis shows that in recent years there has been insufficient technological implementation in pedestrian areas for people with visual impairment, as well as in their mobility within urban environments and open spaces. Given that the world is in the 21st century, it is essential to reflect on feasible technological solutions to address this problem in the country. The lack of accessibility and adaptation in infrastructure and public services for people with visual impairment represents a major challenge in the search for an inclusive society, as this limits their full development in society and their ability to move independently [6].

Currently, around the world, there are effective strategies and technologies that are promising in terms of solving this problem, such as the implementation of smart cities [7]. The development of smart cities is not only about optimizing city services, but also about ensuring inclusion and accessibility for all, including the visually impaired. It aims to use technology to improve the quality of life for all citizens in an efficient and accessible urban environment [8]. In terms of technologies, there are smart electronic canes [6] that contribute to improved mobility. Likewise, portable vibrotactile stimulation devices have shown great potential for improving the mobility of visually impaired people. These devices use vibrations and tactile feedback to provide information about the user's environment and location.

Some of these devices have been integrated with navigation and mapping applications, allowing users to plan their routes and move around more easily [9]. In addition to individual devices, more complex detection and assistance systems have been developed using camera and sensor technology. These systems can recognize objects and obstacles in real-time, providing audible or tactile alerts to the user. Some of these systems have also incorporated facial recognition technology to help identify familiar people and facilitate social interaction [10], and all this thanks to cloud services, which have been instrumental in improving the experience of visually impaired people, through Google's speech and text recognition API's [11] and technologies such as Microsoft speech platform [12].

The review is situated within the institutional research line of Information and Communication Technologies, with reference to the sublines of Software and Virtual Environments, and Automation and Control. These sublines are pertinent in light of the fact that the review encompasses development of applications and platforms that facilitate navigation and assistance in urban environments, integrating diverse devices and digital services to enhance the mobility of visually impaired individuals.

Considering the above, through this literature review article, based on the method "Preferred Reporting Items for Systematic Reviews and Meta Analyses" (PRISMA) [13] and through the application of inclusion and exclusion criteria for the correct selection of articles, we intend to present in detail different technological tools that over the last 5 years have contributed to the inclusion and independence of people with visual impairment or blindness.

II. METHODOLOGY

To identify the technological solutions available worldwide that contribute to improving the mobility of visually impaired people in open urban spaces, a systematic review of the literature was carried out using the PRISMA methodology. [14].

This methodology allows us to increase the effectiveness of the process, as well as to avoid common errors when carrying out a systematic review. Examples of these errors are redundancy and lack of transparency. Additionally, the implementation of this methodology allows readers the ability to replicate the methods that have been performed and to contrast the results obtained [14], through a flow chart showing a step-by-step description of each of the phases of the review [15].

Rigorous scientific articles were selected as a reference, focusing on the most recent advances to provide a comprehensive approach to the available solutions. The criteria used to determine the rigorousness of the articles included, firstly, the selection of articles published in scientific, peer-reviewed journals with high impact in the area of research, thus guaranteeing a high level of quality. In addition, articles that provided an up-to-date perspective on the topic, incorporating cutting-edge technologies and innovative approaches to addressing the mobility and accessibility needs of people with visual impairments were reviewed. This provided solid information supported by reliable research on how the mobility and accessibility needs of people with visual impairment are being addressed in open urban environments.

A. Data Collection

For gathering information, specific searches were conducted in recognized databases, including IEEE, Science Direct, Taylor & Francis, and PubMed using the following keywords for each of the databases:

- **IEEE:** Technology AND Navigation AND “Visual impairment”
- **Science Direct:** "Visual impairment" AND "Technology" AND "Navigation" AND "Streets"
- **Science Direct:** "Technology" AND "Mobility" AND "Visual impairment"
- **Taylor & Francis:** (technological OR technology) AND (solutions OR interventions) AND ("circulation of visually impaired people" OR "mobility of visually impaired people") AND ("urban spaces" OR "urban environments" OR "cities") AND ("visually impaired" OR "blind" OR "vision impairment")
- **PubMed:** (Vision impairment) AND (technology) AND (urban)
- **PubMed:** (Vision impairment) AND (navigation) AND (technology) AND (urban)

Furthermore, articles published in the last 6 years were prioritized, starting in 2018 until 2023, which allowed obtaining a complete and updated view of the solutions that have been implemented in this area.

Once the search for articles was completed, both inclusion and exclusion criteria were established to proceed with the analysis. Papers considered for inclusion belonged to the categories of "conference" or "research article" in the areas of Engineering and Computer Science research. On the other hand, documents that were not related to the object of study were excluded, as well as research whose solutions were limited to indoor environments. In addition, reviews of articles and any non-scientific literature were discarded.

Throughout the review process, priority was given to the quality and relevance of the articles intended for the final analysis. This approach allowed careful selection of the most relevant papers to achieve the goals of this study, thus ensuring the quality of the conclusions. The sequence of methodological steps of the Prisma methodology, mentioned below, can be observed with their corresponding results in the flow chart in Figure 1.

- **Identification:** Total number of articles obtained from the database.
- **Filtering:** Cleaning and selection of articles based on the area of study.
- **Eligibility:** Selection of articles based on the evaluation criteria.
- **Included***: Total number of articles included for analysis.*

Fidelity to the guidelines and criteria established for the evaluation and selection of articles at each stage of the review was ensured. To guarantee the quality of the process, only those articles to which access to the full text was available were taken into consideration.

Once the articles were selected, a methodical evaluation was carried out using variables. These variables are mentioned and defined as follows:

- **Study environment:** Environments in which the proposed solution can be applied.
- **Platform/Device:** Environments or systems in which the solution is executed or developed.
- **Sensors and components:** Identification of sensors and components used by the solution to know how the device works, as well as the inputs it receives from the environment and the outputs it returns to the user.
- **Services and APIs:** Set of interfaces used by developers to access data and services used in the creation of solutions.
- **Programming language:** Programming languages used by researchers and developers to carry out the solution.
- **Technological equipment:** Equipment in which the technological solution is assembled to be used to improve the mobility and sensory perception of visually impaired people.

III. RESULTS

After applying the filter to the articles selected for further review using the Prisma methodology, it was determined that, of the 210 articles initially selected, 36 advanced to the filtering stage. Here, following inclusion and exclusion criteria, 36 were selected, of which 17 were excluded during a second filter, leaving a total of 15 articles for further analysis.

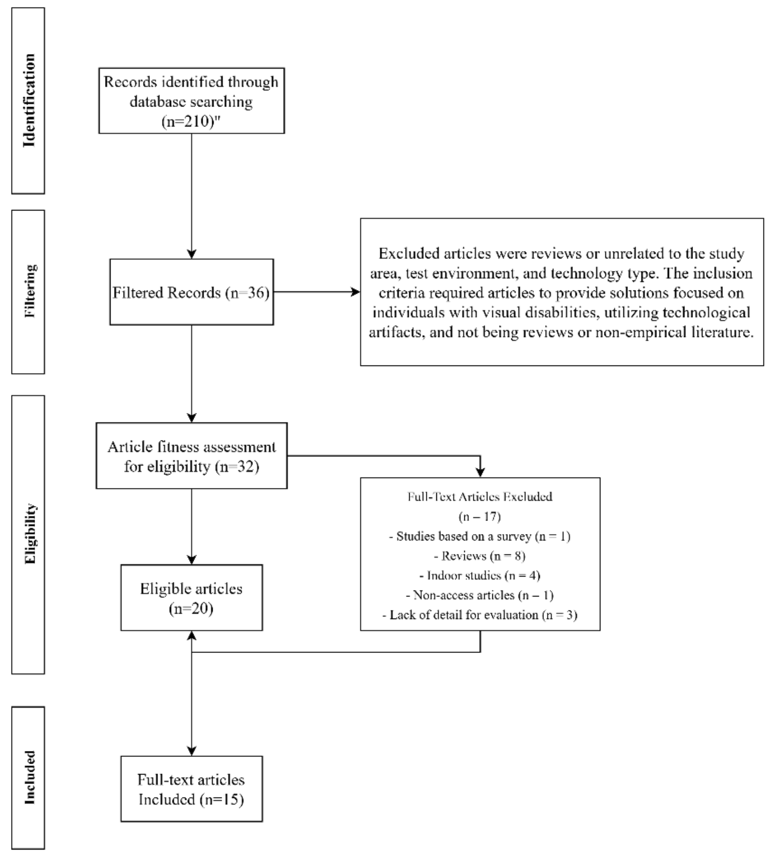

Fig. 1 PRISMA Flow Diagram

The resulting articles were subjected to review and analysis using the variables mentioned above. This analysis reveals the predominant trends in the focus of research, providing a detailed overview of the development of technological solutions that support the improvement of mobility and accessibility for people with visual impairment worldwide (See Table 1)

TABLE I
OPERATIONALIZATION OF VARIABLES

Ref	*Environment*	*Platform*	*Sensors and Components*	*API's*	*Programming Language*	*Equipment*
[16]	OUTDOOR-INDOOR	FPGA	Sensors	YOLO	Darknet Framework	Cane
[17]	OUTDOOR-INDOOR	Cellphone, ESP32	Sensors, Cameras, Vibrators	Google API	Python, Firebase, Native C++, Dart	Belt
[10]	OUTDOOR-INDOOR	M5Stack, ESP32, Cellphone	Sensors	No specific	C - C++ - Java - Kotlin - Python – Shell	Walking Frame
[11]	OUTDOOR	Cellphone	Network services	Google API	Xamarin, Firebase, ASP.NET MVC.	No specific
[18]	INDOOR	Raspberry Pi	Sensors, Cameras, Microphones, Facial Recognition System	Google API, YOLO	Python	Glasses
[19]	OUTDOOR	No specific	Sensors, Cameras	Google API	No specific	headphones
[12]	INDOOR	No specific	Sensors, Cameras	Microsoft Speech Platform	No specific	Cane
[20]	OUTDOOR	Raspberry Pi	Raspberry PI 3, Cameras, Headphones	No specific	Python	Jacket
[21]	OUTDOOR	Raspberry Pi, Cellphone	Headphones, Camera	Gogle API, Kaggle, Mobilenet V2, EfficientDet, YOLO, EASY OCR	Python	Portable tool
[22]	OUTDOOR-INDOOR	Raspberry Pi	VL53L0X, Ultrasonic, Cameras, Arduino, HC 12 TX	OpenCv	Python, C, C++	Glasses and cane
[9]	OUTDOOR	Cellphone, Arduino	Mechanical and Electronic System, MK3S, Bridge in HL293D, DC N20 12V Micromotors, Bluetooth HC-05	No specific	No specific	Gloves
[23]	OUTDOOR	Raspberry Pi	Sensors, Cameras	OpenCv:	C, C++	No specific
[6]	OUTDOOR-INDOOR	No specific	Microcontroller, Camera, Speaker	GAPI, gTTS, Video Intelligence API, OCR	JSON	Cane
[24]	OUTDOOR	Cellphone	No specific	Google Maps Platform, InSta	JavaScript, MYSQL	No specific
[25]	OUTDOOR	Cellphone	Sensors, Micro Motor, Battery	No specific	No specific	Cane

B. Areas of study

As part of the analysis of results, it was important to identify the areas of study with the greatest emphasis in the search for solutions to the problem. Table 2 shows the distribution of these areas in the 15 articles analyzed.

TABLE II
AREAS OF STUDY

Area	*Frequency*	*Percentage*
Computer Science	13	33.3%
Engineering	8	20,5%
Decision Science	5	12.8%
Medicine	4	10.3%
Others	9	23.2%

From the above, the areas of computer science and engineering are the most researched, comprising about 50% of the 15 articles. This provides a valuable framework for understanding the solutions developed in these areas by different countries.

C. Keywords

The keyword analysis in this study (see Figure 2) provides significant insight into the trends and focus areas of the 15 investigations. It allows the identification of recurring themes and connections between studies, which improves the understanding of the scientific overview [26]. It also helps to anticipate and address future problems more effectively.

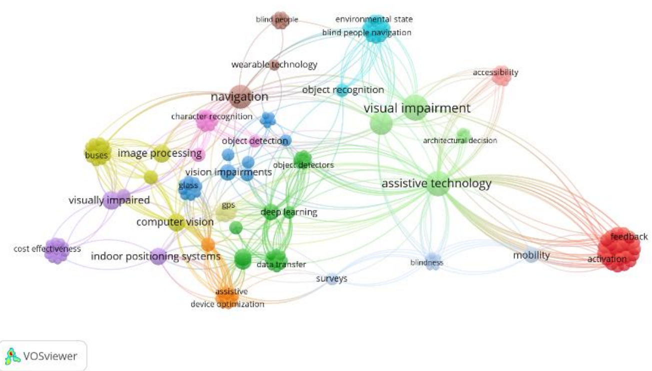

Fig. 2 Scientometric Analysis

As can be seen in Figure 2. In "Scientometric Analysis", there is a trend towards image processing, assistive devices, and computer vision (Computer Vision), which is also shown in Table 3. To perform this analysis, the keywords not related to the problem were discarded to focus only on the technologies used in the solution.

TABLE III
Occurrences between Keywords

Keyword	***Occurrence***	***Total, Enlace Strength***
Assistive Technology	6	99
Imagen Processing	3	53
Computer Vision	3	52
Obstacles avoidance	3	48
Machine Learning	2	36
Assistive Devices	2	34

From the analysis of the results, a correlation between the use of computer sciences related to the recognition of objects and images with the use of algorithms and sensors can be seen in the following Figure 3.

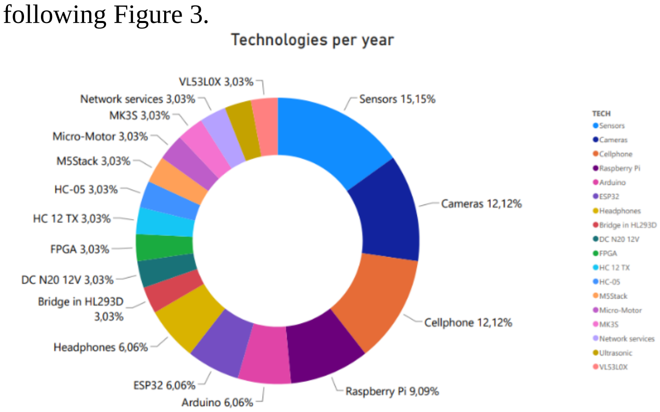

Fig. 3 Technologies per year

However, by analyzing the graph, conclusions can be drawn that contribute to a better understanding of the technological landscape, mainly focused on the problem addressed in this review. The improvement of sensors and cameras is remarkable, evidencing the importance of collecting data on the environments surrounding the subjects of study, as well as the relevance of providing spatial feedback to the user. Likewise, there is a wide acceptance of portable devices and developments in open-source components, such as Arduino and Raspberry Pi. This suggests an emphasis on flexibility and community support in the development of technological solutions for the visually impaired.

IV. Discussions And Proposals

It is important to contemplate different perspectives to explore possible future scenarios that could be both feasible and relevant to address the problem at hand. In this study, the following solutions are proposed:

- **Integration with artificial intelligence and automatic learning:** This can improve the ability to detect objects and perform navigation analysis of visually impaired people to provide them with more accurate and faster solutions.
- **Focus on collaboration:** As we have observed, one of the trends of the solutions is the implementation of open-source components, which could demonstrate the interest of the community to promote the development of more accurate solutions that address the specific needs faced by each visually impaired person because of open source.
- **Touch feedback:** The development of haptic devices could allow visually impaired people to have a better understanding of the environment around them, allowing them to obtain information regarding shapes and distance, which would improve their ability to navigate and perceive the environment.
- **Cross-Platform Accessibility:** The implementation of this resource by developers is crucial for ensuring that users with visual impairments can access information through screen readers and voice assistant integrations. This not only enables inclusive access but also provides a high level of personalization and adaptability to meet the unique needs of each user, significantly enhancing their interaction with digital platforms and promoting a more equitable user experience.

These proposed solutions not only improve mobility for the visually impaired but are also a key component in the development of inclusive smart cities. By integrating these technologies, we are moving towards creating spaces that are not only more efficient, but also more accessible to all citizens, thus improving the quality of life.

V. CONCLUSION

In conclusion, by applying the PRISMA method for the review of articles focused on providing technological solutions to people with visual impairment, the existence of several proposals aimed at improving the quality of life of those who face both mild and severe problems in this area were evidenced. These solutions, tailored in accordance with their original environmental, social, and political setting, show a potential that could be extrapolated to specific contexts in Colombia.

Many of these approaches have been designed considering the characteristics of their original environments. However, the possibility of adapting and applying these solutions effectively in Colombian environments is also perceived. To achieve this, it is essential to carry out a more detailed case study to identify the specific needs of visually impaired people in the country and to ascertain the challenges associated with the adaptation of these technologies in contexts where the urban infrastructure may not be fully prepared for their implementation.

It is also important to highlight that the implementation of this type of technology contributes to the advancement of more inclusive smart cities, where citizens will improve their quality of life. By integrating technological solutions such as assistive devices and accessible navigation systems, it fosters a more equitable community and contributes to the autonomy of people with disabilities, ensuring that no one is left behind in the process of urban modernization.

On the other hand, the implementation of technologies designed for individuals with visual impairments or other disabilities must be accompanied by the establishment of public policies that promote inclusion and accessibility in urban environments. The establishment of clear regulations and the provision of state support can facilitate the implementation of these solutions on a large scale, ensuring that they become an integral part of urban development.

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