Design of a Wearable Assistive System for Visually Impaired People

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Abstract. At least 2.2 billion people are visually impaired, with the main problem being a lack of autonomy and safety when moving around the city. To solve those needs, a wearable assistive system for vision impairment people, with low cost and open-source applications, integrating machine learning and deep learning was developed. We used a mixed methodology, including semi-structured interviews with visually impaired people and specialists in visually impaired needs, including them both in the design process. This allowed us to have an understatement of the specific needs and to generate improvements in the design. The results are auspicious for the feasibility of this type of development, the main considerations and lessons learned are noted, leaving some opportunities for future research.

Keywords: Visual impairment · Machine learning · Face recognition · Obstacle detection · Ultrasonic sensor · Identifying objects

1 Introduction

"Vision is the most dominant of the five senses and plays a crucial role in every facet of our lives" [1]. According to figures from World Health Organization, globally, at least 2.2 billion people have a near or distance vision impairment and 36 million are blind, and those numbers are increasing [1, 2]. Studies have shown that impaired vision may be the initial manifestation of COVID-19 [3] and others that this increase is one more of the consequences of the pandemic on society and health [4, 5].

When an eye condition affects the visual system and alters one or more of its vision functions we define it as vision impairment [1]. The main causes of vision impairment

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are uncorrected refractive errors; cataracts; age-related macular degeneration; glaucoma; diabetic retinopathy; corneal opacity; and trachoma [6]. The classification of visual impairment is based on the distance to the object, separating them into Distance vision impairment (mild, moderate, severe and blindness) and Near vision impairment [7].

This condition is unequally distributed according to the income level of the countries [1]. It has serious public policy implications, being associated with poorer living conditions and poorer health [8] and even a greater impact on the COVID-19 [5].

Some of the consequences associated with visual impairment are three times more likely to be involved in a collision with a vehicle and twice as likely to trip and fall while walking. [6]. These problems are increased by the emotional situation and dependency suffered by the visually impaired, as they are not even sure who they are talking to, and by the lack of autonomy when carrying out tasks that are routine for the rest of the people, all of which generates greater personal dissatisfaction [9]. Another of the main difficulties is travelling abroad, as cities are poorly prepared for the needs of this type of person [8, 10]. For this reason, specially designed aids must be used, the most common of which are canes, guide dogs, and mobility training, as well as the use of IoT and sensors [11].

Measurements of visual acuity and visual field allow various types and levels of impairment to be established, as indicated in the following list [7]:

- Mild: visual acuity less than 6/12
- Moderate: visual acuity less than 6/18
- Severe: visual acuity less than 6/60
- Blindness visual acuity less than 3/60 or inability to perceive light.

This research focuses on people with severe visual impairment or blindness. Using a mixed research method, through semi-structured interviews and the development of a prototype, we propose wearable hardware connected to an algorithm that contains artificial intelligence functions (deep learning and machine learning) which allow the recognition of faces, objects, text, and the use of an ultrasonic sensor.

Our objective was to evaluate the technical feasibility of developing and integrating different tools to generate a system that helps visually impaired people make decisions at a low-cost.

This paper is an early-stage development of the system, our goal is to generate discussion about the solution and contribute with our preliminary results.

The following section presents the theoretical framework. Section 3 describes the problem feature. Section 4 describes the methodology. Section 5 describes the development process of each component. Section 6 discusses the process and findings. Section 7 reports the conclusions.

2 Related Work

Vision has different activities and occupations (see details clearly; allowing differentiation of objects of a similar size and shape; etc.) [1]. However, we will deal with factors that measure efficiency:

- Visual acuity: the sharpness or detail with which objects are perceived (clarity).
- Visual field: space covered by vision when looking straight ahead (peripheral vision).

For people with severe visual impairment, blindness, or whose visual field is so small that they cannot see, technology is an option, which is the set of techniques, knowledge, and resources to provide visually impaired people with the appropriate means for the correct use of technology [12]. These consider character magnification, screen readers, and Braille converters, among others.

Riazi's research [13] reports some situations that annoy and frustrate visually impaired people and that are their main drawbacks:

- Need to ask others and ask for help in routine activities.
- Route identification, having to pay attention to the route and memorize details, including escalators, potholes, and holes in the ground.
- The potential risk of accidents, with bicycles or motorbikes, especially when riding on pavements; scaffolding, and other obstacles both on the ground and overhead (e.g., branches).

Research agrees that lack of autonomy, sense of place, and insecurity when traveling are the main limitations faced by visually impaired or blind people in cities [13–15]. The following are observed to help the visually impaired person: infrared sensors [16], ultrasonic sensors [17], stereo cameras [16, 18], RGB-D sensors [19, 20], and radar sensors [20]. In which the use of stereoscopic cameras or cameras with RGB-D sensors gives a good result for alerting about stairs or the distance of an obstacle, but usually a notebook is used to process the images, which means additional weight to be carried. The literature also state that using networks such as 3G is very slow for information to arrive in real-time, but nowadays networks have improved and there is 4G with speeds reaching 100 Mbps [21, 22], and soon 5G. So, cloud processing could be an option. On the other hand, the use of technologies with high processing and small calculation time as in the project of Jafri [16] using a Tablet, called Tango project, created by Google, that involves an interesting use of stereoscopic cameras and a video card inside the device. This has the disadvantage that it has to be held in a certain way to capture the environment correctly, another concern is the long-term support of this tool, considering that Google may not continue its development. Another alternative is ARcore, a mobile application developed by Google that provides an understanding of the environment, which could allow finding unevenness in the ground, however, it would not meet the criteria of an adaptative architecture [23].

Other research focuses only on object recognition such as in [24] they even consider voice commands, but that has the disadvantage of forcing the person to speak loudly in public which can be embarrassing for the person. Or the apps do not meet the requirements of visually impaired people [25, 26]. Table 1 summarizes solutions found in other published works.

Table 1. Solutions found in other published works. The problems are listed in the first column and appear with a ticket if they are solved in the respective publication. Source: Own elaboration

Problem	[19]	[27]	[17]	[24]	Our solution
Distance sensor	✓	X	✓	X	✓
Face recognition	X	✓	X	X	✓
Step recognition	X	X	✓	X	✓
Object recognition	X	X	X	✓	✓
Light	X	X	✓	✓	✓
Emotion recognition	X	✓	X	X	X
Voice commands	X	X	X	✓	X

3 Methodology

The methodology used is based on the science of design, using metrics that validate the previously defined objectives [23, 35]. Thus, this work consists of three main steps: identification of needs, development of the artefact, and evaluation.

For the first step, weekly meetings were held with the specialist in visually impaired people to determine the different requirements. This resulted in the identification of 22 functional requirements, non-functional, business considerations, and project requirements.

To determine the characteristics of the application, we used as references the requirements set out in the Fundación Auna [36], Schrott [37], and Lopez Delgado et al. [38], these recommendations include the use of large screens, appropriate keyboards, ergonomics, depending on the type of disability being addressed, i.e. characterize the application and develop it through the selected degree of interaction [26].

The requirements were associated with each of the proposed objectives, the system is intended to be a wearable sensor device at head level, which has 2 modes, i) focus mode for obstacle detection, calculating distances, and warning through vibrations or audio in case of danger; ii) recognition mode, which processes the image and indicates to the user the object in front of him/her through audio. A third option is to turn it off when no information is desired.

For quality assurance, the followed standard are reported in IEEE 8282–1998 Software Configuration Management Plans [39]; 730–1998 Standard for Software Quality Assurance Plans; 1233–1998 Guide for Developing System Requirements Specifications; 829–1998 Software Test Documentation, and 12207 -2017 Software life cycle processes.

4 Problem Feature

Having defined our target group (people with severe visual impairment or blindness) and their major problems (lack of autonomy and insecurity), we focus on determining the root cause of these problems. Using the fishbone "Ishikawa" methodology [28, 29], by conducting semi-structured interviews [30] with a blind person and a professional specialist in the field.

With this information, we determined three main causes, as shown in Fig. 1. This analysis allows us to estimate the level of effort and time required for its execution. Each root cause defines an objective alongside the requirements identified. These causes are:

- C1: Difficulty in distance perception: visually impaired people mainly use touch and while walking the cane fulfills this function. However, there are risks due to obstacles above ground or overhead.
- C2: Difficulty in recognizing objects: memory plays an important role in recognizing objects, therefore the necessity to find features to distinguish between objects with similar characteristics.
- C3: Difficulty in recognizing people: the visually impaired person must rely on their memory to remember voices, leading to confusion and misidentification.

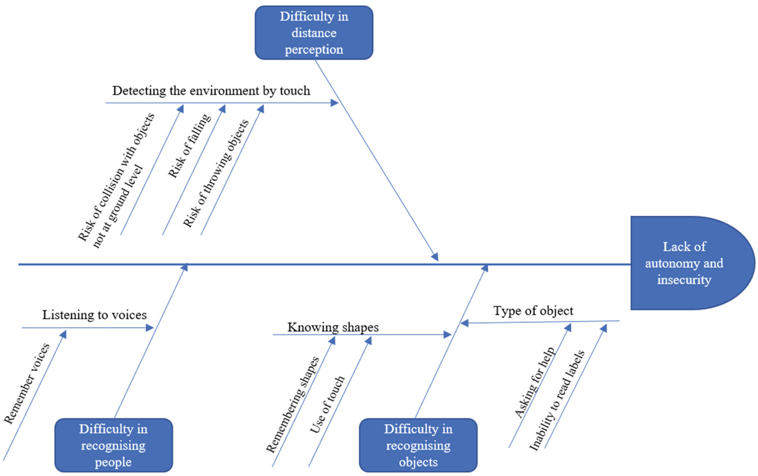

Fig. 1. Ishikawa diagram for root-cause analysis. Source: Own elaboration.

Our objective was to develop and integrate different tools to create a system that helps visually impaired people make decisions.

In Table 2, we show the specific objectives, expected result, and how it will be measured (Metric), and the last column presents the reported accuracy from published literature (APL) for each metric. In Table 3, we associate each of the objectives with the causes (C).

5 Development Process

The schematic of the solution is shown in Fig. 2, and the description about each component is presented in following sub-sections. Figure 3 depict the location of the equipment in the user.

Table 2. Specifics objectives. Source: Own elaboration

Objectives	Expected result	Metric	APL
O1: Recognize the person in front of him/her	Identifying the person through a camera	% Face recognition efficiency (FRE)	FRE ≥ 96% [24, 31]
O2: Inform of the objects in front of him/her	Identifying objects through a camera	% Object recognition efficiency (ORE) % Efficiency in tag reading (ETR)	ORE ≥ 58% [32] ETR ≥ 92% [33]
O3: Information about obstacles that are not at ground level	Identify and alert the visually impaired person to a possible obstacle	% Accuracy of obstacle alerts (AOA)	AOA ≥ 97,95% [34]
O4: Inform about the existence of a staircase in front	Identifying and alerting about stairs ahead	% Staircase Alert Accuracy (SAA)	SAA ≥ 98,6% [18]

Table 3. Associate each of the objectives (O) with the causes (C). Source: Own elaboration

	C1	C2	C3
O1			X
O2		X	
O3	X	X	
O4	X		

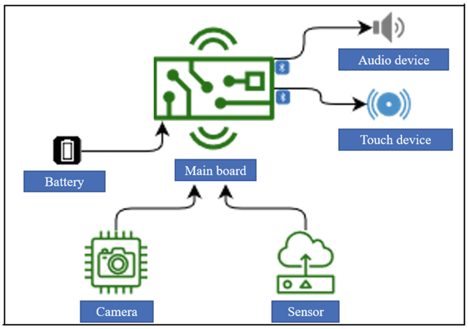

Fig. 2. Schematic solution. Source: Own elaboration.

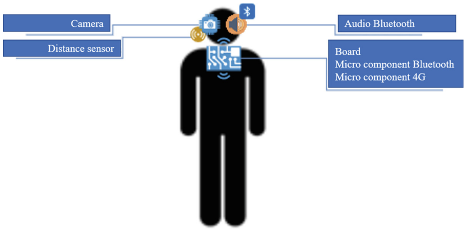

Fig. 3. Location of equipment. Source: Own elaboration.

The following sections present the selection process of the software, hardware and the tests carried out.

5.1 Software Selection

Open-source software and python language are used. In particular the Computer Vision and Digital image processing libraries for python. Three methods were selected based on Deep Learning (Fast R-CNN 2015 y Yolo V3 2018), both use Common objects in context (COCO) a dataset for object detection and segmentation [40]. In the case of Fast R-CNN, it has two two-stage and one-stage approaches (e.g., SSD), both are tested [40].

The pre-trained function for Fast R-CNN, Luminoth, was used to optimize the development process. In both methods, COCO was used as a test set, complemented by a set of images of common objects [40].

We observed that Fast R-CNN in its single-process mode (SSD) delivered immediate results but with a higher error rate. In the case of Fast R-CNN with two parts and YOLO, it took between 1 and 2 s for processing, with a lower error rate. Table 4 shows a comparison of the results after hardware adjustments. This result led us to select YOLO as the visual recognition method.

Table 4. Comparison of results. Source: Own elaboration

	Yolo	Sdd
Average time	1,19 s	2,21 s
Objects	Success rate	Success rate
Mug	4/5	4/5
Mouse	2/5	2/5
People	4/5	4/5
Table	3/5	3/5
Keyboard	4/5	3/5

Text recognition is done by machine learning, using automatic reasoning, natural language processing, and computer vision (similar to the one used in object recognition), using Tesseract.

5.2 Hardware Selection

The hardware environment corresponds to a Raspberry PI 3+. To take advantage of its resources, the Raspbian Lite operating system is used, which does not have a desktop interface, this Debian-based operating system contains default libraries and Python. Part of the code is removed to optimize it.

A Steelseries audio input card was used as audio input. (USB soundcard V2 Model NO.: SC-00003). For obstacle recognition, an ultrasonic sensor is used, with 5V input (VDC), decreasing its response (echo) to 3.3V to not damage the board.

Additionally, buttons are included, which will allow activating the distance measurement, among other actions, for example, On-Off, change function. The sensor and camera are attached to thick glasses. The final prototype is shown in Fig. 4.

Fig. 4. Final prototype. Source: Own elaboration.

5.3 Tests Carried

In addition to the system and hardware tests carried out to verify the functionality of the prototype, we worked alongside a specialist in visual impairment and cane use. User tests were designed by this specialist.

The tests consisted of:

- Moving towards an object above ground level.
- Recognition of people around.
- Reading an emergency sign.
- Recognition of objects.
- Use of buttons, to switch between modes.

Some of the user feedbacks were:

- The system provides extra security by receiving information that the cane does not provide.

- It is a technology that allows more actions to be performed.
- Not having to contract other applications or additional internet plans is especially useful.
- It is necessary to improve aesthetics, and performance and to standardise the outputs so that the visually impaired person can memorise them.
- Notwithstanding the above, the system provides security, autonomy, and independence.

Concerning the metrics of compliance with the objectives set (see Sect. 3), the results are shown in Table 5.

Table 5. Metrics objectives. Source: Own elaboration

Objectives	Metric	APL	Accuracy
O1: Recognise the person in front of him/her	% Face recognition efficiency (FRE)	FRE $\geq$ 96%	FRE = 90%
O2: Inform of the objects in front of him/her	% Object recognition efficiency (ORE) % Efficiency in tag reading (ETR)	ORE $\geq$ 58% ETR $\geq$ 92%	ORE = 60% ETR = 46%
O3: Information about obstacles that are not at ground level	% Accuracy of obstacle alerts (AOA)	AOA $\geq$ 97,95%	AOA = 90%
O4: Inform about the existence of a staircase in front	% Staircase Alert Accuracy (SAA)	SAA $\geq$ 98,6%	SAA = Not tested

6 Preliminary Results and Discussion

There is a broad spectrum of open-source libraries and functionalities, however, we focused on a few that are recommended in the scientific literature, thus, for example, our results regarding the comparison between YOLO and Fast R-CNN are in agreement with those presented by Zhang et al. [40].

In the same way, we took into consideration Sharma et al. [41], regarding the use of machine learning algorithm for facial recognition, which allowed us to reduce the size of the images to optimise processing time in the device.

In data privacy, we agree with Zhao et al. [42], regarding the complications that the facial recognition process brings, however, our prototype does not have interactions with other networks, allowing users to maintain their privacy.

For the objective O1, although the FRE was measured at 90%, the objective is considered to have been met, understanding that the algorithm was trained with only one image for each person, also achieving 90% recognition of the subjects, without considering that facial expressions can complicate recognition [41], and therefore increasing the number of images will increase the accuracy.

O2 is determined as partially achieved, because ORE was achieved, however, further optimisation of the algorithm is required. It should be noted that the ultrasonic sensor allows the user to be alerted to the object, even if it does not allow for full recognition, increasing the level of range and security, as demonstrated by Cardillo et al. [43].

O3 is determined as achieved, as every object with an angle less than 40° was detected, however, when searching for this angle limitation in the literature, no information was found. It should be noted that as in Cardillo et al. [43], the radar system only takes into consideration the existence of the object, not its recognition as to what it is, which motivates us to declare the objective approved.

O4 was not tested because the acquired technology, adjusted to the budget, did not consider this variable when the ladder was descending, so using a conservative criterion it was preferred to leave it as untested.

7 Conclusions

The process described above shows the importance of considering the user in the early stages of software engineering and the importance of understanding the user's needs. In this way, technologies will be an enabler of their development and not an imposition.

Our research demonstrates the feasibility of developing a wearable assistive system for vision impaired people, using open-source tools and low-cost technology such as Arduino systems, integrating machine learning and deep learning technologies in a "pocket-sized" device. The cost of hardware did not exceed 400 dollars.

From this work some lessons were learned, lack of official relays for certain AMD cards meant that applications had to work on unofficial versions and therefore we had to install additional software and utilities, increasing the disk space used.

Notwithstanding the above, the test results were adequate for the time spent and the imaging set proved to be appropriate for the mobility environment.

In addition to that, the mixed strategy of tests on visually impaired users and with experts on this ailment was considered a success, and we consider that is fundamental to consider them in future developments, because placing the user at the center of the technology allows for modifications on the system or knowledge that would otherwise be impossible to obtain. In this respect, we can point out, for example, the need to place sensitive identifiers on buttons so that the user can distinguish them. Therefore, ergonomic knowledge should be considered in future developments.

Future research should address the scalability of the facial recognition system, in particular by increasing the base set of images to improve this process and keep the base updated to the user's needs.

This opens up a field of research associated with the use of Cloud IaaS technologies, as well as integration with 4G and 5G networks, to distribute the processing load, with the hypothesis that this will increase performance.

The limitations of this work are related to the limited test set and therefore, we require further testing in uncontrolled environments that allows for more realistic scenarios.

Although this prototype is working disconnected from the internet, the feasibility of its integration must be evaluated to increase the number of images to be recognized, without the necessity to increase disk space.

Finally, we must point out that our preliminary results cannot be generalized, given the limited number of tests carried out. It is for this reason that our working group is developing a prototype, for which different testing and validation methods have been developed, both quantitative (performance) and qualitative (user impression).

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