IV SEVEN INTERNACIONAL
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Trajeto livre - Obstacle detection device to aid the mobility of the visually impaired

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ABSTRACT
This work aims to develop an assistive technology device to help the locomotion of blind and low vision people, increasing their autonomy and safety, detecting obstacles higher than knee and floor that will not be identified with a regular stick for visually impaired people. To obtain the technical definition of this project it was surveyed academic works, products, it was developed its own methodology to define the optimal position of sensors, components and cost evaluation to achieve a lower final price than the available products on the market. The prototype is made by sensors that will have the signal processed by the microcontroller, which will turn on the vibration motor on the bracelet. To the user, the vibration stimulus will vary in intensity and intermittence to provide which distance and height are the nearest obstacles. The device was built and tested in modules and then tests were done with the complete system by the team and by potential users, in which the operation was evaluated and possible improvements were defined.

Keywords: Assistive technology, Locomotion, Visually impaired, Trajeto Livre.

1 INTRODUCTION

Vision is the sense that has the most influence on our daily lives, and its absence can transform simple tasks into complex and even impending ones. In this sense, the World Health Organization (WHO) states that:

> Vision is the most dominant of the five senses and plays a crucial role in every facet of our lives. It is integral to interpersonal and social interactions in face-to-face communication where information is conveyed through non-verbal cues such as gestures and facial expressions. (WHO, 2019, p. 3)The Brazilian Council of Ophthalmology (CBO) (2019) has established four levels of visual function based on the International Classification of Diseases. These levels are normal vision, moderate visual impairment, severe visual impairment, and blindness. People who cannot see at all are considered blind, while those with visual impairment that makes routine tasks difficult are also classified as blind. The CBO estimates that there were 36 million blind people worldwide in 2015.

According to the Brazilian Institute of Geography and Statistics (IBGE) (2010), in the 2010 Census, 18.8% of the Brazilian population (35.7 million people) declared to have a visual impairment. Of this population, 500 thousand people reported that they could not see at all. According to the CBO (2019), there is an unequal distribution of visual impairment between age groups, with more than 82% of blind people being 50 years of age or older, an age group that represents only 19% of the population.

The WHO projects that:

> Population ageing will impact significantly the number of people with eye conditions. By 2030, the number of people worldwide aged 60 years and over is estimated to increase from 962 million (2017) to 1.4 billion, while numbers of those aged over 80 years will increase from 137 million (2017) to 202 million (111). These population changes will lead to considerable increases in the numbers of people with major eye conditions that cause vision impairment. (WHO, 2019, p. 41).

There are important socioeconomic data on blindness, such as, according to the CBO (2019), more than 90% of people with visual impairment live in poor or developing countries, in this population the prevalence of blindness is four times higher than in those who live than in regions with good economy and health services.

Given the significant number of people with severe visual impairment or blindness and the projections of an increase in this number with the growth of the elderly population, it is essential to take actions that minimize the limitations caused by visual impairment or blindness and provide conditions to perform daily tasks.

In this sense, assistive technology can be a great tool to help the visually impaired, reducing this population's limitations and enabling them to perform their activities independently, autonomously and safely.

An object that helps the visually impaired population with their locomotion is the cane. Still, users do not detect obstacles above the knee line, which can cause accidents. The development of this work aims to avoid this type of accident and complement the functionality of the cane.

1.1 LITERATURE REVIEW

A research and survey of articles and academic works was done, and the topics related to assistive devices for the blind population were carried out. The strengths and weaknesses were evaluated in the works based on the initial idea, which consisted of an ultrasonic sensor attached to a cane and actuators with vibration motors fixed to a bracelet.

The main parameters used in the evaluation of the works were cost, mechanical robustness, ease of use, and reliability of the solution. Of the 17 articles and academic papers evaluated, the ones that were of most significant relevance to the development of this work are listed in Table 1, which contains the most pertinent information.

Table 1 – Evaluation of researched works

Work	Summary	Strengths	Weaknesses
Assistive device for the visually impaired to locate and avoid obstacles on university campuses (Oliveira & Makoski, 2012)	Dispositive to assist in location and moving visually impaired people on university campuses. GPS for an outdoor location, ultrasonic sensors for upper trunk obstacle detection, and indoor micro-location RF modules.	1) Interview with the target audience to verify the main difficulties; 2) Separate testing of each module to ensure its operation and check its feasibility; 3) Interacts with the user through voice.	1) Low battery life; 2) Functional test not entirely performed; 3) GPS with precision error variation. 4) In indoor micro-location, the guidance to the user is only audible, by buzzer, when user passes through the destination.
Accessibility of the visually impaired using Zigbee technology (FONTOURA, 2015)	Bioelectronic gear with an optical sensor to identify a path on the floor and report the location through voice messages on the cell phone. The localization of the environments is carried out through a ZigBee network and Xbee modules.	1) The user is informed of the location of specific environments by voice message on the cell phone.	1) Applied only to a closed environment where the user must follow a predetermined path (demarcated path); 2) There is a delay in warning when the user leaves the predetermined route; 3) It does not identify and signal obstacles.
Higuide: Wearable devices to aid in the locomotion of visually impaired people (Marinho, 2020)	Proposal for a device consisting of a necklace and bracelets to aid locomotion. On the collar would be the sensor that, using Bluetooth, will activate bracelets with vibrating motors to alert the user where the obstacle is.	1) Interviews with the target audience to identify the actual demand; 2)Analysis of similar products based on functionality, structure and aesthetics; 3) The device is ergonomically and aesthetically designed to be an accessory for daily use (necklace/bracelets).	1) There is no indication that the device has been terminated and that functional tests have occurred. The prototype was developed until the physical models of the necklace and bracelets were made without implementing the electronic part.

Source: The Authors (2022)

In Marinho's (2020, p. 61-62) work, it is highlighted that most interviewees reported that they move alone on urban roads and use the cane as the leading and essential assistive resource.

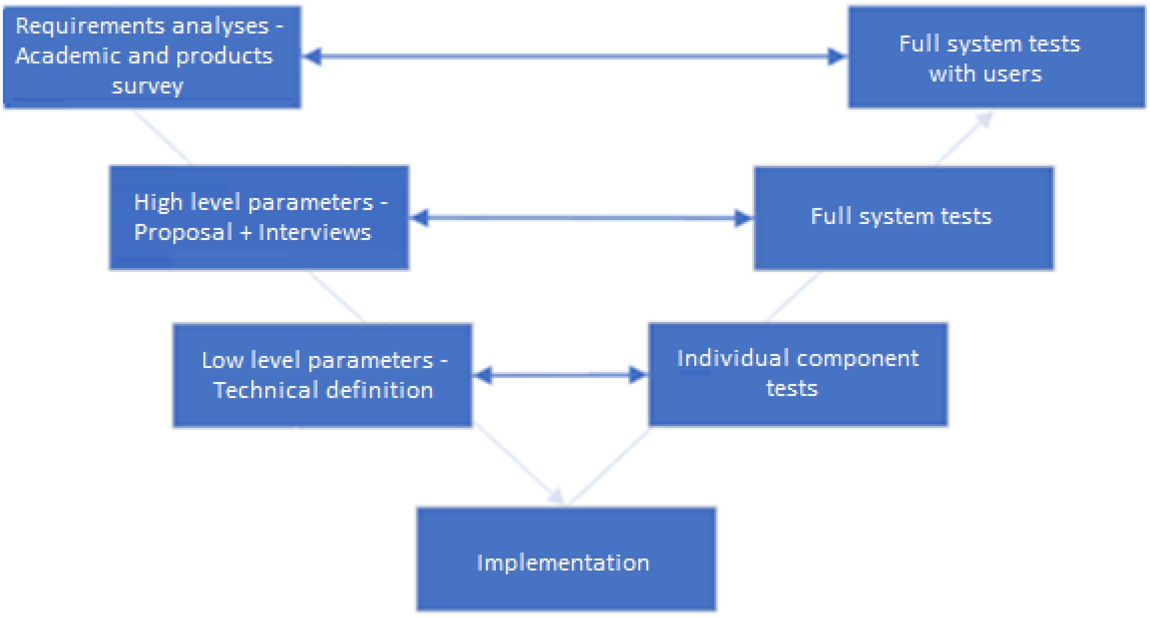
The functionality of the cane was addressed in the work of (OLIVEIRA & MAKOSKI, 2012, our translation), page 23, where in an interview, it was stated that: “… we only need to warn about the upper trunk obstacles, since the others are captured by the use of the cane (essential to the user).” and in the work of (RAHIM, 2017, our translation), page 43, in which an interviewee stated that: “[2]The present reports that for a blind person the use of a cane is indispensable, because with it it is possible to identify the most varied types of environments such as unevenness of the ground, steps, holes, …"The most used types of sensors in the researched studies, were camera and ultrasonic, and the latter seems to be the one that best fits the proposal due to the price and simpler processing of the signals.

With the statements of the interviewees about the needs and functionality of the cane at the lower level, it was concluded that the most significant use of an additional device should be focused on identifying objects that are above the one identified by the cane and, therefore a study of the movement of the cane should be made, and the areas that the sensors should cover.

2 METHODOLOGIES

The development of the prototype will continue based on a V-shaped model, which has its stages defined as illustrated in Figure 1. The requirements analysis stage evaluated the needs of users, existing technologies, and their advantages and disadvantages, which helped to create an initial proposal that was evaluated in the high-level parameters stage based on interviews and thus arrived at the technical definition that covers the needs of users in the low-level parameters stage.

Figure 1 – V-shaped development model



Source: The Authors (2022)

The implementation was done gradually, individually testing the components and functionalities to validate the technical definition, then evaluating if the proposal has adequate functioning with the entire system to be tested later with the user, who will determine if the device solves the reported needs.

3 RESULTS AND DISCUSSION

In addition to academic papers, assistive technology products were evaluated, listed in Table 2.

Table 2 – Evaluation of commercial products surveyed

Product	Strengths	Weak spot
WeWalk – Smart Cane, with sensors to assist mobility and product integration with smartphones. R$ 3,990.00 (MAIS AUTONOMIA, 2022)	1) Robustness; 2) Smartphone integration; 3) Usability; 4) Additional locomotion functions (Google Maps, buses, etc.); 5) Twenty hours of battery life.	1) The cost of the cane can be a deterrent; 2) The integration app has a monthly fee.
Sunu Band – Object detector bracelet with smartphone integration. R$ 2,190.00 (LOJA CIVIAM, 2022)	1) Robustness; 2) Battery life of 1 to 3 days with 8 hours of use; 3) Smartphone integration: alarms, compass, pedometer.	1) The natural movement of the arm can make it difficult to detect; 2) Cost can be a hindrance.
Lysa Guide Dog Robot – Robot guide with artificial intelligence that identifies and dodges obstacles, providing a safe and efficient route for the visually impaired. R$ 15,000.00 (FAPESP, 2022)	1)Robustness; 2) Identification of obstacles by artificial intelligence; 3) Diverts the visually impaired person from the obstacle; 4) Provides a safe route for the visually impaired.	1) Price can be deterrent; 2) The robot moves on wheels, which can impede use depending on the road conditions.

Source: The Authors (2022)

With the statements about the needs of the interviewees addressed in the literature review, an initial proposal was reached that the most significant utility of the device should be complementary to the function of the traditional cane, aiming at a lower cost to the user than the other options on the market, easy handling and placement, sensor coverage in a larger area than the cane, be lightweight, small and discreet device with vibration and sound response.

Interviews were conducted with teachers from the Instituto Paranaense de Cegos (IPC), where we were informed that the most common difficulties in the movement of blind people, such as irregularities in the sidewalks, lack of tactile sidewalks, problems in the exit signs of parking lots, tall objects such as trash cans, dumpsters and branches. This led to the following conclusions about the device requirements:

a) Low cost: It is a necessary requirement;

b) Easy handling and placement: For most of the interviewees, the wrist is the best place to inform the user about the presence of obstacles;

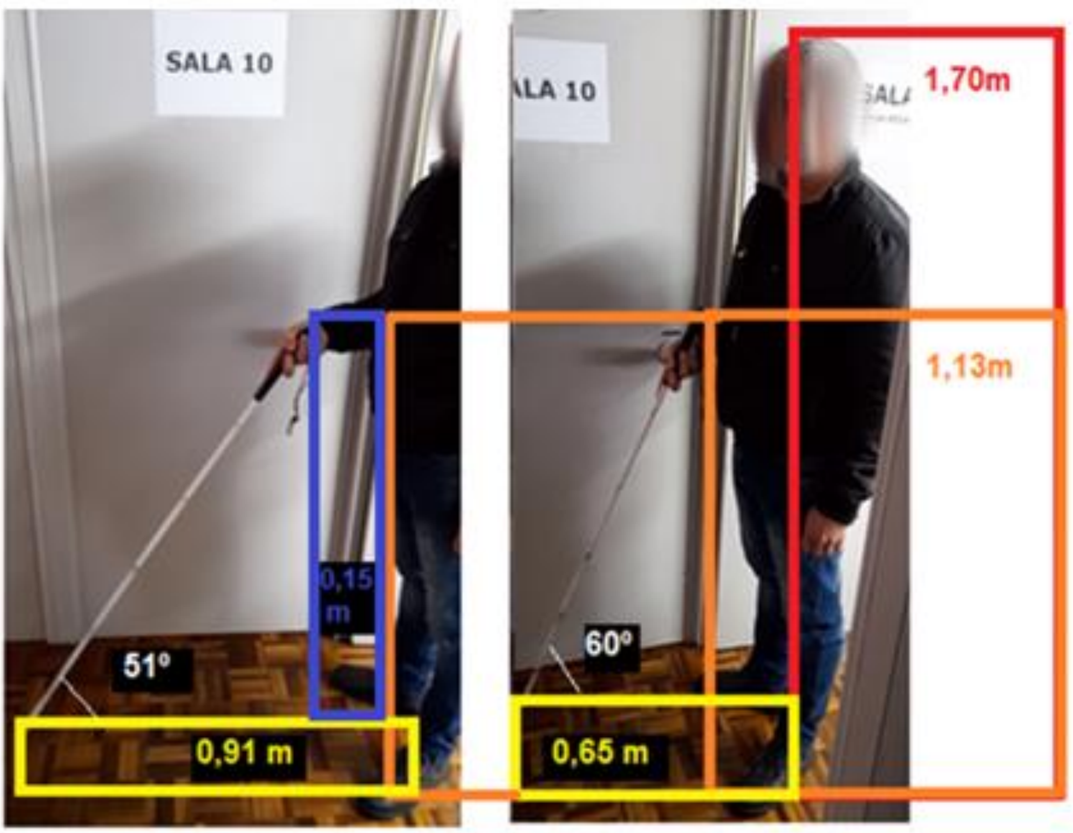
c) Sensor coverage in an area greater than that of the cane: the interviewers evaluated this requirement as essential, and half of the interviewees judged that it would be necessary for the device to detect irregularities in the floor;

d) Lightweight, small and discreet device: and essential, for half of the respondents it would be interesting if the device was similar in size to a wristwatch.

e) Response with vibration and sound: the interviewees assessed that the vibration alert should not cause negative impacts on the commute as long as there is no excessive information that can get in the way. Respondents also rated it as unnecessary for the device to emit sound.

In the IPC, the correct use of the cane was demonstrated, which has its ideal height for each person according to the height of the user's sternum bone that the user should position his index finger touching the cane perpendicularly to increase its sensitivity and the cane should always check if the region where the user will take his next step is safe. It was also discussed that the cane is used differently depending on the environment, being farther away from the user in less crowded environments (Figure 2).

Figure 2 – Angle of the cane in near and far position



Source: The Authors (2022)

A specific methodology was developed to evaluate the coverage and optimal position of the sensors for the largest number of users possible since no way to perform this activity was found in the bibliography.

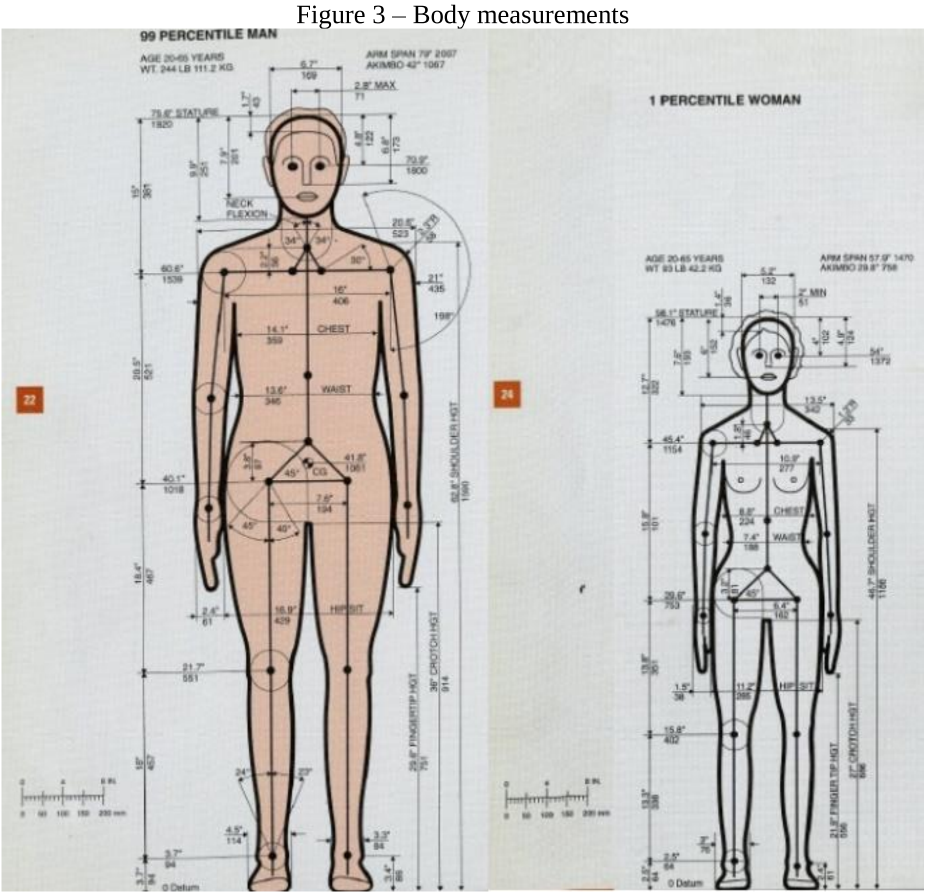
This methodology took into account the configuration of the sensors, as well as the position of the cane used in different positions for different heights.

In The Measure of Man and Woman (TILLEY, 1993), body measurements are given from the normal distribution according to the height of a population. In this way, it is possible to define user data to cover an operating range that serves m people of height from 1% of the lowest female population to 99% of the tallest male population, as seen in Figure 3.

It was necessary to set the angle of the ultrasonic sensor at a specific relative position of the cane to ensure that obstacles were detected from the knee line to the head for everyone in the chosen height range, preventing the device from identifying false obstacles such as the floor or objects far above the user's head line.

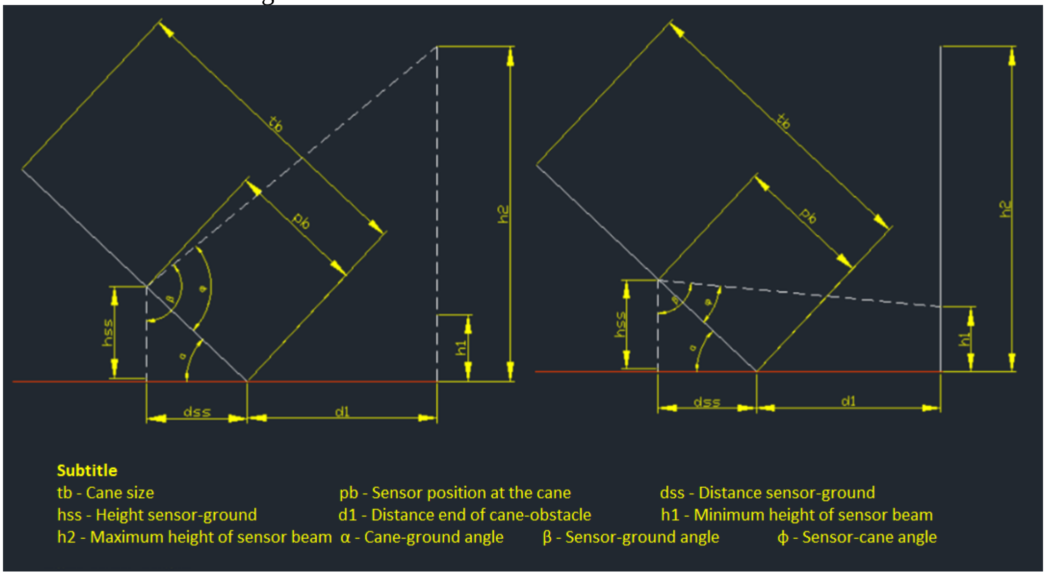
For the analysis of the useful detection range of the sensors, equations were deduced that define the height that the sensor beams (h1 and h2) project as a function of the user's height and the ideal cane size for the same (tb), as well as the distance traveled by the beam (dss+d1), the angulation at which the user is using the cane(α), position of the sensor on the cane (Pb), angle of the sensor with the cane (φ) and the angle of the sensor itself, which is 15 degrees for the model chosen in the project. Figure 4 exemplifies the parameters used.

Figure 3 – Body measurements



Source: Tilley (1993)

Figure 4 – Parameters related to the reach of the cane



Source: The Authors (2022)

The main equations of the design are the angle of the sensor with the cane (Equation 1), the relative position of the cane (Equation 2), the height of the upper beam (Equation 3), the horizontal distance from the sensor to the ground (Equation 4), and the height of the lower beam (Equation 5). The φ and β parameters are 15º smaller in the analysis of the lower beam, a distance corresponding to the sensor's opening angle.

$$\varphi = \beta + \alpha - 90° \quad \text{Equation 1}$$

$$p_b = t_b * \%\,position\ of\ sensor\ in\ relation\ to\ cane \quad \text{Equation 2}$$

$$h_1 = (d_{SS} + d_1) * \tan\beta \quad \text{Equation 3}$$

$$d_{SS} = p_b * \cos\alpha \quad \text{Equation 4}$$

$$h_2 = (d_{ss} + d_1) * \tan(\beta - 90°) \quad \text{Equation 5}$$

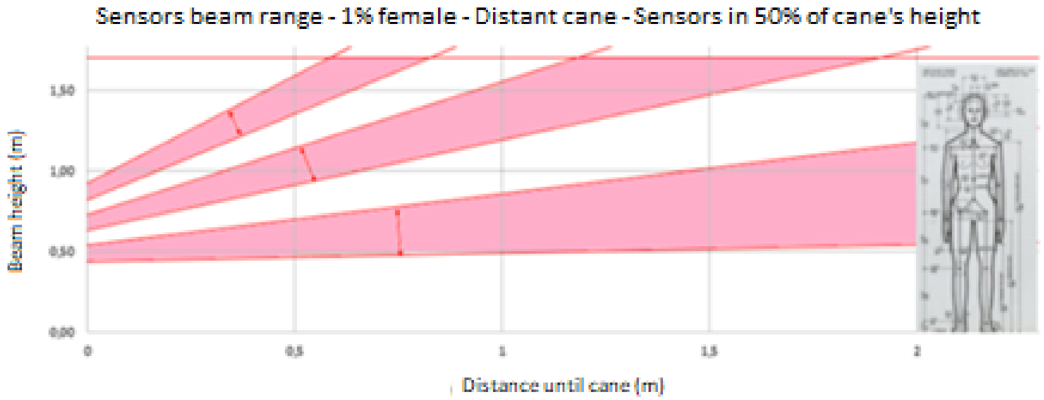
Given the equations, scenarios were simulated, and the best configuration was using three sensors, with the configuration indicated in Table 3. With three sensors, the covered region is larger. It was possible to reach a good coverage compromise both for the 1% female percentile with a distant cane (Figure 5) and a near cane (Figure 6), as well as for the 99% male percentile for a distant (Figure 7) and proximate (Figure 8) cane.

Table 3 – Final configuration of the sensorS

Sensor	Beam distance (m)	Angle sensor cane (º)	Position at the length of the cane
Bottom sensor	2,20	58,5	50%
Superior Sensor	2,01	93,5	50%
Medium Sensor	2,10	76	50%

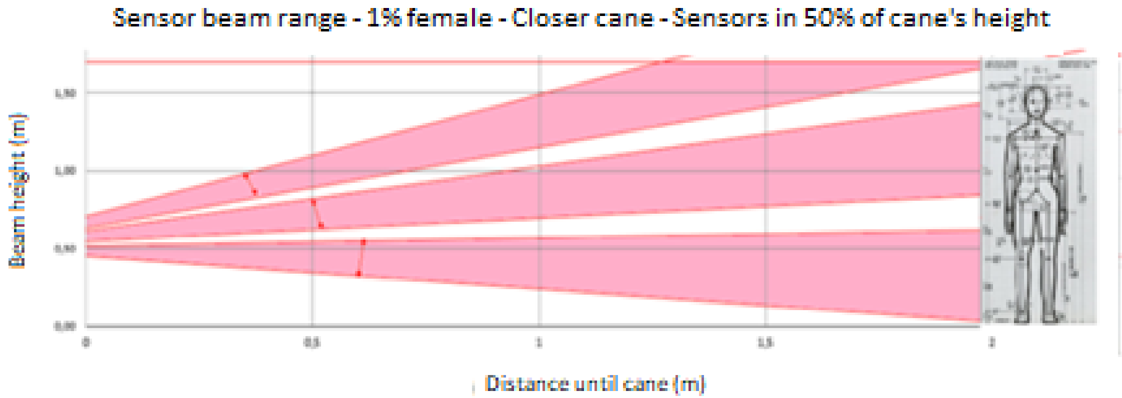
Source: The Authors (2022)

Figure 5 – Opening of the beams – 1% female – distant cane



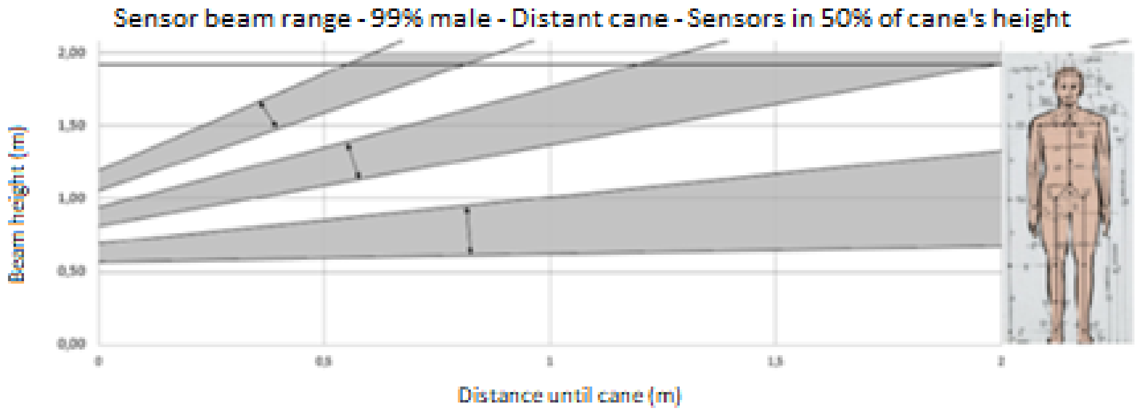
Source: The Authors (2022)

Figure 6 – Opening of the beams – 1% female – close cane



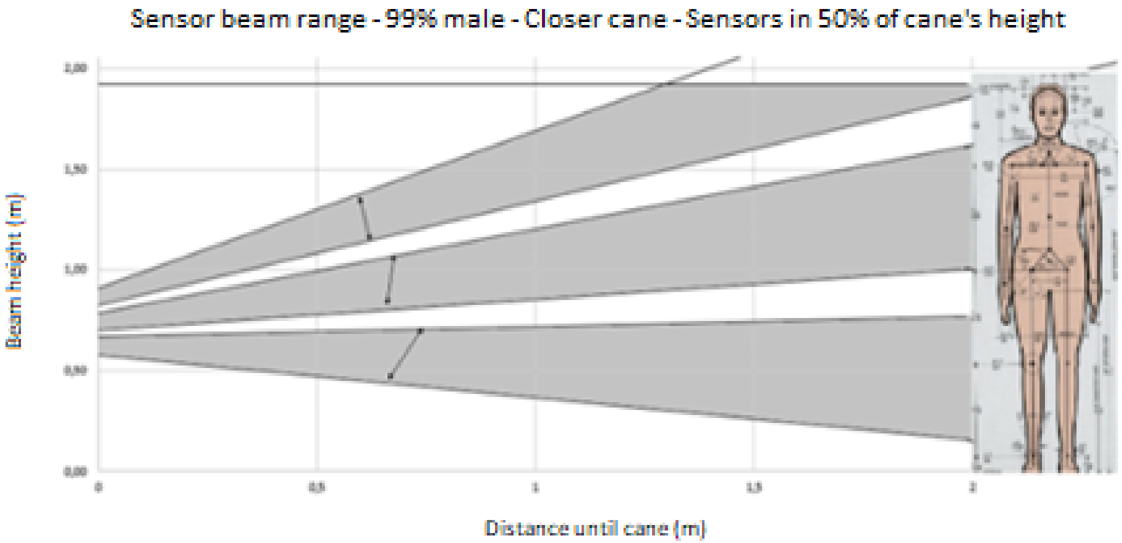
Source: The Authors (2022)

Figure 7 – Opening of the beams – 99% male – distant cane



Source: The Authors (2022)

Figure 8 – Opening of the beams – 99% male – close cane



Source: The Authors (2022)

After conducting bibliographic research, market analysis, interviews and a study of the necessary scope of the equipment, it was possible to arrive at the technical definition of the project. Three ultrasonic sensors model JSN-SR04-2.0 were chosen to detect objects above the knee line. The sensor is waterproof, has an operating range between 2 and 4 meters and has an opening angle of 15º (Jahankitshop, 2022). The ultrasonic sensor sends pulses, and from the time difference between the pulses that the sensor sends and receives the original reflected signal, it is possible to determine the distance from the obstacle since the signal travels at the speed of sound.

The infrared sensor GP2YA02YK0F was chosen to detect irregularities in the floor (holes, unevenness, etc.), which will be implemented after refinement of the operation of the system only with ultrasonic sensors. Still, the same has already been considered in the mechanical and electronic design of the device.

For the sensors to be coupled to the user's cane, which reduces costs and adaptation time compared to developing the system with an included cane, a sensor holder built on a 3D printer was developed, which allows the sensor to be positioned in the calculated optimal position. The fixation between the support and the cane is made with two rubber clamps with screw closure, which ensure good grip without damaging the cane.

The response to the user will be given from two M1027-F17 vibration motors, small in size and with no moving parts exposed, ideal for wearable applications. The motors will be attached to a wristband and arranged at the top and bottom of the wrist so that the user can identify the distance and height of objects.

The processing of the sensors and actuators will be done from the 32-bit microcontroller STM32F103C8T6, which meets the need for digital inputs and outputs, analog-to-digital converters, individual timers and external interrupts.

The system's power supply has been set to ensure at least 5 hours of uninterrupted operation, with maximum charge, which should be enough over a day since the battery will only be consumed when the device is in use. The battery chosen was a 4.8 V rechargeable NI-MH battery, with a capacity of 2700 mAh and with an SMP 02 connector, compatible with a 4.8V charger with an 800mAh capacity, which should fully charge the battery in a maximum of 4 hours.

To couple the processor and battery, a Patola PBL-100 box was selected, with IP65 protection (protected against dust and water jets). The bracelet chosen was an adjustable wristband that can be used on users with different body measurements, is easy to put on, allows a comfortable fit and supports the installation of the motors and the microcontroller and battery box.

The programming was done with the microcontroller STM32F103C8T6 using the STM32 CubeIDE and STM32 CubeMX tools. The languages used in the programming were C and C++, and the configuration is done mainly by the HAL library, which has functions that include all the features that will be used in the device, such as interruptions by timers and external signals, pin writing, and analog signal reading.

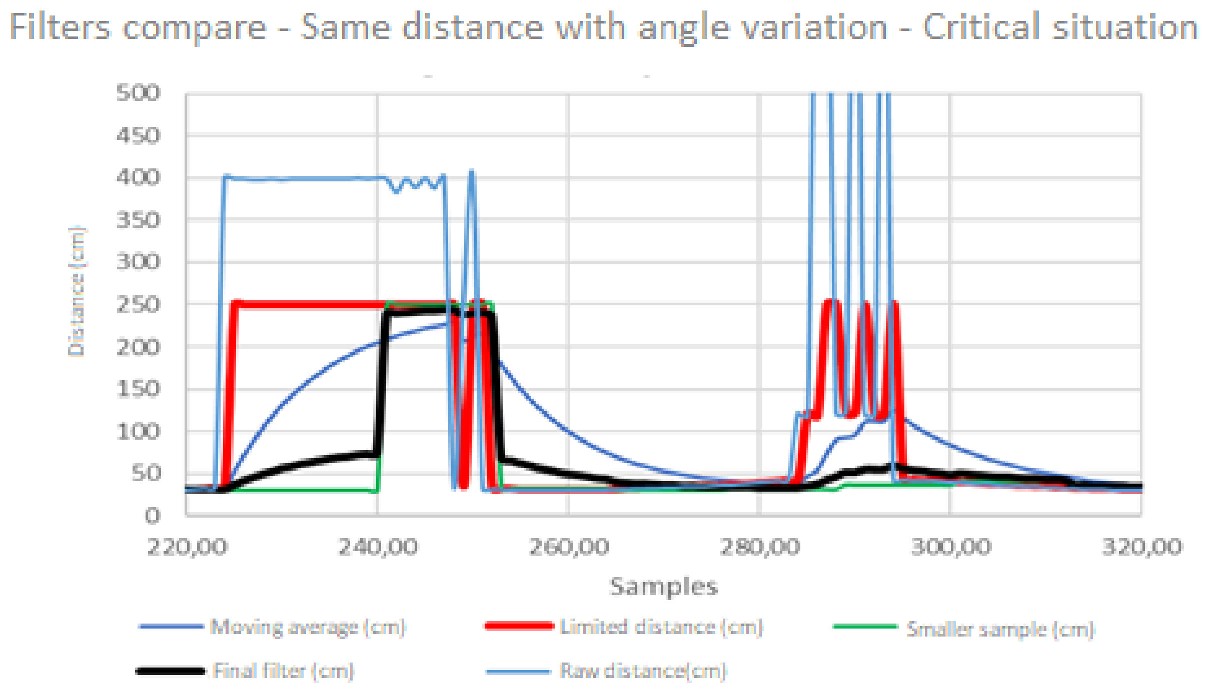
The codes were developed in modules, increasing reliability during development and making it easier to fix problems by reducing the size of the codes. A file with all calibration parameters has been created, which allows easy updating of parameters in real-time which optimizes the adjustment of the device.

The logic used for the reading is to send a trigger signal to the upper sensor and wait for a response that will generate a hardware interrupt up to a limit determined by a timer. It repeats for the medium sensor, later, it also occurs with the lower sensor, and after that, a reading is made from the ultrasonic sensor. The vibration response is updated from a specific timer, and the output is a PWM signal, which, in addition to varying in intensity continuously, can also generate intermittent responses, which increases the number of different responses possible, helping to distinguish the differences in signal responses better. The PWM signal is sent to an NPN BC337 transistor, which acts as a switch to drive the vibration motor.

The first stage of tests was performed individually per component to evaluate their response. At the ultrasonic sensor's test, the response with the sensor stationary had a coherent result, but when the movement of the sensor was simulated, some inconsistencies appeared in the signal at wider angles as the speed of the movement increased. Some signal treatments were implemented to correct these inconsistencies, seeking a consistent response for the user.

The signal treatment was done from a mixture of filters, namely: saturation of the signal at 2.5 meters to reduce the error of erroneous signals captured by the sensor, moving average to smooth the signal, taking the lowest value among ten samples to accelerate the descent of the signal since a non-detection of an obstacle is critical and the moving average delays the decay of the information, which improves the final distance information, as can be seen in Figure 9.

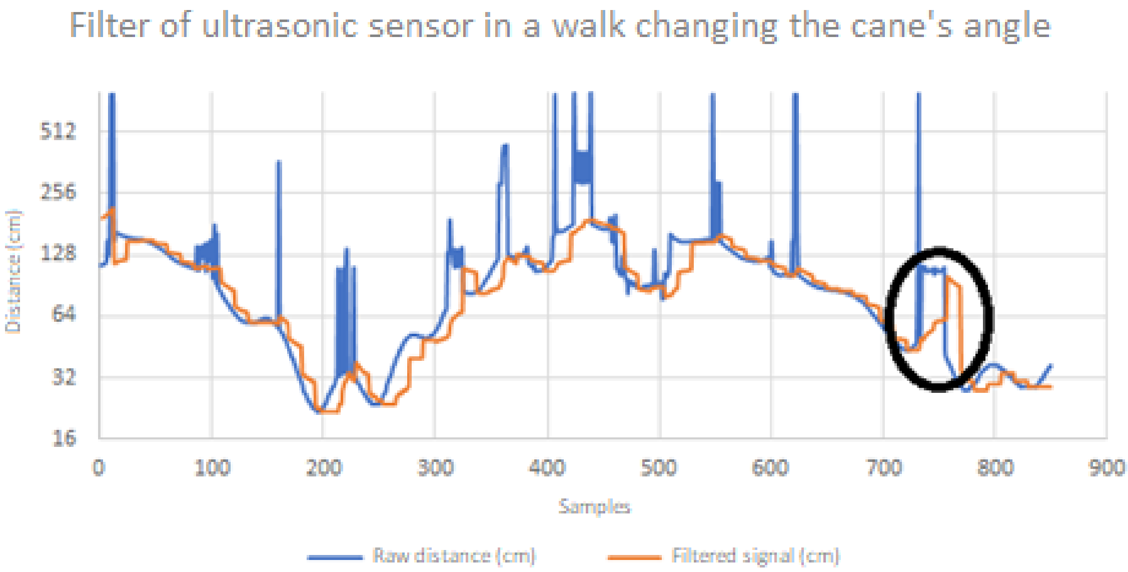
Figure 9 – Comparison of signals with and without filter



Source: The Authors (2023)

The final filter was tested with a walk, moving away and closer to the obstacle, where the improvement in relation to the raw signal is noticeable, but which shows a point at which the distance still had a considerable delay that can be improved, as highlighted in Figure 10.

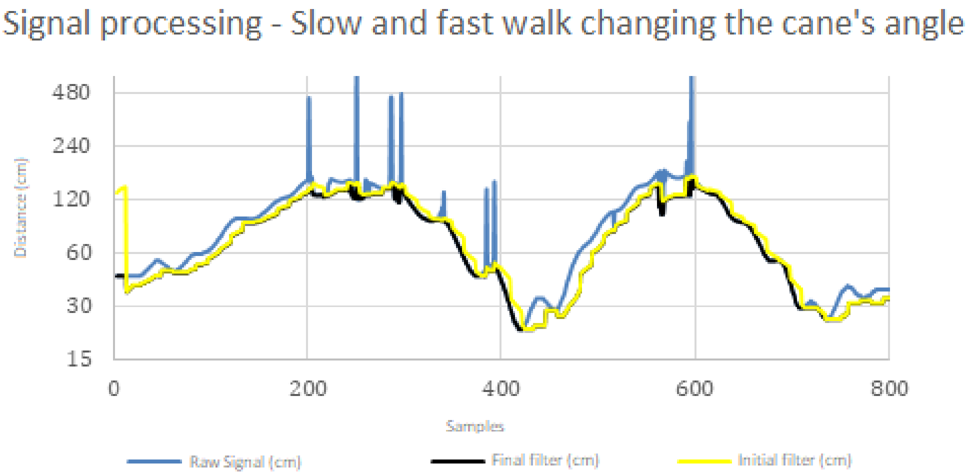
Figure 10 – Signal result for walking simulation



Source: The Authors (2023)

The solution was to use the smallest signal between the filter and the original signal, which proved to be the best solution for signal conditioning, as shown in Figure 11.

Figure 11 – Signal result of the lowest value between filter and original for testing

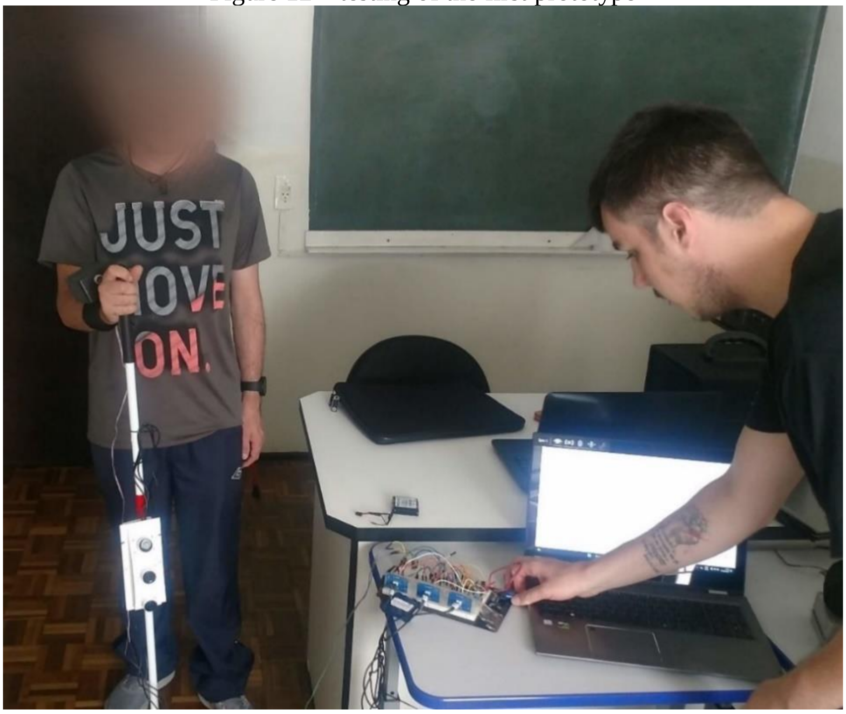


Source: The Authors (2023)

In the second stage, tests were carried out with the electronic circuit of the device mounted on a protoboard, where first, the individual functioning of each part of the circuit was verified and later the test with the entire circuit in operation. In the protoboard tests, it was confirmed that the device was functional. However, it needed some adjustments regarding the programming, mainly referring to the calibration of the responses of the ultrasonic sensors.

At the end of the second stage of testing, the assembly of the first prototype was carried out with the electronic circuit still mounted on a protoboard, which limited the displacement area of the prototype. The prototype was tested with users, including two visually impaired volunteers, and usability and functionality criteria were evaluated (Figure 12).

Figure 12 – testing of the first prototype



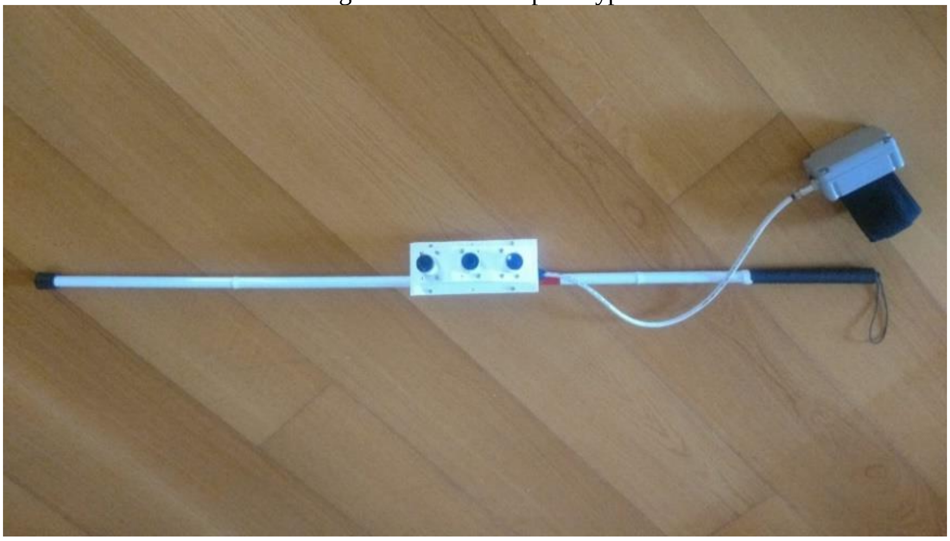
Source: The Authors (2023)

The main perceptions of the visually impaired volunteers regarding the prototype test were that the device is functional, signaling to the user the presence of an obstacle, that the user will need time to train his perception of the stimulus, and that for a final product, there is a need to reduce the weight and size of the device.

Based on the data collected during the tests, the programming code was improved to achieve a better calibration of the ultrasonic sensors and vibration motors and thus have a more appropriate response to the user.

Finally, the second prototype was assembled (Figure 13), with the electronic circuit built on a copper-plated phenolite plate, making it possible to make the device version completely portable, no longer having the displacement limitation that existed in the first prototype. The prototype was also tested with users (Figure 14) but not visually impaired, where its functionality in detecting obstacles was verified.

Figure 13 – Second prototype



Source: The Authors (2023)

Figure 14 – Testing the second prototype

Source: the authors (2023)

4 CONCLUSIONS

The use of assistive technology to aid the locomotion of people with severe visual impairment or blindness is essential because it provides greater autonomy and safety to this population, contributing directly to the reduction of limitations caused by disability and the increase of independence and social inclusion. What is observed, however, is that the vast majority of visually impaired people do not have access to this technology since the products available on the market are expensive, require specific training for use, and sometimes do not reach the knowledge of users.

The main objective of the work was to develop a proposal for assistive technology, at a lower cost compared with the products available in the market, through a device that can be integrated with a cane for the visually impaired in such a way as to complement its function. An advantage of using the device on the cane is that the adaptation time tends to be shorter since the target audience already uses the cane.

To define the proposal of the device, it was essential to carry out a bibliographic survey and interviews with IPC specialists, where it was possible to raise the real difficulties and needs of the target audience and obtain feedback about their expectations about the device. It was also essential to carry out the study on the positioning of the sensors, which made it possible to develop a proprietary methodology to size the number and ideal positioning of the sensors to achieve the best coverage for detecting obstacles.

At the end of the study, a prototype was developed consisting of a support with sensors (ultrasonic and infrared) attached to the user's cane and a bracelet that, using vibration motors installed in it, will signal to the user the presence of obstacles. Also on the bracelet is a microcontroller, which will process the data from the sensors and command the activation of the vibration motors and a battery, which powers the entire device.

The programming of the microcontroller was done using interrupts and timers to optimize its processing, and the codes were made in modules to facilitate future evolution. The calibration module stands out, which made it easier and more efficient to configure the response to the user so that the operation of the device can be customized according to the needs and sensitivity of each user.

The device proved to be functional in bench tests as well as in end-user tests but with limitations in displacement due to the prototype not yet being completely portable. The portable version of the prototype was tested, but not by visually impaired users, and its obstacle detection functionality was also verified. The tests indicated that there are improvements to be made in the weight and design of the device, as well as in the calibration, which needs to be developed to be more effective, but the results indicate that the device has the potential to perform its function of helping the movement of visually impaired people.

It was possible to carry out a project with good marketing potential, as it meets a need of a well-defined large audience, has a cost of materials and a business plan that makes it possible to launch the product at a lower price than the other options on the market and has a planning of partnerships with institutions that can bring a good dissemination of the product.

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