Guidance device for visually impaired people based on ultrasonic signals and open hardware

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ABSTRACT

Visual impairment is a complex challenge that affects people of all ages, and it is estimated that around 2.2 billion people worldwide lack adequate access to medical treatment and support. In Latin America, there is a lack of attention to people with visual disabilities, evidenced by poor urban infrastructure and lack of compliance with inclusion laws. Some projects stand out for the use of prototypes with artificial vision technology, global positioning system (GPS) and smart canes. Therefore, the objective of the project is to use ultrasonic sensors and a low-cost electronic device coupled to canes, for obstacle detection and mobility using an open hardware embedded system. The results confirmed the efficiency in the detection and operation of the ultrasonic sensor by activating the light emitting diode (LED), the buzzer and the vibrating motor according to the programmed distances. Challenges were identified, such as adapting the sensor to the tilt of the cane and the importance of accurate calibration of the ultrasonic sensor. The system met its objectives by detecting objects in a range of 2 to 50 cm and providing sound alerts to improve the perception of blind people.

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1. INTRODUCTION

Visual impairment highlights the complexity that blind people face when interacting in their environment, which does not allow them to perceive objects that are in their path, causing collisions, and injuries. Worldwide, visual impairment is a worrying problem, affecting people of all ages and showing a higher incidence in those over 50 years of age, who are more likely to suffer from visual diseases such as cataracts [1], [2]. This translates to approximately 2.2 billion people worldwide facing visual impairment without adequate access to medical treatment or support [3], [4].

In Latin America, despite the existence of organizations such as the Pan American Health Organization (PAHO), there is a lack of attention and empathy towards people with visual disabilities, as demonstrated by the deficient urban infrastructure and the lack of compliance with Law No. 29973, which seeks the inclusion of people with disabilities in Peru [5], [6]. In Peru, according to data from the National Institute of Statistics and Informatics (INEI), more than 801 thousand people live with visual disabilities, underlining the magnitude of this problem. Furthermore, the situation is more critical for the female population, which constitutes 57% of those affected, and where visual disability represents 48.3% of the total disabilities in the country [7], [8]. This problem requires comprehensive solutions that go beyond street repairs and address the specific needs of this population [9], [10].

In the field of assistance for people with visual impairments, projects such as the smart cane [11] stand out, which uses ultrasonic sensors and other components to detect obstacles and provide guidance to people with visual disabilities in Colombia. However, choosing the most effective device remains a debated topic and depends on the adaptability of the user. In addition, they have developed prototypes that use artificial vision, sound and global positioning system (GPS) technology to help blind people detect objects and obstacles at distances of up to 12 m [12]. On the other hand, there are solutions that use various sensors, such as ultrasonic and infrared, to alert visually impaired people about obstacles in their environment and provide sensitive responses [13]–[15] by generating vibration patterns in a microcontroller.

On the other hand, there are solutions based on the use of canes using a smart geo locator [16], [17] with real-time location, while others use ultrasonic sensors, a microcontroller and GPS to detect obstacles in familiar areas and urban streets [18], [19]. The third approach [20] is based on the experimental design of an electronic cane, with the participation of people with visual disabilities in its development, focusing on their specific needs and experiences [21], [22]. These studies show a variety of approaches and solutions to improve the mobility and safety of people with visual impairments, which could also integrate technologies to detect movement patterns or activities in embedded systems [23].

Based on this problem and considering the accessibility of this technology, this paper proposes to design a low-cost electronic device that can be incorporated into the cane used by people with visual disabilities. This device, equipped with sensors and an audible alarm, will allow the detection of obstacles within the range of movement, thus improving the quality of life and mobility of people with visual disabilities. In addition, it is important to consider scalability at an energy level to use the device continuously.

2. RESEARCH METHOD

The proposed method is based on the use of the HC-SR04 sensor, which emits ultrasonic pulses to identify obstacles. This sensor, in combination with the Arduino Uno board, is rigorously configured and evaluated to achieve accurate obstacle detection within a preset range. This section describes the key features and parameters of the design, structuring the solution into six components: sensor stage, processing device, control algorithm, mechanical structure, and integration (Figure 1).

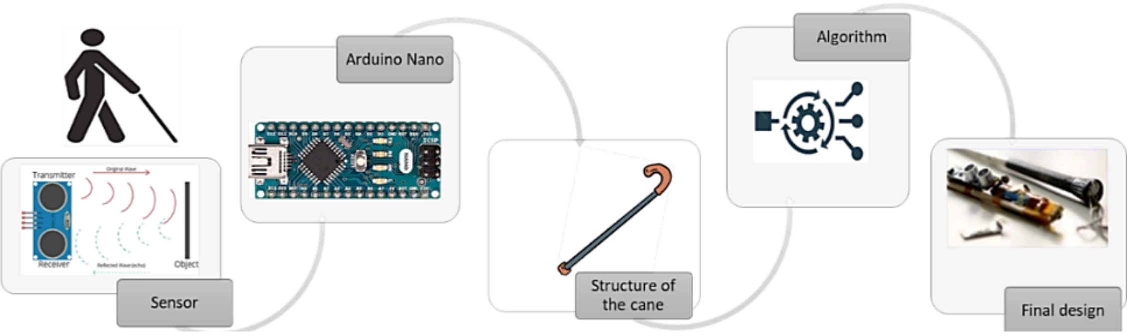

Figure 1. Components of the proposed solution

2.1. Design specifications

For the choice of components, the characteristics and costs available in the local market were evaluated to build a low-cost device. The selected components include the Arduino Uno as the main intelligent component [24], [25], the HC-SR04 ultrasonic sensor, a 9 V lithium-ion battery, a passive buzzer and a coin-type vibrator motor (Figure 2). These components were integrated into the obstacle detection system considering the energy constraints.

2.2. Parameter specification

In this section, the operating parameters and range of both the ultrasonic sensor and the passive buzzer are defined. Since the purpose of the HC-SR04 sensor is to detect obstacles in its environment, it is essential to define the operating range [26], [27]. Instead of maintaining the full range of 2 to 400 cm, it was decided to reduce it to avoid excessive detection at long distances, which could be unsuitable for the needs of the solution, delimiting two specific ranges ([2;20] cm and <20;50] cm). Within these ranges, the buzzer will activate (but with different sound frequencies) and the vibrating motor will only activate in the range

[2;20] cm to provide a more intense and obvious alert when an obstacle is nearby. In relation to the passive buzzer, two distance ranges have been established that require different operating frequencies in 2 ranges:

- For the first range, [2;20] cm, a frequency of 220 Hz (corresponding to the musical note LA) was selected to generate a lower tone. In programming, we will use the "tone" command, specifying the pin to which the buzzer is connected (pin 12), followed by the frequency in Hz and a delay.
- As for the second range, <20;50] cm, we will use a frequency of 415 Hz (which coincides with the musical note SOL#) to obtain a higher pitch. In a similar way to the previous case, we will use the "tone" function to obtain this frequency. Table 1 shows the tones generated for each range, on pin 12, with a duration of 100 milliseconds.

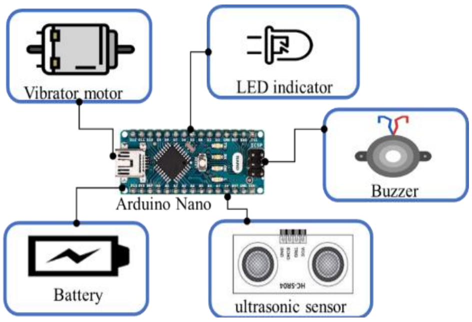

Figure 2. Device components

Table 1. Instructions for tone generation

# Líne	Instruction
1	Tone (12,220,100)
2	Tone (12,415,100)

Subsequently, the operation of the HC-SR04 sensor is validated, for which an algorithm is implemented to perform the calibration. Figure 3 shows the initial evaluation program where the sending and receiving of the generated pulses is conducted to obtain the distance at which the object was located. The algorithm uses an ultrasonic sensor to measure the distance to an object and send that information through the serial port of the microcontroller of the Arduino module, where the connection pins to the ultrasonic sensor and the necessary variables are first defined (Figure 3).

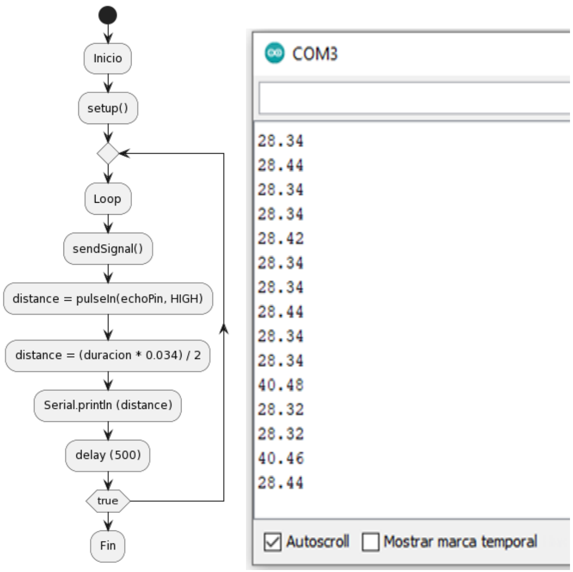

Figure 3. Algorithm for evaluation of the HC-SR04 sensor

An initial implementation was conducted to evaluate the sensors, adding a liquid crystal display (LCD) screen to observe the distance of the object in real time (Figure 4). The sensor detected objects at a specific distance and displayed the measurements on the serial monitor and LCD. Evaluations were then conducted to enable the passive buzzer (pin D12) and the vibrator motor (pin D3) with processes implemented in the microcontroller algorithm.

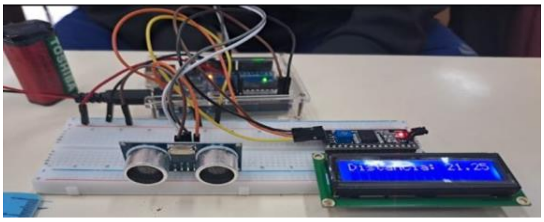

Figure 4. Physical testing of the ultrasonic sensor with an LCD

2.3. Detection algorithm design

The "visualino" development environment was used to generate the code on Arduino, using a variable called "distance" that was initialized with the value zero. The ultrasonic sensor was connected, which had three connection blocks: one for the “distance” variable (where the current value is saved), and the other two to connect the sensor to the digital pins (echo and trigger) (Figure 5). In addition, conditional instructions and loops were implemented in the code to allow proper operation of the ultrasonic sensor, adjusting the "distance" variable in real time according to the readings obtained.

An additional block was added that allowed the distances detected by the sensor to be displayed using a previously generated code to operate the ultrasonic sensor. Then, we proceeded to create control blocks to activate the passive buzzer and the light emitting diode (LED). A condition was established: if the distance was less than 40 cm, the buzzer module and the LED diode turned on (Figure 6). As the next stage, the code was obtained and transferred to the "Tinkercad" program to carry out the simulation. After verifying the operation through simulation in Tinkercad, the ranges were incorporated according to the previously defined parameters and the vibrating motor was added so that it operated. This underlines the importance of validating the algorithm through simulation before physical construction (Figure 7).

Figure 5. Ultrasonic sensor block connection

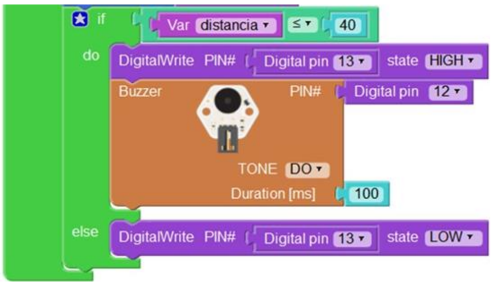

Figure 6. Final program block

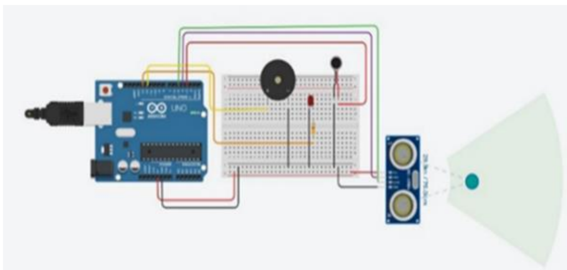

Figure 7. Final test within Tinkercad

2.4. Structural design

This section describes the construction of the cane and the integration of components using different polyvinyl chloride (PVC) tubes and two plugs that were located at the ends (Figure 8). The components were located inside (such as the buzzer, the vibrator motor, and in the case of the Arduino Nano). The key specifications for the design of the mechanical structure have been defined, which are:

- Size: the dimensions of the device must be precise to ensure proper balance and ease of movement. It is estimated that the approximate size will be 9×8×7 cm in length, width and thickness, respectively.
- Shape: the design of the device is conceived in the shape of a parallelepiped.
- Weight: considering technical data, the device should have an approximate weight of 500 grams.

The arrangement of the components on the cane was made to ensure an effective user experience. The vibrator motor was placed close to the grip point, allowing for more immediate detection upon contact with an obstacle. On the other hand, the ultrasonic sensor was located at the front, inclined approximately 20° to maintain a horizontal direction and capture obstacles on the ground. The buzzer was located on the back for a clearer perception of the sound, and an LED indicator was used to indicate proper operation of the device. The battery was positioned at the back and a 9-volt battery holder was incorporated for easy replacement.

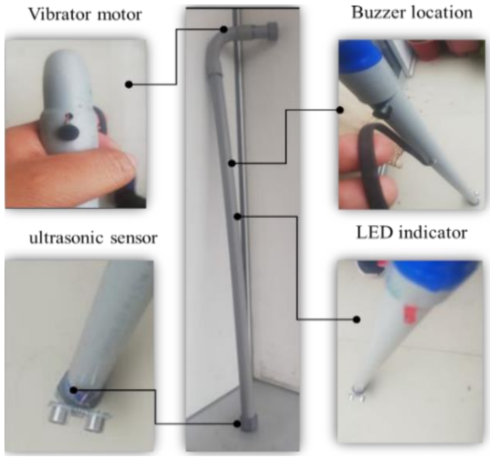

Figure 8. Location of components on the cane

3. RESULTS AND DISCUSSION

The complete assembly of the cane and its integration with the electronic device was conducted, implementing it on a breadboard to evaluate the connections and reduce errors at the time of assembly. After verifying the correct operation of the entire system, the circuit was assembled and placed on the cane (Figure 9). Likewise, a process of adjusting the physical arrangement of the components in the cane was carried out, guaranteeing an ergonomic design that would facilitate its practical use and mobility.

All tests were carried out using the circuit on a breadboard, which allowed the operation of all system components to be evaluated. At distances greater than 50 cm, according to programming, no component was activated. In the range of distances between 20 and 50 cm, an obstacle was placed at 30 cm, which resulted in the activation of the LED and the buzzer, emitting a 415 Hz sound. At distances less than 20 cm, with the obstacle located 15 cm away, the activation of the LED, the buzzer with a 220 Hz sound and the vibrating motor were observed. These tests demonstrated the efficiency in detection and operation of the ultrasonic sensor at different distances (Figure 10).

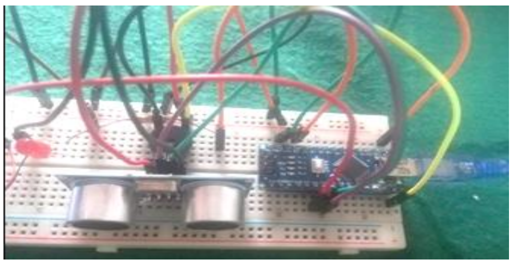

Figure 9. Breadboard connections

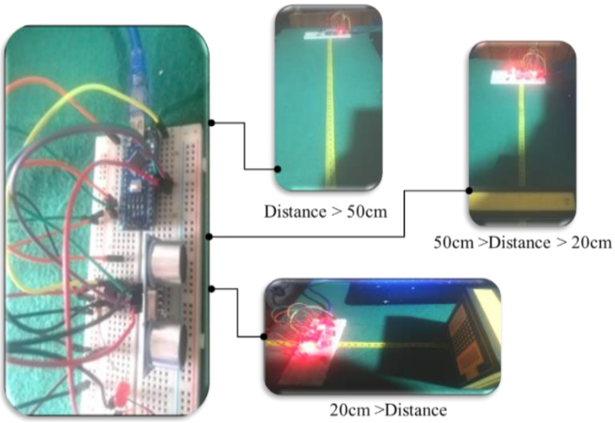

Figure 10. Detection testing

After conducting the tests, its operation was validated by evaluating sound and motor activation at different distances. Additionally, certain challenges were overcome, such as sensor placement, as the typical tilt in cane use was not considered, which required adjusting the sensor position to about 30° to compensate for this tilt. In terms of improvements for implementation, the possibility of using a more compact microcontroller, such as the Arduino Nano, to reduce the size of the cane, and replacing the vibrating component with a smaller one (such as a coin type) is considered for people with hearing impairment. In addition, the importance of properly calibrating the ultrasonic sensor was highlighted so that it emits sound alerts only within the range of programmed distances, highlighting the ergonomic design of the cane to optimize its grip (Figure 11).

Figure 11. Cane for detecting obstacles implemented

4. CONCLUSION

It was possible to satisfactorily identify all the components necessary for the system, prioritizing the choice of economical and easily acquired materials. In addition, an exhaustive verification of the operation of these components was conducted, from the simplest ones, such as the LED diode, to the ultrasonic sensor, in accordance with both hardware and software specifications. In this way, appropriate operating ranges were established for each component, including the different measurement ranges for the sensor.

The device managed to detect objects in a range of 2 to 50 cm and emit sound alerts at different frequencies to improve the perception of information by people with visual disabilities. During the implementation and testing, adjustments were made that improved both the comfort and performance of the device, managing to activate sound, vibration and sensor alerts based on distance. Furthermore, the implementation of the device was not only limited to the detection of objects in a wide range, but also proved to be an effective solution by improving the perception of information for people with visual disabilities.

Among the recommendations for use of the device, avoid using the system in places with high humidity or precipitation, since it is not designed to operate under those conditions. The possibility of using a night LED is suggested to facilitate detection in low light conditions. Finally, flexibility can be improved in the choice of materials for the stick, considering factors such as functionality, overheating and corrosion, and some components can be updated based on technological advances.

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