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Wearable Obstacle Detection System: Enhancing Indoor Navigation for Individuals with Visual Impairments

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***Abstract*—Blindness, a global condition affecting millions, presents significant challenges to independence and daily mobility. Individuals with visual impairments face constant risks of collisions with obstacles, potentially leading to severe injuries. This research focuses on developing an obstacle detection system in the form of smart glasses to enhance safety and mobility for visually impaired individuals. The prototype was designed based on a comprehensive literature review and expert consultations to ensure the optimal selection of electronic components while prioritizing comfort and usability. A V-model methodology guided the iterative development process, incorporating design, implementation, testing, and user evaluation. The device integrates Time-of-Flight (ToF) sensors for precise obstacle detection and vibration motors for real-time haptic feedback. The system alerts users through increasing vibration intensity as the distance to an obstacle decreases, enabling safer and more intuitive navigation. Field tests conducted with 11 individuals and 2 visually impaired provided valuable feedback, leading to iterative improvements. The final prototype demonstrated enhanced obstacle detection, particularly for head-level hazards, offering a practical and user-friendly assistive technology solution.**

***Index Terms*—Assistive technology, Obstacle detection, Smart glasses, Spatial location, Visually impaired navigation**

I. Introduction

Blindness is a clinical condition that affects a significant percentage of the global population. A wide range of degrees of blindness can be identified, from mild vision loss to total blindness. This disease itself possesses a peculiarity that not many share, which is its indiscriminate nature with respect to gender, race, age, and it may even occur without the need for underlying illnesses. In the year 2019, the World Health Organization (WHO) determined that there are approximately 2.2 billion people suffering from some form of visual impairment [1].

Vision can be influenced by congenital conditions, accidents, or various viral infections. Therefore, the assessment of functional vision relies on measurable parameters. Therefore to comprehend the forthcoming definitions and discussions, it's crucial to recognize that electrochemical signals from vision are interpreted and processed by the occipital brain lobes. Sharp vision needs unobstructed travel of light from the ocular surface to the outermost section of the retina, housing photoreceptors that convert light into signals [2].

Luminance, spatial, and temporal discrimination are the abilities encompassed by visual function, allowing for the precise and effective processing and understanding of the environment [2]. The two main parameters indicating visual capacity are visual acuity and visual field.The two main parameters indicating visual capacity are visual acuity and visual field.

Visual acuity (VA) is expressed as the ratio between the distance to the person being tested and the distance at which an observer with unaltered vision can discriminate patterns [3]. Similar to visual acuity, the visual field (VF) refers to the measurement of peripheral vision when looking at a fixed point toward the center [4].

Individuals with visual disabilities are exposed to the risk of impact with objects that can cause them severe harm. They tend to have more confidence when navigating indoor spaces, as outdoor risks are higher and familiarizing themselves with the environment presents a greater challenge. To orient themselves within a confined space, they must first become familiar with it, identify landmarks, and be aware of the location of potential obstacles, creating a mental map of the area [5].

Conventional mobility aids, such as the white cane, are limited in their ability to detect obstacles at head level, posing a significant risk to visually impaired individuals. In developed countries, extensive research, technological advancements, and market availability have led to the widespread development and commercialization of assistive devices tailored for individuals with visual impairments.

In contrast, Honduras faces a critical lack of data regarding the visually impaired population, making it infeasible to conduct a comprehensive statistical analysis at the national level. This absence of data hinders informed decision-making and the development of targeted solutions. However, it can be inferred that access to assistive technologies remains limited, with a significant portion of the population unable to obtain or benefit from such devices.

This investigation aims to develop a device capable of alerting visually impaired individuals about obstacles in front of them, head height. This would empower them to engage in activities with increased confidence and enhance their familiarity with surroundings to enable a more independent lifestyle.

To achieve the main objective of this research, a deeper understanding of the lifestyle and daily challenges faced by visually impaired individuals in Tegucigalpa is needed, which serves as a foundation for designing an effective assistive device. It also focuses on the selection of optimal electronic components to ensure the prototype's functionality, reliability, and efficiency. Additionally, ergonomic and user-centered design principles were integrated into the development process to enhance comfort and ease of use for visually impaired individuals. Finally, usability tests and evaluations were conducted with real users to gather feedback, allowing for iterative refinements and improvements to the prototype.

A. *State of the Art*

A literature review was conducted focusing on technologies and devices aimed at enhancing spatial navigation for individuals with visual disabilities. The review uncovered numerous analogous devices all striving towards a common objective, to create a prototype proficient in aiding individuals with visual impairments by effectively detecting obstacles. Table I shows a summary of the main topics discussed in the review. The reviewed 11 publications were sourced from various indexed scientific databases, including IEEE Xplore, ResearchGate, SciELO, MDPI, and Taylor and Francis.

The literature primarily focuses on obstacle detection devices and prototypes available in the market to assist individuals with visual impairments. For a visually impaired person, any object in their path poses a potential risk. Despite conventional technologies such as the use of a cane, this risk remains a constant challenge.

Over time, assistive devices have been developed to enable visually impaired individuals to navigate independently, without relying on a guide dog or a companion. Most commercially available solutions employ wearable technology, requiring the user to carry the device on a specific part of their body. These devices detect obstacles and provide real-time feedback to the user.

The predominant technologies integrated into these devices include sensors, such as ultrasonic, proximity, and infrared sensors. Some solutions also leverage computer vision and artificial intelligence by incorporating cameras for advanced processing. Additionally, certain devices utilize Bluetooth communication, enabling data transmission through Internet of Things (IoT) based systems that interconnect the device with a mobile application for feedback.

Depending on the type and placement of the sensors, as well as their positioning on the user's body, these devices can detect ground-level hazards such as water, holes, and stairs, as well as elevated obstacles such as hanging objects.

The technologies employed in a large number of these devices include sensors such as ultrasonic [6], [7], proximity, or infrared sensors [8]. Additionally, the use of cameras for processing through computer vision [9] and artificial intelligence is also mentioned [10].

The detection range of these devices depends on the specifications of the electronic components used for obstacle detection. For instance, many studies utilized ultrasonic sensors, whose detection range can vary significantly. One example found in the literature describes an ultrasonic sensor with a range of 0.03 to 6 meters.

TABLE I
SUMMARY OF TOPICS IN LITERATURE REVIEW

Topic of Interest	Summary
Technology for Obstacle Identification [11], [9], [10], [7], [6], [12]	The technologies primarily involved various types of sensors. Some authors also utilized cameras, incorporating artificial intelligence into their work.
Microcontroller [11], [7], [12], [13]	The microcontrollers identified in the publications belong to the Arduino and Raspberry Pi families.
Interconnection [7], [13], [14]	Some prototypes featured modules enabling interconnection with other devices, such as mobile phones.
Device Placement [11], [9], [7], [6], [14], [15]	Common locations for placing included the hand, head, shoulder, chest and waist. The devices varied from gloves, glasses, and belts. Implementation on the cane commonly used by individuals with visual disabilities was also considered.
User Feedback [11], [9], [10], [7], [14], [15]	Feedback mechanisms included vibrating motors, audio through headphones or speakers, and tactile hexadecimal keyboards.
Measurement Range [6], [15], [16]	The measurement range for obstacle detection ranged from 0.03 meters to 12 meters.

The technologies used to provide feedback to the user about detected obstacles varied across sources. In some cases, vibration motors with different intensity levels were implemented, while in others, a tactile module was used to alert visually impaired individuals of nearby objects. Another commonly employed technique was audio feedback, where the device incorporated headphones to deliver auditory cues.

II. METHODOLOGY

The research process began with the identification of the core idea and objectives for the development of a prototype aimed at assisting visually impaired individuals. To incorporate stakeholder perspectives, visits were conducted to a non-profit center institution dedicated to training individuals with visual impairments in Tegucigalpa. Through this engagement, direct communication was established with three visually impaired individuals who voluntarily contributed to the prototype's development.

The V-model methodology for the development of prototypes was used for this research [17]. This methodology divides the process into subsystems: electronic and programming. To develop this methodology two processes were done: design and integration testing. An iterative process was conducted until a complete and functional system integration that meets its requirements was achieved. This methodology divides the development process into three key stages: design and integration testing, following an iterative approach to ensure a fully functional system that meets the specified requirements.

During the component selection phase, in addition to the literature review, guidance was sought from university faculty with expertise in the field. The final selection of components involved interviews and a focus group, where visually impaired participants provided feedback on the proposed hardware elements of the device. Their input guided the selection of sensors, microcontrollers, and feedback motors.

Once the components were obtained, the development process was divided into two parallel tracks: electronic and software design and structural design.

For the electronic and software design, individual component testing was conducted prior to integration. A checklist-based evaluation ensured that each component met the success criteria. The Xiao RP2040 microcontroller was configured in Arduino IDE, with the required libraries installed for proper operation. Basic test codes were uploaded to validate the microcontroller's ability to execute programmed instructions.

To test the vibration motors, an Elvis board was used to apply different voltage levels, assessing the intensity of vibrations at each level. For the sensors, predefined obstacles were placed at measured distances to verify that the sensor readings matched the actual distances.

Following successful individual component testing, full system integration was performed. The software architecture in Arduino was designed to process data from the sensors, transmit it to the Xiao RP2040, and trigger feedback in the vibration motors based on predefined conditions. Once system functionality was validated, a first prototype was assembled.

For the structural design, component measurements were taken and integrated into a 3D model using SolidWorks. The objective was to produce a wearable glasses-shaped prototype, ensuring that all wiring and component connections were embedded within the 3D structure. Various eyeglass styles were analyzed for reference, and dedicated internal conduits were incorporated to house the wiring. The finalized design was processed using Prusa Slicer for optimized 3D printing on a Prusa 3D printer.

The prototype evaluation began with a controlled environment test, where an obstacle course was designed to simulate real-world navigation challenges. After passing initial test parameters, trials were conducted with visually impaired volunteers from the focus group. Their feedback was incorporated into the final adjustments, leading to the development of the final prototype.

III. Results y Discussion

A. Challenges for the visually impaired in Tegucigalpa, Honduras

One of the key activities during the prototype development was engaging with training centers for visually impaired individuals in Tegucigalpa. Additionally, meetings were held with visually impaired individuals to gain a deeper understanding of their needs and opinions regarding the development of a device capable of assisting them in detecting obstacles at head level.

Through this engagement, insights were gained into the lifestyle of visually impaired individual. There are several centers dedicated to the training of visually impaired individuals, and it is common for people with this disability to attend these centers once they begin walking, as they are taught how to navigate using a cane.

It is important to note that visual impairment does not solely refer to blindness; there are conditions that affect the ability to detect colors or depth. As a result, not all individuals with visual impairments require a cane for navigation. It is common for these individuals to memorize the layout of their environment in order to navigate confidently within enclosed spaces.

The primary objective of this engagement was to determine whether the prototype addressed an existing need and whether it was of interest to the users. Participants in the focus group highlighted that objects which cannot be identified with a cane pose a significant risk while navigating. Collisions with objects such as signs, fire extinguishers, and other hanging items are common when individuals are unfamiliar with their surroundings.

B. Electronic Design

1) Ranging sensor: The VL53L0X was selected because of its cutting-edge Time-of-Flight laser-ranging module stands out as the smallest in the market. The ranging module operates on a 3V-5V DC power supply with a current consumption of 10mA (max 40mA). It offers a measurement range from 50mm to 2000mm with an accuracy of ±30mm. Featuring a digital I2C interface at 400kHz. Equipped with a 940nm VCSEL laser, the module includes on-board voltage regulation. It ensures safe use with Class 1 laser standards covered in IEC 60825-1:2014, and anti-interference optics, operating without additional optics.

2) Microcontroller: Initially the Seeduino XIAO SAM21 was selected, but going through some tests the team discovered that the microcontroller was unable to power up the vibrator motors selected because of their need of at least 40mA. So the upgrade to the RP2040 was needed.

3) Feedback to the user: Due to their compact dimensions and encapsulated vibration mechanism, coin vibrating motors were chosen, this vibration motors needed 40mA on a 3.3V structure.

By meticulously scrutinizing each component's performance, and running simulations of the schematic in Fritzing, the team could confidently affirm that the prototype would meet its intended objectives and deliver optimal results for individuals with visual impairments.

C. Structural Design

The goal of the design was that it came to be glasses that looked and felt like regular eye wear, emphasizing user comfort. It also aimed to seamlessly integrate all electronic components within the glasses' frame, ensuring a sleek and

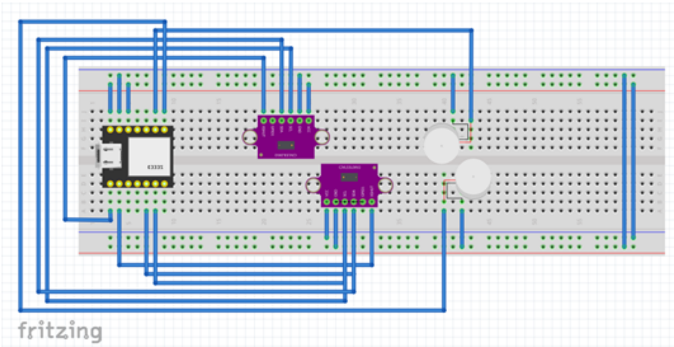

Fig. 1. Electronic diagram of the device

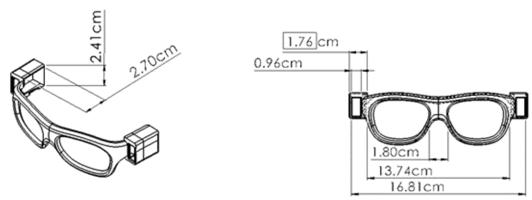

Fig. 2. Final Design of the Frontal Section of the Glasses Prototype

Fig. 3. Final physical prototype generated

```
// address we will assign if dual sensor is present
#define LOX1_ADDRESS 0x30
#define LOX2_ADDRESS 0x31

// set the pins to shutdown
#define SHT_LOX1 28
#define SHT_LOX2 29
```

Fig. 4. Address assignation for I2C protocol

inconspicuous design. The result was a preliminary solution for incorporating electronics into daily life, without the need for bulky attachments or noticeable add-ons.

For this phase, SolidWorks, a 3D computer-aided design (CAD) software, played a central role. It was employed to create a digital representation of the glasses' structural components. This included modeling the frame, arms, and any other relevant parts with precision and accuracy. Within several hours of work the final design came to be as as can be seen in Figure 2.

Actual human measurements, including head shape, temple length, and nose bridge dimensions, were incorporated into the SolidWorks models, ensuring that the glasses fit comfortably on a wide range of users. This data-driven approach helped in optimizing the ergonomics of the glasses, reducing the risk of discomfort or strain during prolonged wear for the final prototype. One of the most noticeable improvements was made to the side pieces, where a more optimized model was created based on the feedback gathered during the screenings. The integration of electronics and physical design is shown in Fig. 3.

D. Programming Design

The programming tasks were executed within the Arduino IDE environment. Nevertheless, challenges arose in the code, primarily linked to the I2C communication protocol. This protocol facilitates the transmission of data from multiple devices over a single physical wire, with considerations related to the processing capacity of the master component—in this instance the Xiao Seedstudio RP2040 and the precise assignment of unique addresses to each slave device. The addresses are depicted in Fig.4

The final code implemented a continuous iteration process for both sensors. Each sensor collected data at intervals of 100 milliseconds. The analog signals were digitized by the microcontroller for the purpose of analyzing distance. Vibration feedback was then provided to the user based on different threshold levels that were directly attached to the average distance detected of both sensors.

E. Assembly and testing

Testing sessions were conducted with users displaying varying degrees of visual impairment, stemming from either congenital causes or simulated blindness. Out of the 13 screening subjects, 15.38% were congenitally blind, while 84.62% simulated total blindness by being blindfolded.

The tests were conducted over two separate days. The first group consisted of blindfolded sighted participants, whose feedback led to several prototype improvements, which will be detailed in the feedback section. The second group, composed of visually impaired participants, tested the final version of the prototype after the necessary modifications had been made.

The test setup included obstacles made of various materials (metal, fabric, wood, and glass) placed at different distances. The height of the obstacles was adjustable to ensure proper representation of face-level hazards, as shown in Fig. 5 . The use of diverse materials allowed for an evaluation of sensor performance in a controlled environment.

Before starting the test, participants were provided with a brief explanation of the prototype's functionality. Additionally, preliminary training was conducted to help them recognize different vibration patterns, enabling them to interpret proximity

Fig. 5. Obstacle course with subjects in device testing

TABLE II
REAL AND MEASURED DISTANCES FROM SENSORS

Item	Real Distance (cm)	Sensed Distance (cm)	% Error
Right Sensor	80	82	2.5
Left Sensor	150	150	0
Right Sensor	200	200	0
Left Sensor	80	81	1.25
Right Sensor	150	115	23.33
Left Sensor	200	120	40

alerts. The vibration intensity increased as the distance to an obstacle decreased.

During the test, participants were accompanied through the obstacle course to prevent collisions in case the prototype failed to detect an obstacle in time; however, no such failures were observed.

One of the noteworthy observation made during the testing phase, both with the subjects and in earlier assessments of the sensors themselves, was that in their default state, they did not register distances up to the 2-meter mark as indicated in the data sheet. This limitation stemmed from the necessity to program the sensors using PIC to unlock their maximum performance, a task that was not possible to get done in the time limit.

To gain a comprehensive understanding of the sensors' capabilities, various distance tests were conducted, and the average values are presented in Table. II for clarity. Each of these values was obtained through individual distance tests using each sensor. The assessment involved comparing the marked distance on a surface with the measured distance recorded by the sensor.

A noticeable result of the sensor's behavior was evident during the glass testing stage with the subjects. Due to the inherent working principle of the sensors, they required orthogonality to any glass surface to account for reflections, as illustrated in Fig. 6 . Any significant angle variation could lead to inaccuracies in measurements, rendering the results unreliable.

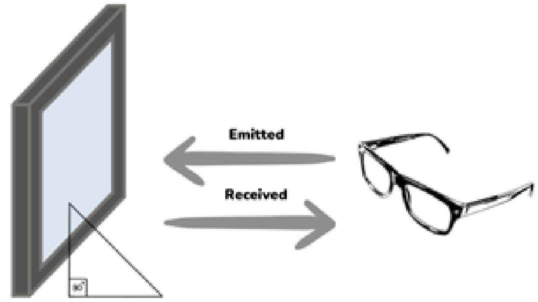

Fig. 6. Prototype behavior on glass surfaces

To gather user feedback, an initial debriefing session was held immediately after the tests to obtain first-hand qualitative insights. Additionally, a digital questionnaire was administered via Google Forms. The questionnaire consisted of 12 structured Likert-scale questions and open-ended questions, allowing participants to express detailed opinions about specific aspects of the prototype.

After completing the screening process, each participant was given a survey to assess various aspects of the prototype, facilitating subsequent analysis by the project team. The remarkable success of the final physical prototype as seen in Fig. 1 is highlighted. 76.92 % trial subjects gave positive feedback on the intuitiveness of the device and 61.538 % returned a high comfort feedback, these two variables were of high importance for the final review of the prototype. Users not only accurately discerned the presence of obstacles in diverse environments but also offered clear and detailed observations regarding the real-time functionality of the device.

IV. CONCLUSIONS

A prototype for obstacle detection was developed to support blind or visually impaired individuals in navigating indoor environments. The device enhances user comfort and accessibility by enabling the identification of head-level obstacles and the detection of various materials. Its vibration-based feedback system alerts users when they approach an obstacle, thereby facilitating safer and more effective navigation. The intuitive interface contributes to the device's potential as a practical tool for improving autonomy and quality of life among people with visual impairments.

This study also provided a deeper understanding of the lifestyle of visually impaired individuals in Tegucigalpa, including the challenges they face in daily mobility and the strategies they employ to navigate their environment. Notably, the training and adaptation process can vary significantly depending on several factors, such as the degree of visual impairment—whether partial or total—and whether the condition is congenital or acquired. These factors play a critical role in determining the specific needs and approaches required to deliver effective and personalized support for fostering independent living.

The selection of electronic components was instrumental in achieving a compact and versatile prototype. Time-of-Flight (ToF) VL53L0X laser sensors were chosen for obstacle detection, and MicroFlat vibrating motors, commonly used in cellphones, were implemented to provide non-intrusive haptic feedback. To optimize comfort and minimize the device's footprint, the Seeeduino XIAO RP2040 microcontroller was used due to its small size and robust control capabilities.

Ultimately, a glasses-based prototype was selected. This form factor was considered both practical and appealing, as glasses are commonly worn as fashion accessories. Moreover, the design is intuitive and user-friendly, enhancing its usability across diverse user profiles.

Usability and functionality tests were conducted with both blindfolded sighted participants and individuals with visual impairments. The valuable feedback collected during these trials informed the design of a potential future version of the device, ensuring its effectiveness and user-friendliness in a wide range of scenarios and among different user groups.

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