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A Necklace Sonar with Adjustable Scope Range for Assisting the Visually Impaired

Luz H. Villamizar, Mauricio Gualdron, Fabio Gonzalez, Juan Aceros, *Member IEEE,* and Carlos V. Rizzo-Sierra

***Abstract*— A sonar based device with tactile feedback was developed to improve the mobility and independence of visually impaired individuals. It features a transceiver/receiver, a potentiometer, a microcontroller, a rechargeable polymer lithium ion battery, and a Nokia Cell phone vibrator. All components are commercially available and housed in a custom acrylic package with 86 mm x 34 mm x 12 mm in dimension, and 120 grms in weight. Additionally, the device features an adjustable detection scheme for user customization of distance range, and a tactile feedback system that avoids interference with auditory sensory information. The device was tested for its navigational efficacy in an artificial indoor environment, and in a live outdoor setting. Ten subjects (9 males and 1 female), with a mean age of 35 years-old (range: 17 to 52) were presented with a series of navigational tasks resulting in considerable reduction of head, shoulder, chest, and arms collisions during their locomotion. We conclude that this device greatly improves the mobility and safety of visually impaired individuals.**

***Index Terms*— Echolocation, Obstacles, Visually Impaired, Assistive Technology, Sonar.**

I. INTRODUCTION

MAMMALS of the order chiropteran -such as bats- as well as aquatic mammals -such as whales and dolphins- have developed over millions of years an advanced active biosonar system for communication and localization of prey even under complete darkness. In such active biosonar schemes, monostatic operation is performed by transmitting sound waves and detecting its reflections. These natural phenomena have inspired the development of recent technologies for assisting visually impaired individuals [1, 2]. Such developments have shown that portable and effective sonars can be employed to improve the locomotion of visually impaired individuals by generating warning signals that let users know the presence of obstacles in their path [3]. This is of great importance as it has been demonstrated that most visually impaired individuals limit themselves to indoor (or familiar settings) due to the dangers presented from objects in unknown environments.

Although there are other forms of assistive technologies such as guide dogs or guide persons, most visually impaired individuals perceive the world through a highly inaccurate white cane. This cane allows them to differentiate objects by the response (hardness or emptiness) gathered through its touch. However, a cane is only able to detect objects in the inferior frontal region of the user path of locomotion leaving a dangerous void on the other regions [4, 5], as shown in Figure 1. This presents individuals with high risk of collisions with common and possibly hazardous objects found in the superior frontal region of locomotion. Hence, their mobility, safety, and independence are limited with such technology.

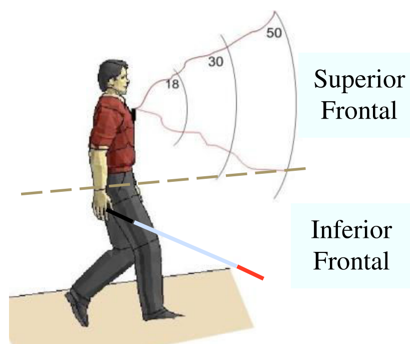

Fig. 1. Superior and Inferior Frontal Regions of Locomotion.

A number of devices have been introduced in the mainstream with the purpose of complementing current assistive technologies, and improving the user's safety and mobility. These devices include laser based cane systems that use IR optical sensors, identifier/locator devices based on ultrasound detectors mounted on glasses, ultrasound systems mounted on canes, headbands, and shirts [6, 7]. Of the cane based systems, the most popular and commercially available systems are the Ksonar, Ultracane and Miniguide [8, 9]. All these systems have the disadvantage of using some sort of audible signal to alert the user of obstacles. This produces a distraction that interferes with the user's most sensitive sensory feedback (auditory). Because of this, new systems with tactile sensory feedback, such as the hand mounted system (Tacit Sonar) are in development [10].

In this work we introduce a system for the detection of

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L. H. Villamizar, was with the Colombian Administrative Department of Science, Technology, and Innovation (Colciencias)

M. Gualdron is with University of Santander, Bucaramanga, Colombia

F. Gonzalez is with the Technology Unit of Santander, Bucaramanga, Colombia

C. V. Rizzo-Sierra is with the School of Industrial Engineering, SIGMMA, St. Thomas University, Bucaramanga, Colombia

J. Aceros is with the School of Engineering, University of North Florida, Jacksonville, FL 32224 (phone: 904-620-1684; email: Juan.Aceros@unf.edu).

objects in the immediate path (superior frontal region) of locomotion of visually impaired individuals. It uses sonar technology for the detection of objects and a vibration system (tactile response) to alert users of objects in their path. After an extensive design survey with visually impaired individuals, the system was ergonomically developed to be worn as a low weight necklace. In addition, the tactile feedback system allows users who are also hearing impaired to employ the device and free their hands to carry out other tasks. Finally, the system was tested on 10 subjects with considerable reduction in the number of physical collisions with their head, chest, and arms.

This paper is organized as follows: Section II describes the overall system design and operation. Section III describes the testing and characterization. Section IV discusses the results. Section V presents future work and conclusions.

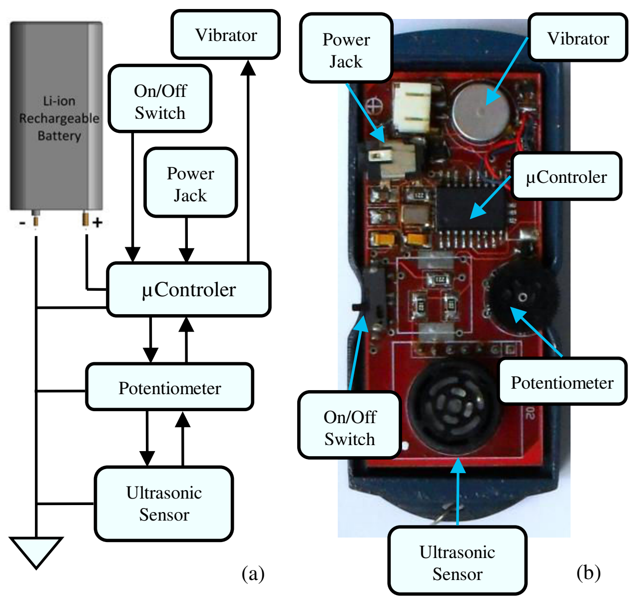

Fig. 2. System Block Diagram (a), and component location (b).

II. DESIGN & OPERATION

A. *Overall System Block Diagram and Device Operation*

Figure 2 (a) shows the block diagram for our system operation while Figure 2 (b) displays a picture of the device component layout. We only employed commercially available components for the fabrication of our current device. It consists of a transceiver/receiver (ultrasonic MaxSonar-Ez1 from Maxbotix), a potentiometer (P4B0103-ND from Panasonic), a microcontroller (PIC16F88 from Microchip Technology), a rechargeable polymer lithium ion battery (PRT-00341, model: 063048 from Sparkfun Electronics), and a Nokia Cell phone vibrator (310-101 Coin Vibrator Motor from Precision Microdrives). The battery is not shown in Figure 2 (b) as it is located behind the populated PCB board. The total cost of all the device components added to $102.00.

The operation of the device is simple. The controller sends a pulse signal to the ultrasonic transducer which emits ultrasound waves into the user's path of locomotion. This transducer then receives the information from the environment and translates it into a signal that is feed to the controller. The controller calculates the object distance using the ultrasound signal speed, and travel time. If the distance crosses a set point (fixed by the potentiometer) an electrical pulse is sent to activate the vibration transducer. The battery delivers the 3.7 V (100 mAhr) needed to run the device with a recharge cycle of 8 hrs under full power consumption conditions. These conditions are found when an object is placed directly in front of the ultrasonic sensor and the tactile feedback (vibrator) is constantly "On" for 8 hrs.

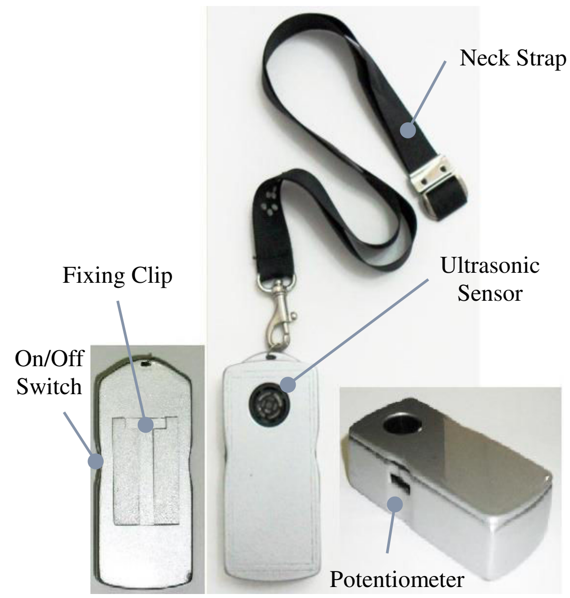

Fig. 3. Fully Packaged Device with Shiny Finish.

The overall power consumption of the device was estimated to be 288 mW. The coin vibrator consumes 255 mW, the MaxSonar-Ez1 11 mW, the potentiometer 0.03 mW, the microcontroller 0.2 mW, and the other various components the remaining 22 mW. It is evident that the coin vibrator motor (for tactile feedback) is the main source of power consumption; however this component is only active during feedback stimulation. Therefore, in practical applications the device can go for many days without the need of a recharge. Additional system features include a power jack, and an On/Off switch for power management.

B. *Device Design and Packaging*

We presented a group of visually impaired individuals with a survey asking them to detail key features needed for a truly useful assistive device, and based on their response our device was developed. The outcome of the survey was a device that features a tactile feedback system that doesn't interfere with auditory sensory information, that frees their hands to carry out other tasks, that is adjustable to their needs (its chest location can be adjusted as well as its detection range), that is low weight, that doesn't damage their clothing, that is comfortable, and that is aesthetically pleasing.

This design was accomplished by selecting the appropriate commercially available components and distributing them in a manner that minimizes its size without affecting functionality. All components were surface mounted on the Printed Circuit board (PCB) substrate, and a press fit mechanism was developed for the enclosure. This enclosure was modeled using Solid Works and fabricated using rapid prototyping of acrylic sheets.

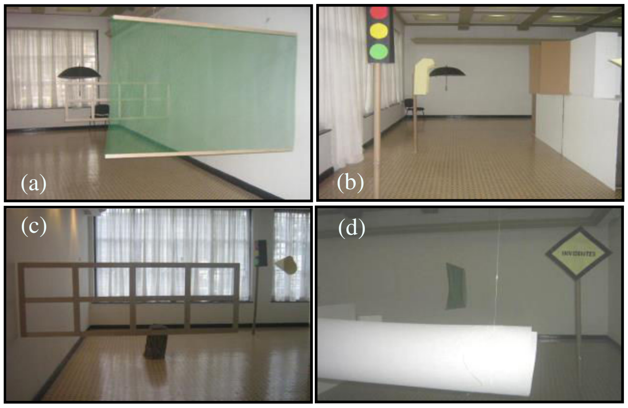

Fig. 4. Obstacle Course for Indoor Characterization.

Due to the unique physical characteristics of each individual we designed our system to be highly adaptable and customizable to the user needs. Each individual has the ability to calibrate the detection scope of the device according to their unique physical traits such as height and arm reach. The calibration of the device is carried out using the individuals white cane and a wall. The length of the white cane is typically set equal to the users shoulder height from the floor. To calibrate the device, the user would walk up to a wall with the potentiometer set at its lowest value. Once the user has reached a comfortable distance, as measured with their white cane, the potentiometer is increased to a value where the device detects the wall and activates the vibration response. The user then rotates his or her body in a 180° turn to make sure that the device is properly working.

III. Testing & Characterization

A. *Artificial Environment (Indoor) Characterization*

The device was initially characterized in an artificial indoor setting with ten visually impaired individuals (9 men, 1 woman). Two (2) were diagnosed with glaucoma, six (6) with retinal detachment, and two (2) with congenital disease. They had no prior training with the device. Before any type of testing they were asked to read the device instruction manual (which we created and wrote in Braille) and then use the device without any assistance. The process of reading the manual, figuring out how to use the device, and calibrating it to their own comfort level (as explained in the previous design section) took on average 10 minutes per individual.

After the initial set up, the first tests involved the characterization of the detection range and angular scope of our device. The ultrasonic transducer EZ1 MaxSonar has a factory specification detection range up to 6 meters and an angle of 35°.The angle measurements were carried out using aerial photography of the subjects while objects were brought into their proximity at 0°, 45°, 75°, 90°, 115°, 135°, and 180°. It was concluded that the manufacturer specification of 35° and 6 meters was not altered by our system configuration and packaging.

The second tests consisted of the characterization of the device navigation efficacy. Devices were evaluated using an artificial maze fabricated using objects commonly encountered in outdoor settings, such as windows, traffic signs and lights, cars, umbrellas, advertisement signs, bollards (vertical posts), various hanging objects, and other individuals, as shown in Figure 4. The core of this maze consisted of 1 traffic sign, 1 traffic light, 4 hanging windows, 1 door, 1 telephone booth, 1 truck chassis, and 1 bollard, all fabricated using cardboard on a 1:1 scale. Other objects, such as opened umbrellas and advertisement signs fabricated out of foam and paper, were added to the maze as individuals memorized the location of objects.

Fig. 5. Visually Impaired Individual using Assistive Sonar Device during Indoor Characterization.

In general, all users expressed discomfort during navigation when the detection range was set at a distance of 6 meters. It was concluded that a maximum object detection range of no more than 3 meters, and an average of 1.5 meters was preferred. In addition, a velocity test was carried out using a plastic ball thrown across the frontal region of the users. This ball was not detected when it crossed the sensor at speeds larger than 1m/s. Finally, multiple objects with a variety of shapes and sizes, ranging from pencils to large concrete walls, were used to explore the device sensitivity. In all of our tests in this controlled environment, users encountered high detection and avoidance rate. This encouraged us to carry out the following live outdoor characterization.

B. *Live Outdoor Characterization*

A real (live) outdoor characterization was carried out with 3 subjects. Directions were given to them on which route they needed to take but the approach to the route was entirely their choice, this included walking in the same direction as other pedestrians, and the use of sidewalks or crosswalks. Subjects encountered between 25 and 43 obstacles during these tasks. These included pedestrians, pedestrians carrying opened umbrellas, fast food carts, curbs, traffic signs, telephone booths, and traffic lights among others.

Users were also asked to follow the same route without the assistance of the device (only a white cane) and the results from both tests (with and without the assistive Sonar device) were compared. In the tests without the assistive Sonar device, all individuals suffered head collisions with opened umbrellas, advertisement signs, and traffic signs, and shoulder collisions with automobiles, and telephone booths. Finally, each participant was interviewed to collect information about the ergonomics, handling, and functionality of the device.

Fig. 6. Positioning of Device on Chest (a).Visually Impaired individual during Outdoor Characterization (b).

IV. RESULTS

Artificial indoor testing resulted in a detection and avoidance rate of 80% for 8 subjects and 100% rate for the remaining two. These two subjects were a 17 year old male and 18 year old female. The calibration and set up time for a new user was timed at 10 minutes, hence proving that this is a quick and simple device that can be rapidly implemented by visually impaired individuals without any type of specialized training. Live Outdoor testing resulted in a detection and avoidance rate of 100% for one individual (17 year old male), while the remaining two 88%, and 76% respectively. It is important to note that these tests were carried out on their first attempt using this equipment. Each individual user took an average of 4.5 min to complete the outdoor tests.

These tests also proved the stability of the chest as a location for an assistive device, as it completely allowed other body parts including head and arms to move freely, and provided an ample line of sight for scanning the frontal region of locomotion. It was found that regular walking speed didn't affect the detection rate, and a final survey of all users determined that this device provided a significant improvement over using only their white cane.

V. FUTURE WORK AND CONCLUSION

The work presented in this paper has shown that these devices improved the safety and mobility of visually impaired individuals. In addition, they also promote their empowerment, independence, self-esteem, and overall quality of living. The described system has been proven to be an economic, accurate, and useful complement to the common white cane aid. The manipulation of our Sonar system does not impose any physical effort on the user, or affects their posture during locomotion or while standing, and does not interfere with the use of their hands or hearing. In addition, it can be adjusted to the users comfort level, and has a battery life time of 8 hrs under extreme power consumption conditions.

Although this device is a great addition to the commonly used white cane there are still areas that can be improved. Zones, such as the lateral regions, are still out of the range of the detector and present a hazard from possible incoming objects. We found that younger individuals had a higher detection and avoidance rate; however this needs to be studied in more detail. As part of our survey, users expressed their interest in adding a Global Positioning System (GPS) to improve the guidance capability of the device, as has been describe by Soeda *et al* [11]. We find that there is also room to further miniaturize the system and offer a variety of aesthetic designs that would make them even more appealing to a larger population of individuals. Finally, improvements to the enclosure, such as waterproofing, are in the works.

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