Evaluation of Electronic Haptic Device for Blind and Visually Impaired People: A Case Study

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Abstract

Blind and visually impaired people face several accessibility and mobility problems due to a lack of information from the environment. The environment information could help visually impaired people to avoid physical barriers and identify alternative ways to reach the desired destination. This work proposes an assistive technology device called the electronic long cane to serve as a mobility aid for blind and visually impaired people. The cane has an ergonomic design and an embedded electronic system, which fits inside the handle of a traditional long cane. The electronic system uses haptic sensing to detect obstacles above the waistline. When an obstacle is detected, the cane vibrates or makes a sound. Experiments are conducted and the interaction between blind and visually impaired people and the urban environment is discussed. Experimental data are processed using a J48 classifier. The obtained confusion matrix output shows a satisfactory validation.

Keywords: Accessibility, Assistive technology, Ergonomic design, Embedded electronics, Haptics, Blind and visually impaired people

1. Introduction

The sense of sight is required to understand constrained urban open spaces as well as dynamic environments in which multiple and simultaneous events occur. Mobility depends on skillfully coordinated actions to avoid obstacles in the immediate path [1]. Most human environments are designed for people without physical handicaps, which does not reflect the situation in actual societies [2]. In general, urban environments provide a lack of a sufficient signalization of, for instance, public phones, mailboxes and twigs of trees, with which a blind or visually impaired person could collide. Accessibility, thus, is an aspect of attempts to change environments in order to take into account physically handicapped people's needs [3]. Access to information about environments is especially essential for blind and visually impaired people [4], since it allows more independent mobility and thus integration into society.

According to Hersh and Johnson [5], several studies have applied available technology to mobility assistive devices, with most effort devoted to assistive technology for avoiding obstacles. Wada et. al [6] proposed a guidance system to the blind based on several sensors mounted on special shoes. On the other hand, Hoyle et al. [7] observed that a traditional long cane, widely used by blind and visually impaired people, does not detect physical obstacles above the waistline. They proposed enhancing mobility by embedding a multi-element ultrasonic sensor to collect spatial data, which are processed to estimate surrounding features and to provide an assessment of potential hazards based on a tactile multiple-stimulus user interface.

Two of the few commercially available electronic canes are Ultracane (Sound Foresight Technology Ltd) and Bat K Sonar (Bay Advanced Technologies Ltd) [8,9]. The proposed electronic long cane and these devices have the same functionality and employ the same ultrasonic sensing, but they differ in ergonomic concepts and costs. The present study adds a simple electronic component based on haptics sensing [10,11] to a traditional long cane to prevent collisions. The electronic system, embedded in the grip, detects obstacles above the waistline and alerts the user via vibration or a sound when an obstacle is detected. This feedback becomes increasingly frequent as the user approaches a physical barrier. Despite its simplicity, the integrated hardware solution improves mobility.

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2. Materials and methods

2.1 Design of long cane

The long cane is a very helpful tool for teaching blind and visually impaired people how to move and orientate more independently in open urban spaces. According to Hoffmann [12], environmental information is captured by tactile sense, perceived by the hand nerve receptors, and sent to the brain. The use of the long cane, which requires the ability to exploit all remaining senses, is taught by a specialized instructor.

A common long cane is long and light. It comprises three parts, namely a handle (grip), a straight shaft (or articulated shaft), which works as an extension of the user's body, and the tip, which makes direct contact with an object or the ground, as shown in Fig. 1.

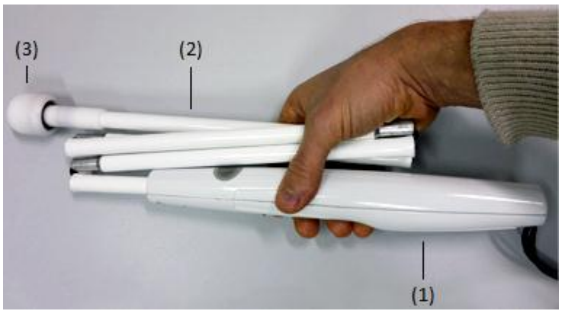

Figure 1. Long cane components.

Common long canes are mainly intended to detect different objects from the ground to the waistline, both under familiar and unknown environments [13]. The touch technique is widely used by blind and visually impaired people during independent locomotion in open urban spaces. This technique is based on space exploration, with the cane tip touching the ground, which stimulates the human tactile sense.

2.2. Electronic long cane project

The Electronic Long Cane Project was motivated by the fact that traditional long canes detect irregularities and obstacles on the ground, but fail to detect those above the user's waistline (see Fig. 2). In order to avoid this limitation, a device was developed to achieve better spatial exploration based on ultrasonic technology (see Fig. 3). To develop such devices should follow five steps: research and data collection, similarity analysis, proposal conception, generation and tuning of choices, and set description [14]. The formal features of the device and its components were defined using this procedure.

The device was designed to detect physical barriers above the waistline based on echo detection and to give tactile feedback in the form of vibration (or sound) inside the cane to warn about potential collisions. It also preserves the original functions of a traditional cane. Echo detection is computationally suitable to be performed in real-time on a small portable device.

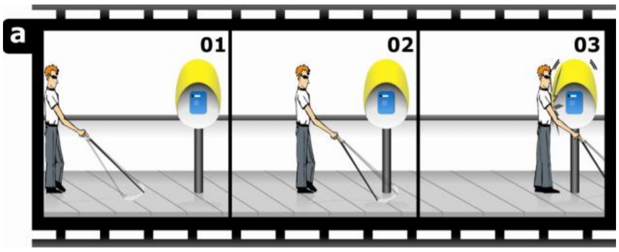

Figure 2. Long cane limitations.

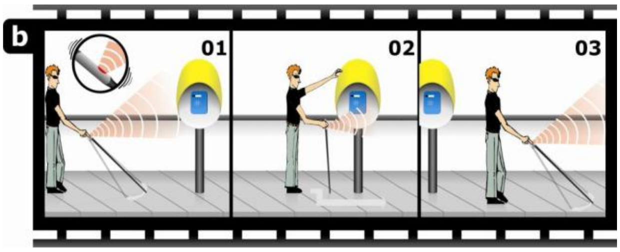

Figure 3. Diagram of how electronic guidance improves spatial perception.

Figure 4 shows a diagram of embedded electronics interface comprising an ultrasonic sensor (LV Max Sonar EZ series, MaxBotix, USA), a micro-motor commonly found in cell phones, a controller (ATtiny13 AVR microcontroller, Atmel, USA) and a 9-V battery. The haptic sensor and controller are embedded in the cane.

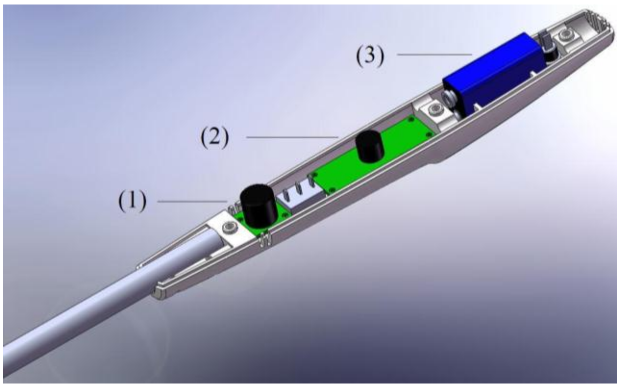

Figure 4. Diagram of gripper components: (1) ultrasonic sensor and micro-motor, (2) microcontroller, and (3) battery.

When an obstacle is detected by the ultrasonic sensor, a haptic response is triggered inside the cane. Tactile feedback becomes increasingly frequent as the user approaches the obstacle. The ultrasound wavelength range was chosen according to cane dimensions to prevent the system from detecting obstacles outside the cane reach. Obstacles beyond the cane reach are not immediately relevant to the user. Tactile feedback was selected to preserve hearing sense, which is necessary for perception and recognition processes.

The first prototype was evaluated in conjunction with experts from the Mobility Techniques Department at ACIC-Santa Catarina Association for the Visually Impaired Citizen Integration. An improved device was subsequently developed and built (see Fig. 5).

Figure 5. New cane prototype.

2.3 Experimental design

The two prototypes were tested in real environments at different times, and a usability study was carried out. The first prototype was tested at ACIC, as mentioned, and the second one was evaluated in conjunction with experts from the Mobility Techniques Department at LARAMARA-Brazilian Association of Assistance to Visually Impaired People. Participants were observed while moving to get a sense of how they faced daily problems in terms of spatial characteristics.

The grip of the second prototype was 22 cm long, 3 cm in diameter, and 0.170 kg in weight. The ultrasonic sensor range was set at 1.5 m, covering an angle of 30°. Battery life was ten hours. A 40-kHz ultrasonic wave was sent to measure the distance from the user to an obstacle. The delay time was obtained when the echo signal arrived, and the distance to the obstacle was computed. Finally, the haptic feedback, which relies on the measured distance, was triggered. The processing time interval for echo localization was set at 100 µs (+/- 3.4 cm error).

The study was descriptive in nature. Qualitative measurements were made, as proposed by Ying [15], who explained how participants should perform previously defined tasks, regardless of time consumed or troubles found during task execution. Four methods and their associated techniques were used to carry out a qualitative evaluation. They were based on data collected on participants' behaviors while using the prototype. Tests were initially done in an open urban space under controlled conditions.

A documentary analysis method was applied by studying related research. An exploratory visit to selected places in the city was then made, and the guided tour method, developed by Brazilian researchers [3], was used. Finally, several interviews and surveys were conducted.

Participants were asked to perform the following tasks related to the touch technique to check whether they used the cane appropriately: 1) turn on and properly set up the device; 2) start walking while keeping the correct handgrip position; 3) stop moving when the haptic signal (vibration or sound) is triggered; 4) recognize, by means of touching, main features of physical barriers, previously identified through ultrasonic sensing; 5) avoid physical barriers and continue walking along predetermined path.

Participants were also interviewed after each tour in order to get their experiences of using the device. Descriptive details from observers and survey output data from participants were mapped.

The whole process was recorded by using common techniques (e.g., notes, audio-video recordings, and photography). The most significant events were included in a synthetic map, as shown in Fig. 6. This map depicts some features of the places where one of the experiments was done.

A database that comprises information gathered from surveys was built. Finally, in order to validate the results, a J48 classifier tree was applied to the samples, and then a confusion matrix [16] was obtained. Weka 3.6.1 software (University of Waikato, New Zealand) was employed.

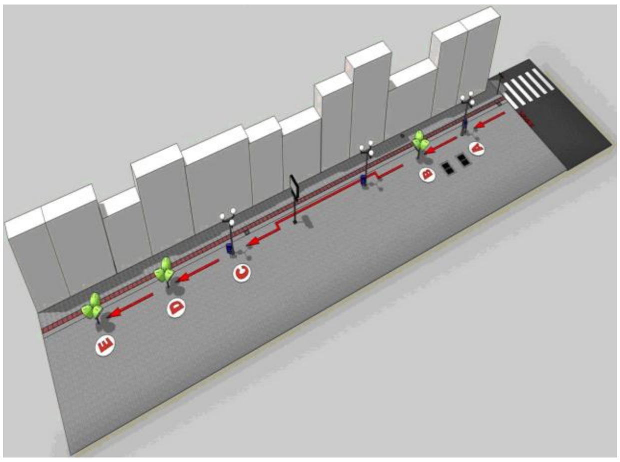

Figure 6. Example of route: departure point, barriers, and goals. A and C indicate plastic garbage bins attached on light posts. B, D, and E indicate public phones.

An optimal number of participants should be defined to carry out experiments with functional prototypes [17]. Some important logistic issues to be considered include schedule, budget, and available resources. Five to twelve participants are sufficient for experiments. Eight male participants from ACIC took part in the first experiment with the first prototype. Tests were made over a three-month period. Seventeen participants (eleven males and six females) from LARAMARA took part in a subsequent experiment with the second device. This time, tests were made over a two-month period. Participants were blind people, with remaining senses intact. Their ages ranged from 21 to 52 years old.

Some routes in the cities of Florianopolis and São Paulo were first analyzed and then selected by considering their physical characteristics. Experiments were conducted over several visits to previously selected places. Participants' proper use of the electronic cane (i.e. touch technique) while facing problems in the selected places was observed in the experiments.

Routes had a departure point and various goals to be reached. Participants were followed during the planned activities, without being led or helped by the observers. Participants were supposed to performed several tasks based on the touch technique and to stop walking only when a tactile signal (vibration or sound) alerted them to the presence of an obstacle. The experiments were carried out at different times of the day (morning and afternoon) and in different seasons (winter, summer), regardless of weather.

3. Results and discussion

Permanent and circumstantial physical barriers located above the imaginary waistline were found during locomotion tests (see Fig. 7). Physical barrier shapes were recognized through exploratory touch. The obstacles were bypassed after their recognition, and participants were able to follow their original routes.

Figure 7. Urban barriers.

Table 1 summarizes the survey output data collected from participants' answers. They were asked to asses the location of buttons and their functions. All participants said that turning the device on or off was satisfactory. They felt comfortable with the grip. They also felt comfortable maintaining the cane position according to the lateral grip mark while using the touch technique.

Table 1. Survey data summary.

	Positive aspects
1	Accuracy related to obstacle detection above the waistline
2	Satisfaction related to the use of the device and its functions
3	Satisfaction related to the ergonomics design
4	Familiarity with traditional cane and classical touch technique
5	Adds spatial extra information to traditional cane

Participants were familiar with the traditional cane and the classical touch technique. In general, they thought that the electronic device could be easily and confidently used. There was no interference by the tactile signal with other senses when obstacles were detected. This means that the feedback signal contributes to make up necessary spatial information. The feasibility of using an ultrasonic sensor to avoid possible collisions with obstacles located above the waistline was tested. It was also tested whether an ultrasonic sensor is useful for making a decision regarding how to act after obstacle detection.

Table 2 summarizes some suggestions made for helping to improve the first prototype. Based on the feedback, a smaller and lighter device was developed. The new device included a sound alarm in addition to the tactile one. A smaller ultrasonic sensor was adopted.

Table 2. Suggestions.

	Suggestions
1	The cane grip should be smaller to allow greater portability.
2	There should be a switch for sound/vibration.
3	Excessive vibration detected with heavy pedestrian flow, must be solved.
4	The tactile signal could be applied to another sensitive region of the body.
5	The price must be comparable to that of similar imported devices.

A second experiment was carried out using the improved device following the procedure of the first experiment. Seventeen participants from LARAMARA were selected. The output data were organized into a database. Eight attributes were defined (number of samples, number of trained people, comfort level, pedestrian interference, and interest to buy the device, position constraints, buy-it-now availability, and device evaluation).

Eight attributes and their corresponding values are shown in Fig. 8. The confusion matrix for two classes is shown below showing the predicted and actual classifications. As can be seen, all instances were correctly classified, which can be seen from the diagonal values 14 and 3.

Good	Bad	← classified as
[14	0]	
[0	3]	

In accordance with the preceding result an 80% of acceptance was obtained, which can be considered satisfactory. This acceptance level is similar to that reported in [4].

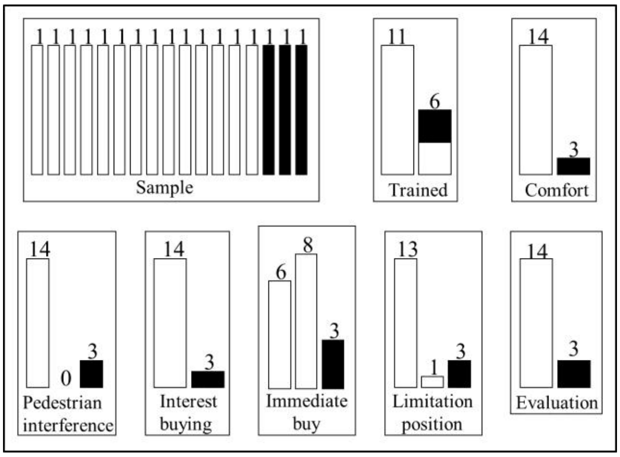

Figure 8. Attributes and their corresponding values. Each label shows an attribute: Good or Bad.

The modifications made to the device resulted in improvements. However, some problems were found (see Table 2), such as excessive vibration detected with heavy pedestrian flow. It was suggested that the haptic signal can be applied to another sensitive region of the body. These problems and suggestions will guide future research.

The feedback sound helps people with reduced hand sensibility without a significant cost increase. Unlike the Bat K Sonar device, the proposed device maintains traditional cane handling, making it more convenient. In contrast to the Ultracane, the proposed device uses only one ultrasonic sensor, considering that main limitation of a traditional cane is elevated obstacles. The device operation can thus be simplified, and its size, weight, and grip cost can be reduced. According to [18], the prices of the Ultracane and K Sonar devices are about $900 and $700, respectively. In comparison, the estimated price of the proposed device is around $350. This study evidenced the need for specific training in the mobility and orientation program, in order to understand the proper functioning of the proposed device, as well as the need for good neuro-perceptive training.

4. Conclusion

To improve blind and visually impaired peoples' independent locomotion, an electronic long cane was presented and evaluated. The proposed cane has an ergonomic design and embedded electronics inside the grip to improve spatial and tactile perception. Observations, surveys, and interviews were conducted to evaluate barrier detection and mobility. The results indicate the feasibility of the electronic long cane project. The study also shows that the prototype is fully capable of being used as an assistive technology product. The device could also be appropriate for mobility and orientation programs. Experimental data were organized into a database, eight attributes were defined, and a J48 classifier tree was applied to 17 samples. In accordance with the preceding result an 80% of acceptance was obtained, which can be considered satisfactory and similar to that reported in literature. The results validate the performance of the mobility aid device and the evaluation procedure.

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