Haptic Wearable System to Assist Visually-Impaired People in Obstacle Detection

Barbara Leporini*
ISTI-CNR, Pisa (Italy)
barbara.leporini@isti.cnr.it

Michele Rosellini
DICI-University of Pisa, Pisa (Italy)
michele.rosellini@unipi.it

Nicola Forgione
DICI-University of Pisa, Pisa (Italy)
nicola.forgione@unipi.it

ABSTRACT

One of the main difficulties encountered every day by visually-impaired people concerns moving and orienting themselves independently and safely in indoor and especially outdoor environments. Although several studies have been carried out to propose electronic aids to support orientation and mobility tasks, problems continue to exist. In this work, a wearable ultrasonic-based obstacle detector is proposed to give a further contribution to the field. The prototype is designed by paying particular attention to (1) the updating of the components and (2) the use by the blind users. It can be mounted on the user's preferred model of eyeglasses and can be used with or without the traditional white cane.

CCS CONCEPTS

• :; • **Human-centered computing** → Accessibility; Accessibility systems and tools; Human computer interaction (HCI); Interaction devices; Haptic devices;

KEYWORDS

haptic, blind, obstacle detection, mobility support, glasses

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1 INTRODUCTION

Moving and orienting independently and safely in indoor and especially outdoor environments are very challenging tasks for visually-impaired people, who normally rely on prior knowledge of the environment, and objects along the path [1]. The need for supporting aids was - and is - an important research field. There is a wide range of navigation and supporting tools available in the literature for visually-impaired people. Guide dogs and white canes are the traditional assistive travel aids used for decades [7]. White cane (or white stick) is the simplest, cheapest, most reliable and thus the most popular navigation aid. Traditionally blind persons have been using the conventional cane stick to guide themselves by touching/poking obstacles in their way [3]. This may cause a lot of accidents and may be dangerous for them and others. In fact, it does not provide all the necessary information such as speed, volume, and distances, which are normally gathered by eyes and are necessary for the perception and the control of locomotion during navigation [16]. So, blind people need some support to feel safe while moving [12].

Thanks to the advances in technology and software development, numerous new devices and tools have been proposed as supporting aid in the orientation and mobility of a blind person [5], [10], [14]. The work in [5] reports a comparative survey among different portable/wearable devices especially made for blind people to inform the research people and other users regarding the efficiency and performance of each of the devices by considering both qualitative and quantitative parameters. The authors compare different available products for blind people. This would be helpful to analyze and understand the effort in helping blind people with technology. Electronic aids are available in different forms, such as handheld devices, smart canes, and wearable systems. In this work, we refer to the latter. To sum up, studies have investigated systems to support navigation, user location, and obstacle detection.

This work proposes a lightweight wearable system to support blind people in detecting obstacles while walking independently in both indoor and outdoor environments. There are many assistive tools proposed for blind and visually impaired people, but only a few can provide dynamic interactions and adaptability to changes, and none of those systems works seamlessly both indoors and outdoors. Moreover, even if there is a system that can work fine in all situations, it tends to be complex and does not fully address the needs of a blind person ranging from the ease of usage, simple interfaces, and also lower complexity [10]. The system proposed in this work provides a contribution to these aspects. Compared to other products, the tool we propose has been designed by paying particular attention to (1) System modularity and reuse, (2) user interface, and (3) position-based obstacle detection. For the latter, the detection of open doors has been particularly taken into account.

Our idea is that the user wears the device in such a way that leaves the user's hands-free. In addition, our solution is designed to be used both in indoor and outdoor environments thanks to the opportunity to set the detecting distance by the user at any time just by pressing a button. Haptics has been used as a feedback modality, even if the designed system will include both audio and tactile feedback.

2 OBSTACLE DETECTION

The need is felt for a system to detect objects that can be present along the path of a blind or low-vision person, which may be possible obstacles against which the blind or low-vision person can stumble.

With regards to obstacle detection, electronic systems use different technologies, such as lasers, ultrasonic sensors, and digital cameras to gather information on the surrounding environment. In

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[13] the authors refer to range-based and camera-based obstacle detection systems as a criterion to detect obstacles. In range-based systems, obstacles are objects that extend a minimum distance above the ground. In camera-based systems, obstacles are objects that differ in appearance from the ground surface. In our system, we used the range-based methodology.

Another important aspect to consider in obstacle detection is related to the modality of how to communicate the information to the user. Feedback is the communication of information to the visually-impaired user for perceiving the surroundings [15]. It should convey information to be easily understood by a user. Effective feedback communicates three things: the message, the situation, and the risk. People with vision impairments have a high risk of injury or falling if they are unfamiliar with the environment, especially outdoor. Therefore, feedback saves time, reduces frustration, and helps blind persons to focus on what they are doing correctly [9]. Auditory or haptic feedback is used to communicate. Voice is direct communication that can deliver many messages to blind people. The latest smartphones offer screen reading services (e.g., Talkback and Voice over) for visually impaired users to interact with their surroundings. Many studies have used smartphone' speakers, headphones, external devices, and screen reading software to generate voice feedback. However, this feedback is not efficient in the case of noisy environments and has a high level of disturbance. The same issue may occur for sonification feedback [9]. Sonification is the use of non-speech (musical tones) to represent information such as feedback messages. It is sometimes difficult to understand the message and cannot be heard in a noisy environment. This is especially true when navigating in an outdoor environment. An alternative approach that has been explored is based on the usage of haptic feedback [6]. The feedback mechanisms used by many systems are audio, tactile, or both. The advantage of tactile feedback is that it does not block the auditory sense and can be used also in a noisy environment. Haptic feedback uses vibration patterns to convey information to the user. It uses a vibration motor/actuator for pattern generation, driven by an electronic circuit. Haptic/vibration feedback is widely used for notification systems and is especially useful when the user's auditory and visual senses are occupied. We referred to this type of feedback for communicating the information on the detected obstacles.

The white cane is an inexpensive assistive aid that requires user training and awareness to scan objects ahead, side by side and round-about is more time-consuming. Many solutions attempt to make the white cane smart by equipping it with sensors. In [11] a solution based on a walking stick is presented. The device is integrated with Infrared Sensor to detect stair-cases and a pair of ultrasonic sensors to detect the obstacles in front of the blind person. The stick uses speech warning messages and haptic feedback when any obstacle is detected. The obstacles are detected in the range of 4 meters. An important drawback of this electronic aid is that the users by themselves must point the stick in a particular direction to detect the obstacles. Such an approach could be ineffective since the obstacles might have different heights and shapes, and moving the stick just above the ground level in a specific direction might not be able to detect it. In addition, handling the device with the hand can be tiring and provide some exploration limitations due to the blind user's habits in using the traditional white cane. The device presented in [3] is designed for the guidance of a blind person in an outdoor environment. The walking stick is based on radio frequency signals having different carrier frequencies for different paths to different destinations from the user's position. Many other solutions are based on electronic and smart sticks which are equipped with sensors to detect obstacles and offer many additional functions [4], [11]. Such devices use ultrasonic sensors to detect obstacles in front, and additional sensors to detect other useful aspects, such as water sensors or GPS detectors. Solutions like these are mainly based on electronic and smart white sticks equipped to include sensors and any other needed components. Our approach differs from theirs because it is intended to propose a wearable device that is seamlessly integrable in the usual user environment, to be used in addition to the traditional white cane, which any user can have or not.

3 THE PROPOSED SYSTEM

The proposed system is for assisting a partially or totally visually impaired person in the mobility and orientation tasks. It is the result coming out from two funded projects (1) 'OCCAM-NVI' by the University of Pisa, and (2) 'TIGHT' by the Italian Ministry of Research. The aim of the two projects was to design a system able to offer various functions integrated into a single device for everyday user independence and especially in the orientation and mobility tasks through haptic feedback. In particular, the 'OCCAM-NVI' project investigates how to combine haptic feedback and audio in a single device depending on the functions and information to be conveyed to the user. For this reason, the system was defined by the project as a " Multifunctional haptic-based system".

The system consists of: (1) Obstacle detector, (2) Output device to be used by other devices for multiple purposes/functions, and (3) Environment information detector (e.g. light sensors). In this work, we present the development of the prototype equipped with the obstacle detector.

4 SYSTEM REQUIREMENTS

In the design phase of the project, interviews and focus groups with visually-impaired people were conducted to gather user needs and preferences about the system. The results allowed us to define the specifications of the prototype. Details of the interviews and focus groups are not provided here and are the subject of another work.

Users expressed a number of requests and requirements that were taken into account when defining the main features of the system. They allowed us to define the main functions of the system which should:

- Communicate to the user the presence of obstacles that can be present in both a front-bottom or front-top position and front-right or front-left position with respect to the user, distinguishing these positions when notifying their presence;
- Be well-suited for use in both outdoor and indoor environments;
- Be well-suited for use in both a crowded place and a poorly peopled place;
- Not require the user to wear any special and intrusive support, i.e. any other object than the equipment commonly worn or used by a blind or low-vision person;

- Leave hands free as much as possible for the white cane and for carrying other objects (umbrella, suitcase, etc.);
- Allow to drive the user towards a predetermined destination, providing the user with context information related to the presence of various obstacles along the path;
- Not engage the user's auditory channel to receive obstacles notifications or data about the direction to be followed in a path towards a predetermined destination (while the user is walking).

The system has been prototyped as a "Multifunctional haptic-based Glasses" device capable of supporting orientation and mobility tasks for people with vision impairments by offering multiple functions.

In particular, the module "obstacle detector" can notify the user about the presence of possible obstacles arranged laterally with respect to the user, on the right or left side. The system is designed especially to (1) detect open doors and (2) distinguish possible obstructions located frontally on the bottom or top side. This type of detection is lacking in other prototypes and is the one most reported by users as an important requirement.

5 THE PROTOTYPE

The prototype was developed to be worn like eyeglasses. This addresses the user's requirements that the system should be wearable, with hands-free usage, and enable easy and flexible scanning of the surrounding environment.

As mentioned, the first version of the prototype focused on the obstacle detection function. Particular attention has been paid to (1) the modular components and the reuse of the system in case components need to be replaced, (2) the user interface and user interaction. The haptic feedback has been used to convey information on the obstacles detection: (a) obstacle presence; (b) obstacle direction (in front, right and left, bottom and top), and (c) obstacle distance. Haptic messages have been encoded with different frequencies and frequency intensities to inform about the distance to the obstacle. The direction is communicated with three actuators located on the left and right sides of the device.

The prototype is composed of three modules:

- Detection module. Three ultrasonic sensors have been installed to detect the central (bottom) and lateral (right and left) front obstacles.
- *Switchboard module.* When the ultrasonic sensors return more than one signal, these are processed and managed by a switchboard module. In particular, it handles situations such as the detection of open doors along walls or central-bottom obstacles to be distinguished with respect to the floor. For this, specific processing was necessary.
- *Feedback module.* The feedback module consists of 3 actuators to reproduce output vibrations. Each actuator is placed in a position corresponding to the direction of the obstacle. If the detected obstacle is on the right, the actuator placed on the right will emit vibrations. Similarly, it occurs for the other obstacles. In this version, only the haptic feedback has been exploited. In the future, we plan to extend the feedback module to include also audio feedback to be used for the other system functions.

In addition, some aspects of the system interface have been particularly well taken care of. These include:

- *Device wearable on any model of glasses.* This allows the user not only to choose the preferred model of glasses but, especially for those who are low vision, to use their own sight lenses.
- *Well-perceivable switch for detection distance settings.* Different settings can be used to adjust the obstacle detection range in order to use the device indoors or outdoors. Possible settings are 1, 2, 4 and 8 meters. This has been developed through a specific well-perceivable switch button with four positions. The switch consists of notches and each notch position clearly indicates the meters selected. This should be better perceivable by touch. This is useful to switch from the indoor to outdoor mode and vice versa.
- *System confirmation notifications.* It has been haptic coded to give confirmation of system power on and when a setting is made by the user like that for the distance. This is often underestimated and therefore missing in existing systems.
- *Modular device components.* System components can be easily replaced. This permits: (1) when a component stops working, it can be replaced without changing the whole device; (2) replacing a component to upgrade with newer components.

The current prototype version of the developed device is shown in Fig. 1.

The devices proposed in [2] and [8] are also mounted on a pair of eyeglasses, but they can provide only auditory feedback to the user through a headphone. In addition, there do not appear to be specific aspects of the user interface that take into account the needs of the visually impaired users about settings, as well as the ability/possibility to replace components in the device. Features designed into the interface, such as the scrolling button and confirmation notifications are examples of attention to user needs, as suggested in [10].

A preliminary evaluation was conducted with two totally blind users: a 70-year-old male and a 47-year-old female. The first person usually uses a hand-held obstacle detector (i.e. the miniguide, www.gdp-research.com.au/minig_1.htm) in combination with the white cane; while the second one relies on only the white stick. Both of them found the device useful but observed some inaccuracies with the detection of open doors and bottom-placed objects. For example, car parking bollards were detected correctly, while some difficulties were observed in the detection of kerb steps. The algorithm will therefore have to be improved for better detection of such obstacles. Obstacle detection outdoors was evaluated very positively, as it made it possible to perceive objects such as cars on the opposite side of a street. The button to select different detection distances in meters to switch between indoor and outdoor modes was very appreciated by the users. They found it practical and very clear thanks to the positions of the notches in the switch button, also confirmed by haptic feedback to indicate the setup distance. The user of the mini-guide observed that our device was able to better detect the distant obstacles in the outdoor environment, allowing the user to detect the distance to a wall located on the opposite side of a square. A square can present numerous mobility problems for a totally blind person. Understanding how far away the wall

Figure 1: ***Picture of the developed prototype.***

is on the opposite side can help to better explore the surrounding environment. This feature was absent from the devices he has tried over the years.

6 CONCLUSIONS

In this paper, we presented a wearable device that can be used by visually-impaired people as an aid to help them to detect obstacles along the walking path. The wearable obstacle detector is part of a multifunction system designed to support the visually impaired user when orienting and moving independently. The system is designed to provide support as (1) obstacle detector; (2) navigation to a given destination; and (3) communication on environmental information. The first prototype includes the development of the obstacle detector component herein discussed. The prototype is designed to be mounted on the user's preferred model of eyeglasses. When worn, the glasses are able to communicate different types of information to the user through vibrotactile signals perceivable by the body, such as obstacle detection, direction and distance. It can be used with or without the traditional white cane.

Compared to obstacle detectors proposed in other works, in our study we focused primarily on the design of the wearable system. Particular attention was paid to (1) the system reuse - with the opportunity to replace individual components and (2) the ease of use and the user interface - with specific hardware buttons for settings. With respect to specifically obstacle detection, the prototype was tested on the specific detection of bottom-front objects and open doors. The two users who evaluated it expressed positive opinions and encouraged further developments to improve the accuracy of the obstacle detector.

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