Towards a Haptic-based Virtual Cane to Assist Blind People in Obstacle Detection

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

Michele Raucci
DICI-UNIVERSITY OF PISA, Pisa (Italy)
michele.raucci@unipi.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

Blind persons rely on the traditional white cane to explore and avoid obstacles while moving independently in indoor and outdoor environments. Although numerous electronic aids have been proposed in the literature and on the market, orienting and moving are still a challenge for people who cannot see. Usually, electronic support devices are used in combination with the stick as blind people consider it a fundamental tool for exploring and getting information about the surrounding. In this paper, a virtual version of the traditional white cane based on the use of a laser sensor, actuators and haptic feedback for obstacle detection is proposed to move towards a single aid for mobility tasks. Although the proposed electronic aid is the first prototype tested in an indoor environment, it is a first step towards a discreet and lightweight virtual 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, electronic aid, Smart white cane

ACM Reference Format:
Barbara Leporini, Michele Raucci, Michele Rosellini, and Nicola Forgione. 2023. Towards a Haptic-based Virtual Cane to Assist Blind People in Obstacle Detection. In *Proceedings of the 16th International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '23), July 05–07, 2023, Corfu, Greece.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3594806.3594864

1 INTRODUCTION

Orienting and mobility are still challenging tasks for people who cannot see. "Blind individual's expertise difficulties once travelling to their intended destination. One in every of the larger obstacles is to notice foreign objects across their walking path" [12]. For this reason, visually impaired and blind people usually rely on prior knowledge of the environment and objects along the path [1] when orienting independently and safely in the environment. However, getting in advance the path to be taken and especially the obstacles that will be encountered is unrealistic in real life, and - in any case - this would greatly limit the person in their movements. Therefore, the blind person takes into account supporting aids to move around freely and safely [18].

White canes and Guide dogs are the traditional assistive travel aids used by the visually-impaired for decades [3], [6]. 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 [2]. In fact, the information that the white cane provides is transmitted at the moment of contact with the object and not before [3]. This approach allows the detection of obstacles, but it may be a somewhat intrusive method as delicate objects and people can be 'touched' by the stick when moving and exploring around. This might not be appreciated by all the visually-impaired as many of them might prefer to behave as naturally as possible when walking among people. To overcome this inconvenience, many electronic aids have been developed to inform the user in advance about the presence of obstacles before the cane collides with them. The use of electronic travel aids enhances the preview provided by the white cane and might reduce anxiety and embarrassment related to unwanted personal contact with objects or with people [3].

The subject of supporting electronic aids in the mobility of blind and low-vision users was - and is - an important research field [7], [14]. Electronic aids are available in different forms, such as handheld devices, smart canes, and wearable systems, and include detection and feedback functions on obstacles to prevent the user from colliding with objects and people. Nevertheless, many blind people want to rely on the white cane because they are used to it and consider it an indispensable tool [8].

In this work, an electronic aid (virtual cane) - able to reproduce the behavior of the traditional white cane - is proposed as a lightweight, non-intrusive device (i.e. that does not actually really "touch" objects and people). It is an obstacle detector device based on the use of a laser sensor, actuators and haptic feedback. The idea behind is to move towards a single electronic device that can

*Corresponding author.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.
PETRA '23, July 05–07, 2023, Corfu, Greece
© 2023 Copyright held by the owner/author(s). Publication rights licensed to ACM.
ACM ISBN 979-8-4007-0069-9/23/07…$15.00
https://doi.org/10.1145/3594806.3594864

give the user the assistance and feedback provided by a traditional white cane.

2 OBSTACLE DETECTION AND SMART WHITE CANE

Electronic aids exploit different sensors for detecting obstacles: lasers [4], [9], ultrasonic [11], [16], or infrared [10], and digital cameras [9] to gather information about the surrounding environment. We used the range-based methodology by using laser sensors. In range-based systems, obstacles are objects that extend a minimum distance above the ground [13]. The communication (feedback) to inform the user about the presence of obstacles plays a crucial role for an effective electronic aid. It should convey information to be easily understood by the user [15]. Effective feedback communicates the message, the situation and the risk [8]. Auditory or haptic feedback is usually applied to communicate. It is sometimes difficult to understand audio or voice message and cannot be heard in a noisy environment as well. In our prototype we used haptic feedback.

Many solutions attempt to make the white cane smart by equipping it with sensors [2], [4], [5] and [10]. A large number of sensors, actuators and accessories make the device (i.e. the stick) very delicate for everyday use, especially on the street where there are many objects and obstacles that could damage it. In addition, the use of numerous sensors to detect different types of obstacles may require the user to explore the surroundings while holding the stick in a more unnatural and uncommon way. Feedback can also prove quite complex when there is a lot of differentiated information to be provided. Vibration or haptics may no longer be sufficient to provide so much semantic information. Prolonged use of the stick may prove annoying for the user due to the continuous vibrations used to detect different types of obstacles. Developing such an articulated white cane can be very expensive, not to mention repairing it if one component gets damaged. Our approach is aimed to overcome those limitations by proposing an electronic aid that behaves like a traditional white cane and that is easy to use and inexpensive. The electronic aid we are proposing is primarily designed to provide feedback to the user that produces the perception of the presence of obstacles as if they were just "touched" by the tip of the stick. In other words, in our prototype we try to focus not only on the detection of the obstacle, but also on the haptic effect reproduced and returned to the user.

3 SYSTEM REQUIREMENTS

In the design of the device, we took into account both the user's needs and how the traditional white cane behaves in detecting obstacles when the user holds it and explores around him. Six blind people were asked about their needs with respect to such an electronic aid. The 6 persons were aged between 28 and 61 years, were totally blind, and were regular users of white cane to move independently in indoor and outdoor environments. The answers pointed out: spatial exploration in a similar way of stick; haptic and clear feedback for obstacle detection; alerting about dangerous situations; lightness and ease of use; indoor and outdoor use; non-intrusive tool and discreet in use. Specifically, concerning obstacles, 4 out of 6 users requested that the device communicate just the presence of the obstacle, without any indication of direction and distance. This is what the white stick does: the distance is within the range of the user's exploration of the stick anyway; the position (right, left and in front) is consequential to the direction of exploration with the stick. In short, users stated that too much information to be interpreted makes the use more complex and tiring. This request differs from that reported in many other works in which a clear indication of the distance and origin of the obstacle was an important feature to be supported [3], [8]. Furthermore, two users suggested not using a continuous vibration, as this can be tiring in prolonged and repetitive use. Almost all people (5 out of 6) agreed that the types of vibration to provide information about obstacles detected often require considerable effort to be interpreted; this may be a problem, especially when moving outdoors where attention must be maximized to avoid danger. The complexity of the messages to be interpreted continuously during exploration while the user is moving and needs to detect obstacles can be a reason for slowing down mobility. This was investigated in a recent study that observed as pairing an electronic aid with a traditional white cane may require the user to make a greater cognitive effort to interpret the feedback that the electronic device can provide [17]. Our approach is aimed at simplifying the haptic feedback by learning from the response provided by the white cane. Thus, in addition to requests expressed by the users, we analyzed the behavior of the stick in order to define the attributes of our device so as to simulate it.

The white cane is an assistive aid that requires user awareness to scan objects ahead, side by side and round-about; it is a time-consuming task, but it allows the user to be aware of obstacles and surroundings [3]. The white cane provides detection of obstacles and information about the travel path in advance, as it allows detection of obstacles within about 90 cm [3] range. Different cane techniques are used to guide the locomotion. For instance, during the orientation and mobility detection technique "constant touch", users hold the cane with their preferred hand, extending the preview of their path by around one meter at ground level. They sweep the cane from side to side, synchronized with the gait cycle while maintaining orientation by detection and following of continuous edges, e.g. tactile paving and walls (shorelining) [15].

The following aspects have been defined to design the system prototype:

- Obstacle detection within a range of 1 meter;
- Haptic feedback to leave the auditory channel free to perceive other details of the environment;
- Obstacle presence with a discreet feedback, i.e. avoiding continuous long vibration;
- Obstacle distance and details on demand;
- Safety function to alert when the user gets too close to the obstacle/object;
- Lightness, ease of use, non-intrusive and discreet aid.

4 THE PROTOTYPE

In our obstacle detector prototype, we especially focused on the interface to (a) reproduce the feeling perceived when the tip of the stick collides with an object, and (b) make moderate use of haptic feedback. So, the behavior of the proposed virtual white

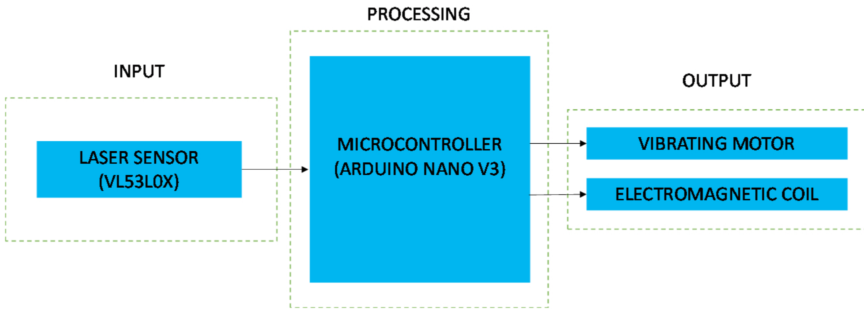

Figure 1: ***Process flow chart of the prototype.***

cane prototype can be summarized in: (1) when the (virtual) tip touches (virtually) the obstacle, a very short pulse is reproduced on the device case; (2) when exploring an obstacle, a continuous and proportional frequency vibration depending on the distance is reproduced by hold down a specific button while pointing and moving the device in the direction of the obstacle. This should simulate what the stick returns as feedback when touching objects, but without actually touching them.

The hardware consists of an AVR microcontroller (Arduino Nano V3 device), the laser sensor (emitter) with its receiver, a mini electromagnetic coil acting on a mass to reproduce the colliding effect, a "coin" vibration motor to provide the haptic vibration feedback with a frequency proportional to the obstacle, a push button and some electronic components (see Figure 1). The push button provides the user with information about the distance to the object when kept pressed (i.e. it is 'on demand' button).

In specific, a VCSEL (Vertical-Cavity Surface-Emitting Laser) sensor type was used to generate the laser beam and a SPAD (Single-Photon Avalanche Diode) was used as a beam receiver. The choice of the VCSEL sensor was based on the fact that it emits a very collimated beam without creating a cone that is otherwise emitted by ultrasonic sensors. This should allow for greater accuracy in detecting an object/obstacle. In addition, the used laser beam is totally invisible to the human eye and is not a danger to the eyes of people because it is compliant with the latest safety standards (Class 1).

The device has a cylindrical shape with a diameter of 3.5 cm and a length of 11 cm. It appears as a part of a traditional stick to allow a similar grip by the user. The current version of the prototype is shown in Figure 2 (left), while Figure 2 (right) shows the prototype during its use. This is a first prototype that can be further miniaturized to a smaller size.

The proposed electronic aid scans the environment in the direction in which the user points the device. When an obstacle is detected, the electromagnetic coil is activated and a short pulse on the device case is reproduced; no additional vibration is provided in this phase. This differs from other devices in the literature, which emit a vibration for as long as the sensor detects the obstacle. When the obstacle is no longer detected, the electromagnetic coil will be deenergized and the user receives a moderate pulse which indicates that no more obstacles are detected. The two haptic feedbacks - reproduced by energizing and deenergizing the electromagnetic coil - are distinct and therefore perceived differently by the user. So, the user is aware that an obstacle has been detected as soon as a short haptic feedback is perceived as a result of the electromagnetic coil activation. As soon as the obstacle is no longer detected, due to a change in direction of the device pointing, the electromagnetic coil releases the mass and a moderate haptic feedback is emitted allowing the user to be aware that no obstacle is present in that direction. Thus, the presence/absence of an obstacle is perceived by the two distinct haptic feedbacks related to the electromagnetic energization and denergization. By holding down the push button, information about the obstacle distance is gained on-demand: a frequency intensity of vibration proportional to the distance of the obstacle detected is emitted for as long as the button is held down. Thus, the user can gain information about the obstacle (width, height and distance) by simply holding down the button while pointing the device to the different directions to explore the object.

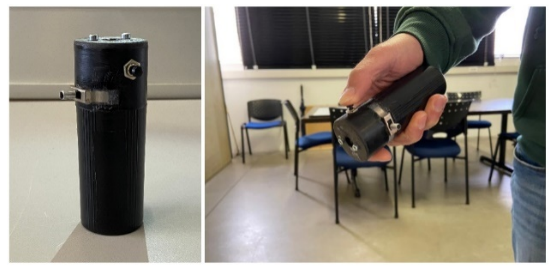

Figure 2: ***Picture of the developed prototype (left); prototype during its utilization (right).***

When moving along a corridor, for example, the user can detect walls by pointing the device from left to right to scan the surrounding environment. When the wall is detected, the electromagnetic coil is energized and the short typical pulse is emitted; when the aid is pointed in front in the direction in which the wall can no longer be detected, the actuator is deenergized emitting a different very short and moderate pulse. By scanning several times from left to in front, or right to front, the aid simulates the behavior of the stick moving it from left to right as if it were touching the walls and thus managing to hold the line as suggested in [3].

Finally, to ensure a certain level of user safety, if the electronic aid checks on an obstacle within 30 cm or less, an intense and continuous vibration is emitted until you move away from the obstacle. This should alert the user when getting too close to an object/obstacle. In this version of the prototype, a distance of less than 30 cm from the obstacle was considered a dangerous condition for a blind person.

5 EVALUATION

An initial evaluation was carried out with 3 blind users to assess whether the approach is valid. The tests were carried out in the university corridor. The path included a corridor about 1 meter wide, with the presence of many doors and a 90° angle. The aim was to find out whether the user could (1) follow the corridor by keeping away from the wall, (2) reach a laboratory room which had the door open, and (3) detect an object within a nearly empty room. The room to be reached was the only room with an open door along the corridor. All users were unfamiliar with the environment and were not given any information about the path. All the users were able to go along the corridor with no problem; they well identified the open door after turning the 90° corner in the corridor; however, they found some difficulty in finding the object in the middle of the room, because they preferred to follow the walls for a better orientation. It was observed that one user had some difficulty in understanding that the device was still detecting an obstacle. Perhaps this may be due to the fact that the user would like feedback from the device again after a while. It would be sufficient to press the on-demand button to check if an obstacle is still detected, but this may not be practical and intuitive for all users. This feature could be further improved. However, the evaluation yielded encouraging results. The users expressed their appreciation for the non-intensive use of the vibration, leaving the person free to obtain more information about objects and obstacles by means of the on-demand button. Observing the users during the test, we noticed the accuracy of the device in detecting the open door: the doorframe (left and right side) is detected very well in relation to the empty space of the door opening. This functionality differs from other devices that are proposed in the literature. Users expressed their appreciation about the prototype for its portability and accuracy of obstacle detection, but mainly for the discreet haptic feedback used for the different detections.

6 CONCLUSIONS

In this work, a portable electronic aid that simulates the use of a traditional cane for the blind has been proposed. In the first prototype, we reproduced different perceptions by the hand to simulate when the tip of the stick "touches" the obstacle (i.e. there is a collision), and when it is no longer detected. This was developed by reproducing two distinct haptic feedbacks that can be associated differently with when the object is "touched" (i.e. detected), and when the object is no longer in the detection range. A laser sensor, a mini electromagnetic coil acting on a mass to reproduce the colliding effect, and a "coin" vibration motor to provide the haptic vibration feedback (with a frequency proportional to the obstacle) have been used to develop this first prototype.

The electronic aid herein proposed differs in its work from those proposed in the literature and the commerce for: (1) the vibration is not emitted continuously for as long as the device is pointing at (and thus detecting) the obstacle, and (2) the obstacle distance is announced only on demand by keeping pressed a specific button which accordingly reproduces a long and proportional vibration. This answers the request made by users regarding the non-use of a continuous vibration in order not to burden the cognitive load, while retaining the ability to vibrate on demand to communicate the distance to the obstacle.

Although it was only tested with a limited number of users (i.e. three blind persons), and only in an indoor environment, the results are encouraging to proceed with the design of further functions for a virtual white cane that is lightweight, non-intrusive and intuitive for the user.

ACKNOWLEDGMENTS

This work was funded by the Italian Ministry of Research through the research projects of national interest (PRIN) TIGHT (Tactile InteGration for Humans and arTificial systems).

REFERENCES

[1] Abu Doush, I., Alshatnawi, S., Al-Tamimi, A. K., Alhasan, B., & Hamasha, S. (2017). ISAB: integrated indoor navigation system for the blind. Interacting with Computers, 29(2), 181-202.
[2] Agrawal, M. P., & Gupta, A. R. (2018, April). Smart stick for the blind and visually impaired people. In 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT) (pp. 542-545). IEEE
[3] Goldschmidt, M. (2018). Orientation and mobility training to people with visual impairments. Mobility of visually impaired people: Fundamentals and ICT assistive technologies, 237-261.
[4] Hertel, J., Schaare, A., Feuerbach, P., Ariza, O., & Steinicke, F. (2019). STIC-sensory and tactile improved cane. In Proceedings of Mensch und Computer 2019 (pp. 765-769).
[5] Husin, M. H., & Lim, Y. K. (2020). InWalker: smart white cane for the blind. Disability and Rehabilitation: Assistive Technology, 15(6), 701-707.
[6] Khan, A., & Khusro, S. (2021). An insight into smartphone-based assistive solutions for visually impaired and blind people: issues, challenges and opportunities. Universal Access in the Information Society, 20(2), 265-298.
[7] Kuriakose, B., Shrestha, R., & Sandnes, F. E. (2020). Tools and Technologies for Blind and Visually Impaired Navigation Support: A Review. IETE Technical Review, 1-16.
[8] Leporini, B., Rosellini, M., & Forgione, N. (2022, June). Haptic Wearable System to Assist Visually-Impaired People in Obstacle Detection. In Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments (pp. 269-272).
[9] Mai, C., Xie, D., Zeng, L., Li, Z., Li, Z., Qiao, Z., ... & Li, L. (2023). Laser Sensing and Vision Sensing Smart Blind Cane: A Review. Sensors, 23(2), 869.
[10] Menikdiwela, M. P., Dharmasena, K. M. I. S., & Abeykoon, A. H. S. (2013, December). Haptic based walking stick for visually impaired people. In 2013 International conference on Circuits, Controls and Communications (CCUBE) (pp. 1-6). IEEE.
[11] Mind, P., Palkar, G., Mahamuni, A., & Sahare, S. (2021). Smart stick for visually impaired. Int. J. Eng. Res. Technol, 10, 196-198.
[12] Pakale, P. B., Nikam, R. G., & Pawar, A. M. (2018). Survey on assistance systems and Navigation for blind people by using sensors. IAETSD Journal for Advanced Research In Applied Science.
[13] Patil, K., Jawadwala, Q., & Shu, F. C. (2018). Design and construction of electronic aid for visually impaired people. IEEE Transactions on Human-Machine Systems, 48(2), 172-182.
[14] Plikynas, D., Žvironas, A., Gudauskis, M., Budrionis, A., Daniušis, P., & Sliesoraitytė, I. (2020). Research advances of indoor navigation for blind people: A brief review of technological instrumentation. IEEE Instrumentation & Measurement Magazine, 23(4), 22-32.
[15] See, A. R., Costillas, L. V. M., Advincula, W. D. C., & Bugtai, N. T. (2021). Haptic Feedback to Detect Obstacles in Multiple Regions for Visually Impaired and Blind People. Sensors and Materials, 33(2021).
[16] Sheth, R., Rajandekar, S., Laddha, S., & Chaudhari, R. (2014). Smart white cane–an elegant and economic walking aid. American Journal of Engineering Research, 3(10), 84-89.
[17] Skovfoged, M. M., Rasmussen, A. S., Kirsh, D., & Knoche, H. (2022). The cost of knowing: How obstacle alerts reduce walking speeds of augmented white cane users. Proceedings of the ACM on Human-Computer Interaction, 6(MHCI), 1-16.
[18] Wiener, W. R., Welsh, R. L., & Blasch, B. B. (2010). Foundations of orientation and mobility (Vol. 1). American Foundation for the Blind.