Intelligent Mobility Cane – Lessons Learned from Evaluation of Obstacle Notification System using a Haptic Approach

Jagannadh Pariti
Rochester Institute of Technology
Rochester, NY 14623, USA
jsp3721@g.rit.edu

Vinita Tibdewal
Rochester Institute of Technology
Rochester, NY, 14623, USA
vt2173@g.rit.edu

Tae Oh
Rochester Institute of Technology
Rochester, NY, 14623, USA
thoics@rit.edu

CHI'20 Extended Abstracts, April 25–30, 2020, Honolulu, HI, USA

ACM ISBN 978-1-4503-6819-3/20/04.
https://doi.org/10.1145/3334480.3375217

Abstract
Existing smart cane prototypes provide audio and/or haptic feedback to inform people who are blind or visually impaired about upcoming obstacles. However, limited user research is conducted to evaluate the usefulness of the haptic feedback provided by these devices. To better understand the users' perceptions of haptic feedback, we developed a smart cane prototype called Intelligent Mobility Cane (IMC) that consists of 2 haptic vibrators on the handle. They are used to inform different parts of the user's hand that an obstacle is detected. 8 people who are blind and 3 people who have low vision explored the IMC's handset by navigating an indoor obstacle path. The participants provided their feedback on the IMC's haptic notification system with regards to the intensity of the vibration and location of the vibrators and discussed various scenarios where the feedback will or will not be useful to them. In this case study, IMC handle design recommendations based on the participant's feedback and suggestions are presented.

Author Keywords
Accessibility; Intelligent Mobility Cane; Feedback; Handle; Vibration

CSS Concepts

• Human-centered computing~Accessibility~Accesibility System Tools

Introduction

In 2015, the World Health Organization estimated 217 million had moderate to severe visual impairment and 36 million were people who were blind [18]. Mobility is a critical element to them. The most common tools to assist in navigation are the walking cane and service animals [1]. Users tap the ground with the bottom tip of the white cane to help detect and notify them of the presence of any obstacles. This notification is clear and helps provide a mental map of the surroundings [16]. However, these tools have limitations in providing the users with the necessary information for safe mobility [10, 16]. The walking cane only detects obstacles at a distance equal to its length [5]. Obstacles further away cannot be detected.

Attempts to address some of the walking cane's challenges are made by smart cane prototypes and products. Many implementations use sensors to detect obstacles in addition to the cane's length and inform the users with audio or vibration methods. The feedback provided by the smart canes also needs to be clear to provide a mental map of the surroundings [16]. However, smart canes have not been widely adopted by people who are blind or visually impaired in part because of smart cane's challenges with safety, high cost, and user interface [8].

The goal of this study is to evaluate whether the haptic vibration notification system on the cane handle provides clear notifications of upcoming obstacles in an indoor environment. An Intelligent Mobility Cane (IMC) was developed to assist in the evaluation.

This study outlines the IMC handle design and evaluation methodology. First, an Orientation and Mobility (O&M) Specialist from the Association of Blind and Visually Impaired (ABVI) in Rochester, NY, USA was consulted to discuss the needs of the study and participants. Then, 11 people who are blind or visually impaired were recruited to evaluate the IMC's haptic notification system.

Background

Using ultrasonic sensors is a common method of detecting upcoming obstacles for smart cane prototypes. Different notification methods like audio and haptic vibration are used to notify users of the obstacles. However, limited research has been conducted to evaluate users' preferences of haptic vibration notification systems.

Yiting et al. developed a cane that informed the user with audio and vibration feedback [19]. In Ulrich et al., a prototype called GuideCane used a servo motor to steer the cane away from the obstacle and the user is notified as the cane moves away from the obstacle [13]. User feedback on the notification systems of both studies was not captured. Kumar et al. developed an ultrasonic cane that used three speakers worn around the user's chest [6]. In Wang et al., a white cane attachment called HALO informed the user with haptic cues [15]. Both studies used blindfolded participants to evaluate the prototypes' notification systems. In Gallo et al., a white cane was extended with an attachment that informs the user through vibrations that an obstacle is present and the potential distance of the user from the obstacle [3]. Only one person who was visually impaired participated in the study and limited feedback was provided by the user on the haptic notification system.

User feedback was captured on the prototypes' notification systems in the following studies. In Wahab et al. users were informed through three voice alerts

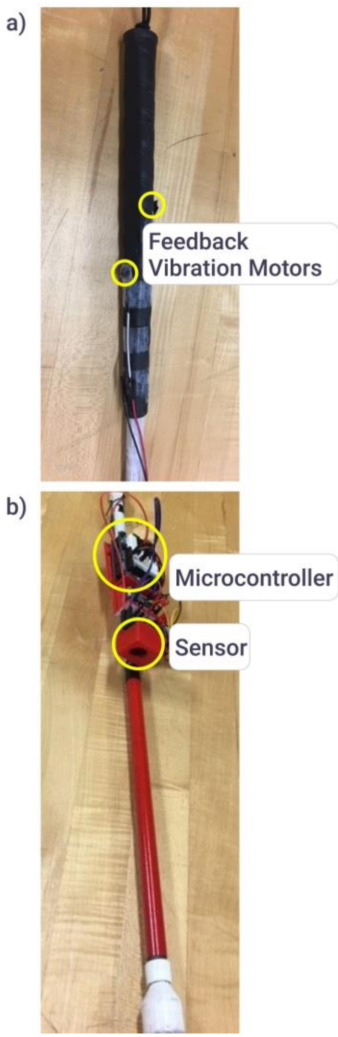

Figure 1 a) IMC handle with 2 vibration motors. **b)** IMC microcontroller and sensor

and haptic vibration [14]. Each alert is enabled based on the distance from the obstacle. The participants found the voice alerts confusing and misleading. Now considering user evaluations on the haptic feedback, Kim et al. developed a prototype that used a haptic vibration method built within the cane to inform the user of obstacles and provided design guidelines for the future smart canes based on the users' feedbacks [7]. The guidelines provided a foundation for structuring the design of the IMC used in this study.

Commercial Products

Commercial smart canes are also available in the market. The Sherpa from Handisco integrates with a crosswalk and uses audio to inform the user when to cross the street [12]. The Bawa Cane from Bawa Tech uses ultrasonic sensors to detect obstacles and informs users through vibration [2]. The UltraCane from Sound Foresight Technology and the WeWalk use ultrasonic sensors to detect obstacles and a vibration interface on the cane handle to inform the user [11,17]. In Roentgen et al, the study evaluated how the UltraCane would assist cane users in an indoor course [9]. Diverse feedback was collected on the UltraCane's haptic notification system and functionality overall. However, design guidelines were not provided.

IMC Design

A foldable walking cane is used as a base to develop the IMC prototype. The cane is mounted with a Maxbotix MB1240 ultrasonic sensor for ground-level obstacle detection. The sensor is connected to an Arduino Uno microcontroller (Figure 1b). The sensor and microcontroller are contained in a 3D-printed casing that is mounted towards the bottom of the cane to ensure they remained together. The casing's location on the cane can be adjusted by the user such that the ultrasonic sensor can detect obstacles at different heights.

The Arduino Uno is connected to two vibrators. One vibrator is positioned at the middle of the cane grip. The other vibrator is located towards the bottom of the cane grip (Figure 1a). Each vibrator is smaller than a penny in size and provides a vibration with 10000 rpm frequency when an obstacle is detected. An external battery is also connected to the microcontroller and was selected to ensure ample battery life was available for the participants. The total weight of the cane after adding the external battery was approximately 7lbs.

Participants would begin to be informed 4ft away from an obstacle. This distance threshold was selected to provide the participant time to react when an obstacle is detected, after analyzing the 3.5ft, 4ft and 6.5ft distance thresholds used by prototypes [6,14,19].

Ground-level and overhead obstacles were detected by using multiple ultrasonic sensors in [7,19]. The IMC only used a single sensor for ground-level obstacles. A single vibrator on the handle was used in [7,19]. However, the IMC uses 2 vibrators in different locations on the handle to distribute the vibrations across the cane handle in consideration of users who might have challenges feeling in parts of their hands.

Methods

Before conducting the Usability Test, the team consulted with an O&M specialist from ABVI to understand the basics of how people who are blind or visually impaired are taught to use a white cane. The O&M specialist indicated that people may start using a cane at different ages. The cane users are taught how to hold a cane on the grip and tap objects with the tip of the cane to detect obstacles and understand the surroundings. However, some users might hold the cane handle in a different way. Based on the guidance from the O&M specialist, the study procedure and interview questions were designed.

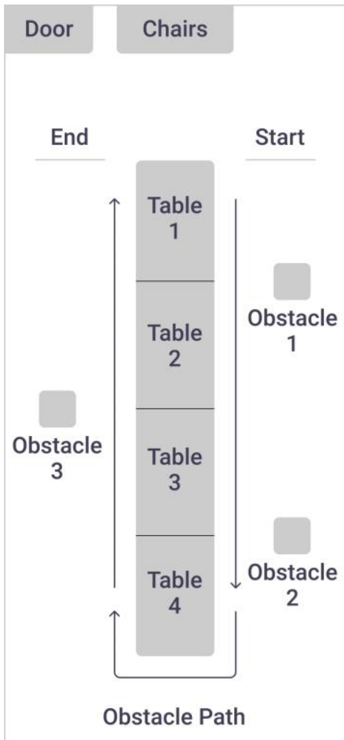

Figure 2) Obstacle path followed by the participants

Eleven volunteers (4 women, 7 men) from ABVI participated in the study: 3 people who had low vision and 8 people who were blind. There were 3 recruitment criteria for the participants: 1) the minimum age is 18 years; 2) able to understand and speak English, and 3) an experience of using a white cane for everyday navigation. The average age of the participants was 49.3 (SD = 8.7). The participants had an average of 18 years of experience of using a white cane. The participants were informed earlier they would not be compensated in any monetary form for participating in the study. However, they were explained their feedback would be used for improving the IMC.

The Usability Session was divided into four phases: Pre-Interview, IMC and Obstacle Path Description, Usability Testing of IMC Handset, and Post-Interview.

Pre-Interview: The participants were asked general questions like their height, their years of experience using a cane and awareness about the smart cane. They were asked to show how they hold their walking cane to understand if their method is different from what they were taught. The participants were also asked how they detect obstacles.

IMC and Obstacle Path Description: After the pre-interview session, the research team explained and demonstrated the IMC and how it works. The purpose and functionalities of the components like the sensor, microcontroller, and vibrators were also described. The participants were encouraged to feel the cane with their hands to understand its components. The team also described the obstacle path (Figure 2) that consisted of 4 tables set on their side in the middle of the conference room, two plastic garbage bins placed to the left of the tables and a third plastic garbage bin to the right of the tables.

Usability Testing of IMC Handset: The participants walked along the obstacle path and audio/video data was collected during this time for analysis. The users evaluated the comfort level of the cane handle, the positioning of the vibrators and understanding of the haptic feedback. The research team sought any challenges the users faced when using the IMC's handset.

Post-Interview: The participants were asked a series of questions to understand their experience with the haptic feedback received from the IMC handle. Questions regarding the vibrator's location on the handle, the vibration intensity and frequency, and suggestions to the haptic method were asked.

Results and Insights

The data from the usability test was recorded (video and audio) and was analyzed by watching the videos and marking different observations such as how the participants are holding the IMC, how many times they are tapping the obstacle and how many times they are avoiding the obstacle. The qualitative data from the interviews were coded into 25 different themes such as learning curve, exploration, awareness, white cane experiences, haptic system feedback and more. Then, using affinity mapping different themes were grouped into separate categories and subcategories and the findings were prioritized to support the goal of the study.

Observations from the Study

The participants maneuvered the obstacle path and all of them completed the task with an average time of 3 minutes. It was observed that the participants faced challenges while using the IMC. 4 participants stopped walking along the obstacle path because they were not sure where they were when the IMC's handle was vibrating and when it was not vibrating. 2 participants could not feel the vibrators on the handle. They inquired about how the IMC's haptic notification system is supposed to function. However, they appeared to not rely on the vibrations to guide them. They touched the obstacles at different heights using the tip of their cane.

9 participants stopped and asked how to interpret the vibrations. However, once their doubts were clarified, they continued to slowly navigate the obstacle path appearing to use the handle vibration to help them move forward. They still tapped the obstacles as they continued to walk along the path, but they did not appear they were reliant on tapping. It was observed that 5 participants avoided touching at least one of the obstacles with the IMC: tables or garbage bins. It was not clear if the handle vibrations were used to guide the users away from the obstacles.

IMC Feedback Evaluation
The participants gave mixed reviews about the haptic feedback of the IMC. They evaluated the IMC based on their previous experiences with the white cane. A learning curve was observed when the participants started using the cane but then they were able to adapt and liked the feedback method. They provided some suggestions based on their experiences and general concerns regarding the cane.

Learning Curve: A learning curve was observed when the participants used the IMC. 2 out of 11 participants had previous experience with a smart cane through another study. However, none of them have used a smart cane previously as part of their daily routine. In the beginning, 6 participants were not able to clearly connect/understand the vibration feedback when the obstacle was detected, and why the vibration intensity was changing. Some of their comments from the study are; P1: *"I think in the beginning it might just be a little distracting"*; P2: *"I could tell there was something there because of the vibrations. I did not know the range because I was not familiar with the cane. I did not know where the obstacle was. So it made me hesitate in my steps"*; P11: *"I felt them* [the vibrations on the IMC handle] *but did not know what they meant."*

IMC Feedback: After the usability testing which took mostly around 3 minutes, the participants became comfortable with the IMC and liked the idea of communicating using haptic feedback. Some of their comments from the post-interview session are; P4: *"I like the vibrators on the handle. A lot of times traffic and other noises impede my hearing. So the haptics is great."*; P9: *"It is a good idea because it actually vibrates while you are walking. It alerts you. I would prefer having those than a beeping sound."*; P10: *"It was good. It was not something you can be annoyed by."*

Walking Cane Concerns: The participants' previous experiences with their regular walking cane or any other assistive technologies were used as a reference and influenced the way they evaluated IMC. They asked questions based on the different scenarios and some of their considerations were: P4 (white cane): *"The hardest mobility time for me is in the wintertime because the terrain changes constantly."*; P6 (miniguide with white cane): *"Is it waterproof?"*; P5 (white cane with a guide dog): *"I would need to try it like I usually use my cane and see how it works for me."*

User Suggestions on Haptic Notification System
In the post-interview session, the participants were asked questions to obtain feedback on the vibration frequency and intensity, and vibrator locations.

Vibration Frequency and Intensity: 8 participants said that having vibration patterns would be helpful to have a clearer idea of the location of the obstacles. Another point that came up was the users want to turn off the vibrations anytime they want when they prefer to use it as a regular walking cane. Some of the comments from the participants are as follows; P2: *"If you had sensors on the top, left and right, each has a different pulse. Like a pulse pulse pulse. Like morse code, longer pulses on the right. Steady pulses straight ahead. It would be* *easier to detect."*; P3: *"I think one thing that might be helpful would the closer you are to the obstacle, maybe having a pattern of where it vibrates more frequently."* P5: *"Make the vibrators vibrate different ways, like one* [vibrator] *on the thumb and the other on the index finger to detect different things."*

<u>*Vibrator Locations:*</u> After an average of 3 minutes through the usability testing, the participants got adjusted to the IMC handle and began to feel the vibrations. In the pre-interview session, they were asked to demonstrate how they usually hold their cane in different scenarios like indoor, outdoor and staircase. Every participant held the cane in a minimum of 2 different ways. In the post-interview session, upon being asked *"What do you think about the vibration location?"*, 6 participants suggested making the vibrator location adjustable. Some of their comments are; P5: *"The vibrator location should be adjustable. The vibrators were lower than where you typically placed your hands. Sometimes you have to choke up on the grip."*; P7: *"If it was able to be adjusted for a person, it would be better."*; P3 (comment based on personal cane holding style): *"I would probably move that up more so that you are not putting so much strain on stretching from here to here."*

Personalization of the IMC

Although this study focused only on the IMC's haptic feedback notification system, the participants had several expectations and personal preferences with regards to the IMC.

<u>*Foldable/Non-foldable:*</u> The IMC used for this study was built upon a foldable white cane. When the participants were asked about their preference with foldable and non-foldable canes, 3 people mentioned that they did not have any preference and the remaining 8 people said that they prefer foldable canes because it is easier to store, and it does not obstruct with other people's way. They gave examples to explain it such as; P1: *"If this never folds, and I am on a bus, what am I going to do with it? It is going to lay on the floor and be in people's way. So, if I can fold it and put it across my lap, then it is a lot user-friendly."*; P7: *"It is more convenient. When you are not using it, you can fold it up and store it."*

<u>*Weight and length of the cane*</u>*:* In the post-interview session, 5 participants mentioned that the cane is heavier as compared to their own white cane. The weight of the cane matters because using heavy canes might cause serious wrist issues; P3: *"When using a cane, you are going back and forth and have that repetitive motion, and you have to put your hand further down, which would put a lot of strain. That would concern me."* Similarly, the length of the IMC was also a topic of consideration for the participants as all of them had different heights and they had to hold the cane accordingly.

IMC Handle Design Recommendations

Based on the feedback from the participants, they can rely on haptic vibration to inform them of upcoming obstacles in an indoor environment. The recommendations are with respect to the location of the vibrators, the intensity of the vibrators and overall handle design.

<u>*Obstacle Detection and Notification System:*</u> The users should be able to attach the obstacle detection system to any cane because every user has a different personal preference for the cane. An audio feedback option can be added on the handset for users to hear a sound when an obstacle is approaching. Also, it should be ensured that the users can choose the type of audio and between being notified using audio, haptic or both [4,7].

<u>*Location of the Vibrators:*</u> The users should be able to adjust the location of the vibrators on the handset to their liking to minimize hand strain. This option will also help the user feel the vibrations in part of their hand

that has challenges with the sense of touch (Neuropathy).

The location of the vibrators should be marked in some way to ensure proper cane orientation. Also, different vibrators should be placed in various locations on the handset to indicate the direction of the obstacle with reference to the handset. This feature would require additional sensors on the cane that detect obstacles in the various directions in reference to the handset.

Vibrations: The haptic feedback should have varying vibration patterns for different types of obstacles (e.g. overhead obstacles, stairs). 2 participants indicated they could hear the vibrations more than feeling the vibrations, and the sound sounded like a tapping sound. Some users have neuropathy in which they have challenges with the sense of touch in their hands, including vibrations. If they wear gloves during cold weather, they might not feel the vibrations at all. Therefore, the vibration intensity and frequency should be adjustable.

Conclusion

Multiple smart cane prototypes are developed which provide haptic vibration feedback to inform the users about the upcoming obstacles, but limited research has been conducted to understand the user's requirements and preferences. The goal of this study was to evaluate whether a haptic vibration notification system on the cane handset provides understandable feedback to the users. The findings indicate they were being informed by the IMC, but they faced some challenges initially. The participants provided valuable suggestions to improve the haptic feedback system of the IMC. Based on the team's observations and user feedback, a set of handle design recommendations are suggested in this case study to consider for future prototypes. Through this study, it is understood that many parameters apart from the price and feedback method are considered by people who are blind or visually impaired regarding which navigation assisting tool they want to use. This study provides recommendations of future IMC handle designs that will improve the cane users' experience using haptic vibration to notify them of upcoming obstacles.

Limitations and Future Work

This study was designed to evaluate the IMC's haptic notification system with 11 participants within a conference room at ABVI. While observing the participants, a longer obstacle path with additional obstacles is recommended to explore the IMC's haptic notification system thoroughly. Additionally, the feedback of the participants was based on their first-time experience with the IMC. The results might vary if they used it for a longer time. To address this limitation, the team is planning to conduct another study where the participants will use the IMC for a few sessions in different scenarios and environments to evaluate its haptic notification system more rigorously. During this study, the researchers will first conduct a practice session to ensure that the participants are familiar and comfortable with the idea of IMC.

Acknowledgments

We thank all the ABVI volunteers who participated in this study and to ABVI for allowing us to use their office space to conduct the experiment.

References

[1] Douglas Baldwin.2003.Wayfinding technology: A road map to the future. Journal of Visual Impairment & Blindness.97:612-620.
[2] BawaTech.2018. BawaCane. Video. (19 April 2018). Retrieved October 6, 2019, from https://www.youtube.com/watch?v=wDAPYzbtF7U
[3] Simon Gallo, Dominique Chapuis et al.. 2010. Augmented white cane with multimodal haptic feedback. 2010 3rd IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics. Tokyo, 2010, pp. 149-155.
[4] Arturo Garcia, R. Fonseca et al. 2011. Electronic long cane for locomotion improving on visual

impaired people: A case study. *Proceedings of the 2011 Pan American Health Care Exchanges (PAHCE)*. Rio de Janeiro, Brazil. 28 March – 1 April 2011.

[5] Christophe Jacquet, Yacine Bellik et al. 2006. Electronic locomotion aids for the blind: Towards more assistive systems. Studies in. Computational Intelligence. 19, 133-163.

[6] Krishna Kumar, Biswajeet Champaty et al. 2014.Development of an ultrasonic cane as a navigation aid for the blind people. *Proceedings of the 2014 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT)*. Kanyakumari District, India. 10–11 July 2014.

[7] Sung Y. Kim and Kwangsu Cho. 2013. Usability and Design Guidelines of Smart Canes for Users with Visual Impairments. International Journal of Design. 7(1), 99-110.

[8] Aslam Muhammad, Muhammad Umair Ahmad Khan et al. 2010. Analytical study of intelligent assistants to help blind people in avoiding dangerous obstacles. Journal of American Science, 7(8), 480-485.

[9] UR Roentgen, GJ Gelderblom, et al. 2012. User evaluation of two electronic mobility aids for persons who are visually impaired: a quasi-experimental study using a standardized mobility course. US National Library of Medicine National Institutes of Health. 2012 Summer;24(2):110-20; quiz 121-2.

[10] Chirayu Shah and Mourad Bouzi. 2006. Evaluation of RUNetra tactile feedback navigation system for the visually-impaired. *Proceedings of the International Workshop on Virtual Rehabilitation*; New York, NY, USA. 29–30 August 2006; pp. 72–77.

[11] Sound Foresight Technology. Ultracane. 2019. Retrieved October 6, 2019, from https://www.ultracane.com/

[12] Sherpa. Handisco. 2019. Retrieved October 6, 2019, from https://handisco.com/

[13] Iwan Ulrich and Johann Borenstein. 2001. The GuideCane-applying mobile robot technologies to assist the visually impaired. Journal IEEE Transactions on Systems, Man, and Cybernetics, Part A: Systems and Humans. Volume 31 Issue 2, March 2001 Page 131-136.

[14] Mohd Wahab, Amirul Talib et al.. 2011. Smart Cane: Assistive Cane for Visually-impaired People. IJCSI International Journal of Computer Science Issues. 2011;8:4.

[15] Yunqing Wang and K. J. Kuchenbecker. 2012. HALO: Haptic Alerts for Low-hanging Obstacles in white cane navigation. 2012 IEEE Haptics Symposium (HAPTICS). Vancouver, BC, 2012, pp. 527-532.

[16] William R. Weiner, Richard L. Welsh et al. 1997. Foundations of Orientation and Mobility. 2nd ed. AFB Press; New York, NY, USA.

[17] YGA.2019. WeWalk. Video. (10 May 2018). Retrieved October 6, 2019, from https://www.youtube.com/watch?v=Rr9RaisO11E

[18] World Health Organization. Visual impairment and blindness Fact Sheet N°282". 2014.

[19] Yiting Yi and Lunfu Dong. 2015. A design of a blind-guide crutch based on multi-sensors. *Proceedings of the 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*. Zhangjiajie, China. 15–17 August 2015.