PERCEPT Navigation for Visually Impaired in Large Transportation Hubs

Aura Ganz, James Schafer, Yang Tao, Zhuorui Yang
Electrical and Computer Engineering Department, University of Massachusetts

Charlene Sanderson
Orientation and Mobility Consultant

Larry Haile
Assistive Technology Consultant

ganz@ecs.umass.edu, schafer@umass.edu, ytao@umass.edu, zhuorui@umass.edu, charlene.sanderson@gmail.com, hailelarry1@gmail.com

Abstract

In this paper we introduce PERCEPT indoor navigation system deployed in North Station subway in Boston and the successful experimental results with Blind and Visually Impaired (BVI) users. This is the first time PERCEPT system is deployed in a large venue such as North station which is a crowded open space multimodal transportation hub. Using Bluetooth low energy tags we can localize the BVI users in real time. Given the user location, PERCEPT provides the BVI user with detailed landmark based navigation instructions to the chosen destination. Our experiments show that using PERCEPT system, the users can successfully and independently reach their chosen destination. All participants were very satisfied with PERCEPT and thought it was easy to learn and had a friendly user interface.

Keywords

Indoor navigation, blind and visually impaired, user interface, navigation instructions, transportation hub

Introduction

The World Health Organization reported that 285 million people are estimated to be visually impaired worldwide: 39 million are blind and 246 million have low vision (World Health Organization, 2016). There is a recognized positive correlation between independent travel employment, and issues of social equity. Independent navigation through unfamiliar indoor spaces is beset with barriers for BVI individuals. A task that is trivial and spontaneous for people without disabilities has to be planned and coordinated with other individuals for the BVI population. Although many improvements and aides are available to assist BVI individuals in outdoor settings, there has yet to be developed a reliable system that combines independence with accuracy and affordability for indoor navigation.

Currently there are no commercial systems that enable BVI users to independently navigate in indoor environments using real time localization and detailed navigation instructions that are automatically generated. There have been a number of research projects that aim to help BVI users navigate in unfamiliar indoor environments (Ahmetovic, 2017; Basso, 2015; Cheraghi, 2017; Doush, 2016; Garcia, 2015; Idrees, 2015; Jaffer, 2016; Jonas, 2015; Kim, 2016; Riehle, 2013; Rituerto, 2016; Serrão, 2014; Tandon, 2015; Waris, 2015; H. Zhang, 2016; X. Zhang, 2015). However, none of these papers has introduced an automatic generation of detailed navigation instructions which is necessary for a scalable and affordable indoor navigation system for BVI users.

PERCEPT system, first generation affordable and accurate indoor navigation system for the blind and visually impaired in buildings, which was introduced by the authors in (Ganz, 2014) was developed with the cooperation of the Massachusetts Orientation and Mobility division from Massachusetts Commission for the Blind. In PERCEPT system (Ganz, 2014) the user carries a Smartphone that runs PERCEPT application that provides landmark based navigation instructions helping the user navigate through indoor spaces to a chosen destination. PERCEPT includes three main modules: the vision free user interface using Android and iPhone accessibility features, the localization algorithm and the navigation instructions algorithm. The user downloads the application from PERCEPT server prior to his/her arrival to the indoor environment. The application flow includes the following steps: 1) start the application, 2) localize the user and determine current location, 3) select the destination using the accessible “vision free” interface, and 4) receive audible detailed navigation instructions.

In the first generation PERCEPT system we used Near Field Technology (NFC) for user localization which requires the BVI users to detect the landmarks (e.g. doors, stairs, escalators). NFC is a passive technology that does not require any maintenance (i.e., no need to replace batteries) and works well in buildings and indoor spaces where the users can follow the walls. We conducted IRB approved trials with 24 blind and visually impaired subjects that successfully navigated through a three-story building on the UMASS Amherst campus.

However, the users that participated in the trials requested changes so they can obtain navigation instructions anywhere in the physical environment. Motivated by the user feedback as well as the need to deploy the technology in large indoor environments (e.g. large transportation hubs) we developed the second generation of PERCEPT system. In this paper we introduce the second generation of PERCEPT system that involves Bluetooth Low Energy (BLE) tags deployed in the environment which enable PERCEPT to locate the users anywhere in the space and provide them with proper navigation instructions towards the chosen destination.

We have conducted a total of 6 trials in North Station subway. North Station is one of the main transportation hubs in Boston for the commuter rail and at peak time there are crowds filling the platform. Each study participant was asked to navigate from each of the main entrances to a unique subway platform in the station. When reaching the platform, they were asked to exit the station through a specific exit. Despite these environmental challenges all the study participants were able to successfully utilize PERCEPT to reach the subway platforms as well as find the specific exit. All participants were very satisfied with PERCEPT and thought it was easy to learn and had a friendly user interface. When asked if they would use PERCEPT in the subway if available, all subjects said yes. The feedback provided from the subjects was that overall the app is great for providing wayfinding in the subway and in its current state it would be beneficial in their daily lives.

In this paper we briefly introduce PERCEPT system without providing technical details on the localization and navigation algorithms. We focus on the system usability through a scenario as well as the trial results.

The paper is organized as follows. In the next section we outline the second generation PERCEPT system and in Section C (PECEPT in North Station) we provide a case study. The trials are described in Section D (Trials) and Section E (Conclusions) concludes the paper.

PERCEPT System

In PERCEPT system (Ganz, 2014) the user carries a Smartphone (Android or iPhone) that runs PERCEPT application which provides detailed landmark based navigation instructions helping the user navigate through indoor spaces to a chosen destination. PERCEPT includes three main modules: 1) the navigation instructions generation algorithm (Section B.1. Navigation Instructions), 2) the localization algorithm (Section B.2. Localization) and the vision free user interface using Android and iPhone accessibility features (Section B.3. Vision Free User Interface). Due to the complexity of the localization and navigation instruction generation algorithms we omit them from this document.

The user downloads the application from PERCEPT server prior to his/her arrival to the indoor environment. The application flow includes the following steps: 1) start the application, 2) localize the user and determine current location, 3) select the destination using the accessible "vision free" interface, and 4) receive audible detailed navigation instructions.

Navigation Instructions

In this system the user receives instructions through two modes: 1) detailed landmark based navigation instructions generated by the PERCEPT navigation instructions generation algorithm introduced in (Tao, 2015), 2) in case the user is lost he/she presses "Where am I" the user will receive a detailed description of the landmarks around him/her, the distance to the landmark and the orientation relative to the user orientation. In Section C (PECEPT in North Station) we illustrate the navigation instructions and "Where am I" modes through a detailed scenario.

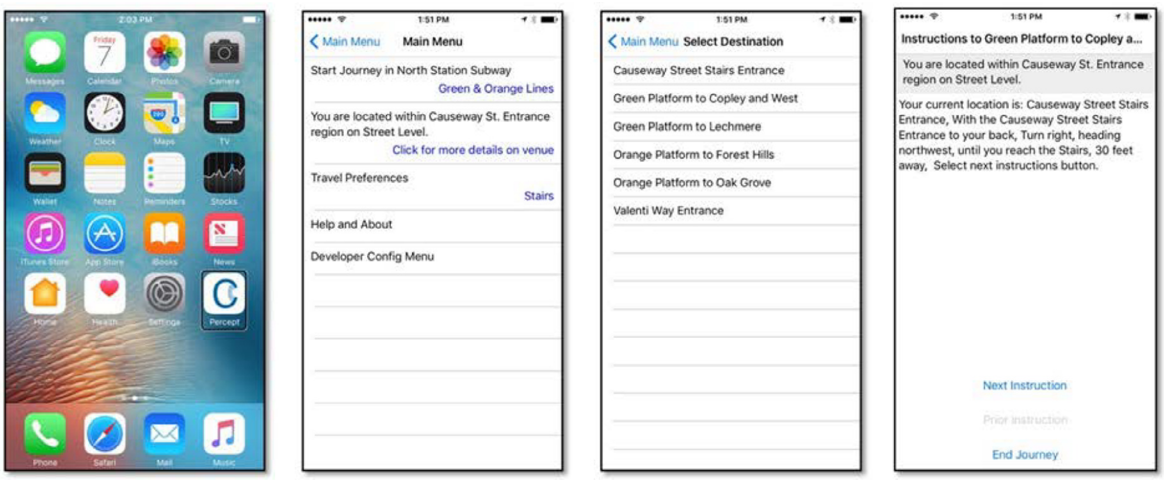
Localization

The user is localized in specific zones (e.g., entrances, platforms, etc) in the venue using the receive signal strength indicator from multiple BLE tags which are deployed in the venue. BLE tags are used in many indoor venues such as malls. Retailers push to the users' Smartphones advertising information when they are in the proximity of the product.

We have developed an optimal BLE tags deployment scheme which minimizes the number of tags while ensuring that every zone in the venue is covered by at least three tags. In case we deploy PERCEPT in a venue that has deployed infrastructure for localization we can use it in our system replacing the localization algorithm we developed.

Vision Free User Interface

The visually impaired user interacts with the Smartphone using vision free accessibility features provided by the Smartphone operating system. On Android this accessibility features is called “Talkback” and on iOS “Voiceover”. PERCEPT app is tightly integrated with these services to provide an accessible user experience. On both platforms the user can navigate the device through gestures on the screen. Using this accessibility service the users can immediately interact this application as they would with other common applications (Mail, Web Browser, Messaging, etc…). An example of the user interface is provided in Figure 1. In addition to vision free interface PERCEPT also is integrated with large font accessibility features for low vision users. This provides the user with consistent accessible font size across all applications that support this feature.



Open PERCEPT Application | Select ‘Start Journey’ From Main Menu | Select Your Desired Destination | Receive Detailed Instructions to Destination

Fig.1. PERCEPT application user interface

PECEPT in North Station

We selected North Station Subway in Boston as an evaluation site for PERCEPT due to the following reasons:

- It is multi-modal hub for subway, commuter rail, bus, and Amtrak lines
- It gathers considerable foot traffic with often crowds of people waiting along the subway platform
- It has a large, complex layout, with vast open areas

Therefore, North Station is an excellent testbed for PERCEPT since it is a large, complex, open space, and crowded venue.

Figure 2 depicts the layout of all three floors of the North Station Subway starting from the street level entrance and going underground for two levels. We have deployed in all three levels 148 BLE tags in the environment (approximately 25 feet apart).

These tags are manufactured by Kontakt.IO which have a battery life of 5 years, have a small footprint (15mm x 55mm x 56 mm) as well as a replaceable battery. The cost of each BLE tag in quantities is approximately $15 (for larger quantities the cost is lower).

Scenario

The following scenario illustrates how PERCEPT system works in North Station. We follow the navigation experience of our hypothetical user, Kara, in North Station Subway. Kara would like to board the Inbound Green Platform to Copley and stations West. To get an idea of how Kara will use PERCEPT to navigate the station, we will cover the first five steps in her journey (follow the steps in Figure 3 using the markers):

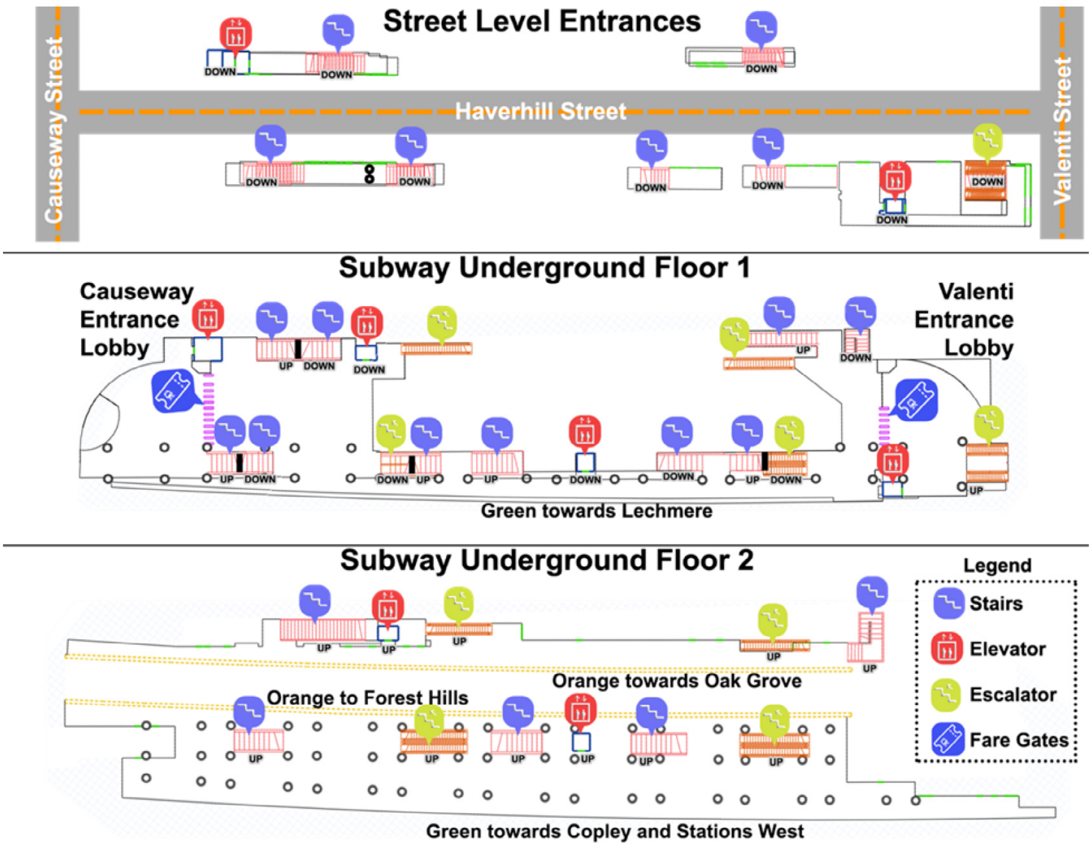


Fig. 2. North Station layout.

1. Valenti Street Entrance (Marker 1): Kara arrives at North Station and enters through the Valenti Street Entrance. Once inside, Kara takes out her iPhone and opens PERCEPT App. PERCEPT App informs Kara, "You are in North Station Subway that services green and orange subway lines. You are located on street level at the Valenti Street Entrance." Kara selects 'Start Journey' in PERCEPT main menu, and then selects 'Green Platform to Copley and West' from a list of destinations. PERCEPT app responds: "Your current location is: Valenti Way Entrance, With the Valenti Way Entrance to your back, Walk straight ahead, heading north, reach the Escalator to your right side, 20 feet away, You will hear the escalator noise. Take the escalator down. Select next instruction button."

2. Valenti Street Unpaid Lobby (Marker 2): After Kara reaches the bottom of the escalator she selects the next instruction button and the app responds: "With the Escalator to your back, Walk across the opening, heading north, until you reach the Fare Gates, 40 feet away, You will reach: Fare Gates. Select next instruction button."

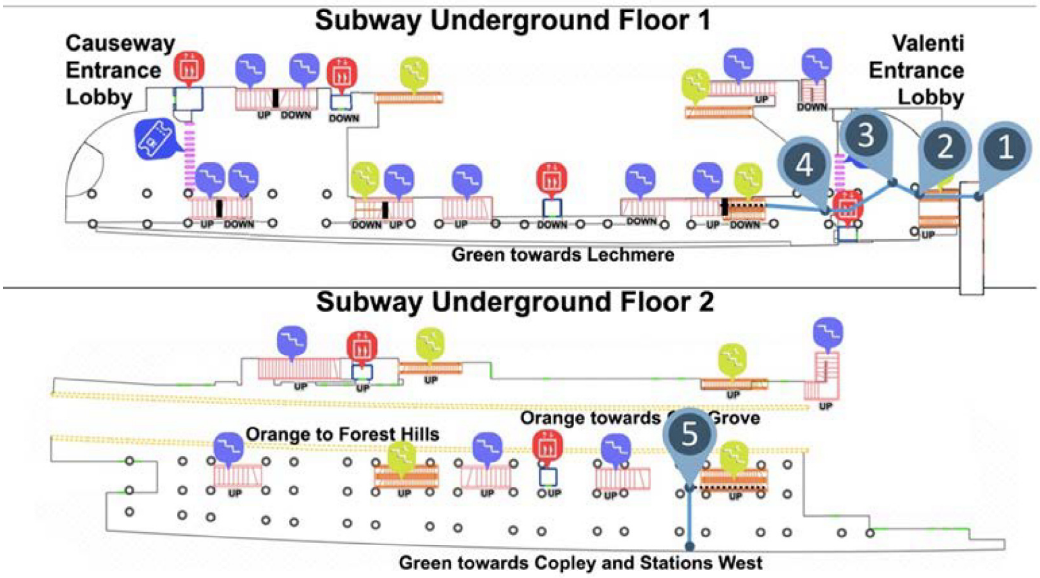


Fig. 3. User navigation journey in North Station (markers represent the navigation steps).

1. Lost in Unpaid Lobby (Marker 3): Kara follows the instructions but becomes disoriented along the route and is now unsure where to go. She shakes the phone to bring up the help menu and selects "Where Am I" option. The app then responds with the rerouting instructions: "You are currently in the Southern Unpaid Lobby region. You have been traveling northeast. The fare gates unpaid side is located 25 feet to your 11 o'clock in the northwest direction. Head towards fare gates unpaid side and go through the fare gates. Select next instruction button." Kara follows the rerouting instructions and is back on track and heading towards her destination.

2. Paid Lobby to Lower Platforms (Marker 4): Once through the fare gates Kara selects next instruction button and the app responds: “With the Fare Gates to your back, there is Escalator to your 12 o'clock direction, Walk across to the Escalator to your 12 o'clock direction, heading northwest, 50 feet away. Take the escalator down. Select next instruction button.”

3. To Green Platform to Copley and West (Marker 5): At the bottom of the escalator Kara selects next instruction button and the app responds: “Your current location is: Escalator, With the Escalator to your back, Turn left, Walk straight ahead, heading southwest, until you reach the Green Platform to Copley and stations West, 40 feet away, You will face the track. You have reached your destination: Green Platform to Copley and stations West. Select End Journey to end the journey.”

Trials

The user perspective is very important for our project. Given that our system is an assistive technology for the blind and visually impaired, it needs to be designed and constantly improved with user feedback. Users’ feedback helped us 1) identify the important landmarks to include in the navigation instructions, 2) determine level of details of the navigation instructions, 3) identify methods to reorient when the BVI user becomes disoriented in the venue, and 4) improve the user interface.

In this paper we report PERCEPT testing with 6 blind and visually impaired participants. None of the participants were familiar with the North Station venue and its layout although a few participants had shared that they have been in the station in the past. We do not collect information such as age, vision acuity, and other personal health metrics, however the participants did share the level of vision they had which ranged from no visual acuity, to some light perception, to some vision and shapes, to partial blurred vision with a limited field of view.

Each trial includes hands-on orientation, PERCEPT trial, and post-trial questionnaire.

Part I: Hands-on Orientation

The hands-on orientation includes sit down orientation and on site experimentation:

- Sit down orientation: The instructor goes over PERCEPT app functionality and answers any questions the participant has. When the participant is comfortable they proceed to on site experimentation.
- On site experimentation: the participant uses PERCEPT App in North Station subway along routes that will not be included in the actual trial. This allows the participant to become familiar with use of PERCEPT in the environment without compromising the trials. The Instructor answers any questions the participant has and when the participant is comfortable they move to Part II described below.

Part II: PERCEPT Trial

We asked the participant to accomplish the following four navigation tasks (see Figure 4) that include two entrances (to/from) and two subway platforms inbound/outbound (to/from):

- **Task 1:** Causeway Street Entrance (**A**) to Green Line Platform towards Lechmere (**B**) – **RED**
- **Task 2:** Green Line Platform towards Lechmere (**C**) to Causeway Street Entrance (**D**) – **BLUE**
- **Task 3:** Causeway Street Entrance (**A**) towards Green Line towards Copley and stations West (**E**) – **GREEN**
- **Task 4:** Green Line towards Copley and stations West (**F**) to Valenti Street Entrance (**G**) - **PINK**

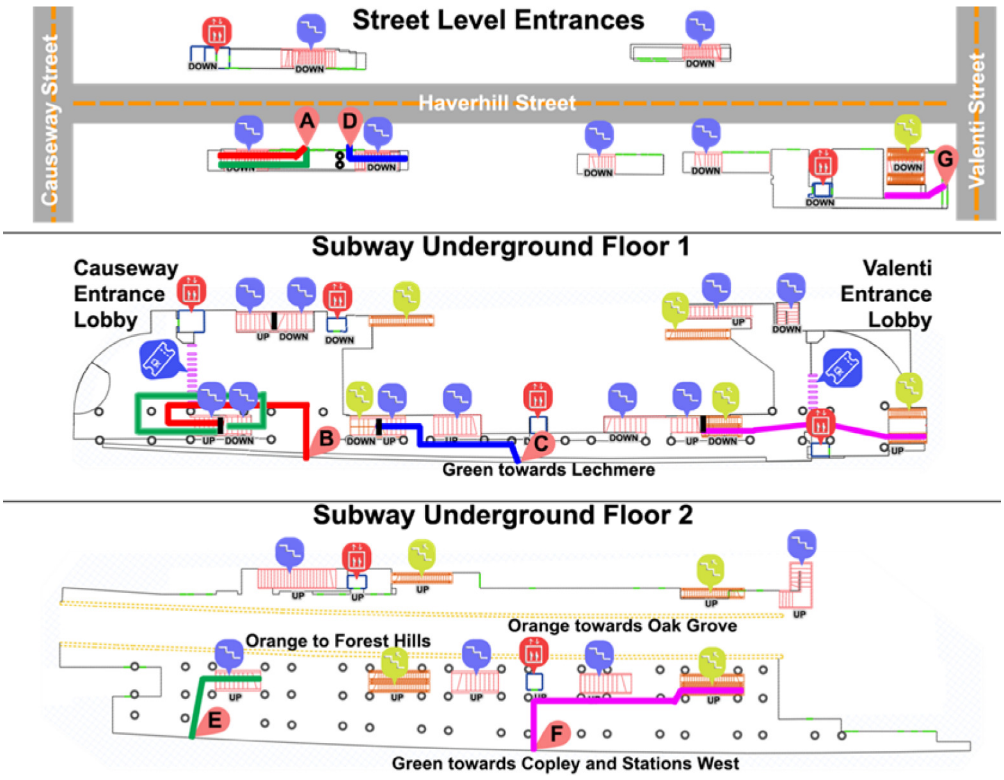


Fig. 4. Landmarks (markers A-F) used in trials navigation tasks

During the trial the participant is asked to complete these tasks relying only on their mobility skills and PERCEPT App. The Instructor accompanies the participant at all times but will no longer answer any questions. For each navigation task each participant was brought to a specific starting location in the venue and was told to navigate to a specific destination. Once the study participant had confidence that they reached the destination, they were required to indicate to the instructor that they had reached the destination. In the circumstance that they had indeed reached the destination the instructor would bring the participant to the next starting point to begin the next navigation task. If the participant was not at the location they would be informed by the instructor and asked to continue to the destination. In case the participant cannot proceed without assistance we determine the navigation task as unsuccessful. The trial ends either when all tasks are completed or the participant decides to stop.

Part III: Post Trial Questionnaire

After the trials we collected the participants' feedback and experience using a qualitative questionnaire. All six participants were able to use PERCEPT to complete each of the four navigation tasks with no outside assistance.

It is important to note that we expect for that the user will make mistakes (i.e., reach wrong landmarks or just get disoriented in the environment) and therefore require rerouting as provided by the application. Rerouting assistance in the application includes the ability to press "Where am I" as well as getting instructions from any landmark to the chosen destination. It was interesting to observe that the participants reported that they have built a mental map of the environment using the application rerouting feature as well as the "Where am I" feature.

Feedback per Task

The study personnel observed each one of the trial participants (P1-P6) while performing each one of the four navigation tasks. Table 1 includes these observations quantified as follows:

1. Reached destination with no issues

2. Reached destination with few issues

3. Reached destination with issues and required rerouting

4. Unable to reach destination.

Table 1. Users (P1-P6) feedback for the four navigation tasks

Navigation Tasks	P1	P2	P3	P4	P5	P6
Task 1	2	1	1	1	1	1
Task 2	1	1	1	1	1	1
Task 3	2	1	2	2	1	2
Task 4	3	3	3	1	1	3

We observe that the study participants had the most trouble with Task 4 which is indeed the most complex. In Task 4 the participant begins in a large open area and is asked to cross this large open area to reach an elevator in the middle of the open area. However after some time, the participants reached the destination.

Trial Feedback

Each participant was asked to score their agreement with specific statements related to their experience during the trial. The score followed Likert scale from 1 strongly disagree to 7 strongly agree with, with 4 being neither agreeing or disagreeing with the statement. The six statements, individual participant scores, and averaged score are provided in Table 2.

Table 2. Post-Trial questionnaire using Likert Scale scores

Statements	Average Score	P1	P2	P3	P4	P5	P6
Easy to learn how to use system	6.7	7	7	7	7	6	6
Easy to use the system	6.7	7	7	7	7	6	6
Trial design was easy to complete	6.3	6	6	7	7	7	5
Easy to use User Interface	6.5	7	6	7	7	5	7
System provided sufficient re-orientation information when lost	5.5	5	7	7	6	3	5
I am confident I will reach the destination using the system	6.7	6	7	7	7	7	6

Conclusions

In this paper we introduced the second generation PERCEPT system which enables independent indoor navigation in large and open indoor environments such as subway stations. The system was deployed at the North Station subway in Boston. We describe in details the experiments conducted with BVI users. All six BVI users successfully navigated through this subway station using PERCEPT application. Moreover, all participants were very satisfied with the system as evidenced by their very high scores in the post-trial questionnaire.

Acknowledgements

This project was supported in part by Grant 80424 from the Massachusetts Department of Transportation and National Science Foundation under Grant No. 1645737. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Massachusetts Department of Transportation or National Science Foundation.

Works Cited

Ahmetovic, Dragan, et al. "Achieving Practical and Accurate Indoor Navigation for People with Visual Impairments." in *Proceedings of 14th. International Web for All Conference on The Future of Accessible Work*, Perth, Australia, (2017). Print.

Basso, Stefano, Guglielmo Frigo, and Giada Giorgi. "A smartphone-based indoor localization system for visually impaired people." in *Proceedings of IEEE International Symposium on Medical Measurements and Application*, Torino, Italy, (2015): 543-548. Print.

Cheraghi, Seyed Ali, Vinod Namboodiri, and Laura Walker. "GuideBeacon: Beacon-based indoor wayfinding for the blind, visually impaired, and disoriented." in *Proceedings of IEEE International Conference Pervasive Computing and Communication*, Kailua-Kona, HI, USA, (2017): 121-130. Print.

Doush, Iyad Abu, et al. "ISAB: integrated indoor navigation system for the blind." *Interacting with Computer* 29.2(2016): 181-202. Print.

Ganz, Aura, et al. "PERCEPT-II: Smartphone based indoor navigation system for the blind." in *Proceedings of IEEE International Conference Engineering in Medicine and Biology Society*, Chicago, IL, USA, (2014): 3662-3665. Print.

Garcia, Gladys, and Ani Nahapetian. "Wearable computing for image-based indoor navigation of the visually impaired." in *Proceedings of ACM Wireless Health*, Bethesda, MD, USA, (2015): 17-22. Print.

Idrees, Affan, Zahid Iqbal, and Maria Ishfaq. "An efficient indoor navigation technique to find optimal route for blinds using QR codes." in *Proceedings of IEEE 10th. International Conference Industry Electronic and Application (ICIEA)*, Auckland, New Zealand, (2015): 690-695. Print.

Jaffer, Mr Abdul, and Mr P. Sathishkumar. “Indoor Navigation System for Visually Challenged Using Ultrasonic Sensor Map with Vibrational Feedback.” *Imperial Journal of Interdisciplinary Research* 2.6 (2016) 966-970. Print.

Jonas, Stephan M., et al. “Imago: image-guided navigation for visually impaired people.” *Journal of Ambient Intelligence and Smart Environments* 7.5 (2015): 679–692. Print.

Kim, Jee-Eun, et al. “Navigating visually impaired travelers in a large train station using smartphone and bluetooth low energy.” in *Proceedings of ACM 31th. International Conference Symposium on Applied Computing*, Pisa, Italy, (2016): 604-611. Print.

Riehle, Timothy H., et al. “Indoor inertial waypoint navigation for the blind.” in *Proceedings of IEEE 35th. International Conference Engineering in Medicine and Biology Society*, Osaka, Japan, (2013): 5187-5190. Print.

Rituerto, Alejandro, Giovanni Fusco, and James M. Coughlan. “Towards a sign-based indoor navigation system for people with visual impairments.” in *Proceedings of ACM 18th. International Conference Computer and Accessibility*, Reno, NV, USA, (2016): 287-288. Print.

Serrão, M., et al. “Computer vision and GIS for the navigation of blind persons in buildings.” *Universal Access in the Information Society* 14.1 (2014): 67–80. Print.

Tandon, Kushagra, et al. “A blind navigation system using rfid for indoor environments.” *International Journal of Computer Systems*, 2.4 (2015): 115-118. Print.

Tao, Yang and Aura Ganz, “Scalable and vision free user interface approaches for indoor navigation systems for the visually impaired,” M.S. thesis, ECE Department, UMass Amherst, Amherst, MA, 2015. Print.

Waris, Sadique, and S. B. Somani. “Indoor Navigation Approach for the Visually Impaired.” *International Journal of Emerging Engineering Research and Technology* 3.7 (2015): 72-78. Print.

World Health Organization. (2016). [Online]. Available at: http://www.who.int/mediacentre/factsheets/fs282/en/. [Accessed 20 Nov. 2016]. Web.

Zhang, He, and Cang Ye. “An indoor navigation aid for the visually impaired.” in *Proceedings of IEEE International Conference Robotics and Biomimetics*, Qingdao, China, (2016): 467-472. Print.

Zhang, Xiaochen, et al. “A slam based semantic indoor navigation system for visually impaired users.” in *Proceedings of IEEE International Conference Systems, Man, and Cybernetics*, Hong Kong, (2015): 1458-1463. Print.