



Technologies for Safe & Efficient Transportation

THE NATIONAL USDOT UNIVERSITY
TRANSPORTATION CENTER FOR SAFETY

Carnegie Mellon University

UNIVERSITY of PENNSYLVANIA

Enhancing the Safety of Visually Impaired Travellers in and around Transit Stations

FINAL RESEARCH REPORT

M. Bernardine Dias, Ermine Teves, Eric Hochendoner,
Praneetha Sistla, Byung-Cheol Min, and Aaron
Steinfeld

Contract No. DTRT12GUTG11

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

Introduction

Safety is a primary concern for the visually impaired when navigating unfamiliar urban environments. Since most environments are constructed to be easily navigated by sighted people, visually impaired people have to often seek help and use secondary clues to navigate many urban environments safely. As a result, daily activities such as using transit systems remain challenging tasks for people with visual impairments even though the use of transit systems is often a key factor for participation in employment, and educational, social, and cultural opportunities. Visually impaired adults have several challenges when navigating unfamiliar environments. First, they must pre-plan their navigation routes as much as possible and need to build a mental map of the new environment they will be navigating. Next, they need to figure out how to navigate between locations of interest from a known environment. They also need to be informed of dynamic changes to the unfamiliar environment which may impact their safe navigation. Furthermore, they need to be able to “record” their navigation experience for future trips and also potentially share this information with others who might find it useful. Finally, if they get into any unsafe or difficult situation while navigating the unfamiliar environment, they need to have a reliable means of getting help.

The TechBridgeWorld research group at Carnegie Mellon University has been exploring specific needs and constraints encountered by this user population when using transit stations. Through this work, our findings indicated a strong need for a tool that allows these travelers to annotate routes with their own notes of useful information, and to easily obtain and use relevant information from trusted sources. These trusted sources can fall in the category of authorities, individuals in the area who have been vetted or have a reputation for providing trustworthy information of relevance, and personal contacts (both sighted and B/VI) who the user trusts to provide useful and accurate information. The information needed and the level of detail/nature of the descriptions needed can be very different for people with different levels of visual impairment and/or familiarity of the environment. While Google Maps provide online map services that enable route planning, it does not provide continuous and dynamic information and notices that are often useful for B/VI travelers to accomplish safe and independent navigation. In addition, it does not allow users to verbally annotate their route. This is because Google Maps does not provide a real-time map and mainly targets sighted users.

Background

We initially prototyped an accessible Android smartphone tool that has significant potential to enhance the safety of these travelers. This tool allows travelers to annotate their paths and choose/invite trusted sources to enhance the relevant information that can enhance the safety and efficacy of their travel. Figure 1 shows some screenshots of the early prototype and Figure 2 shows the system architecture.

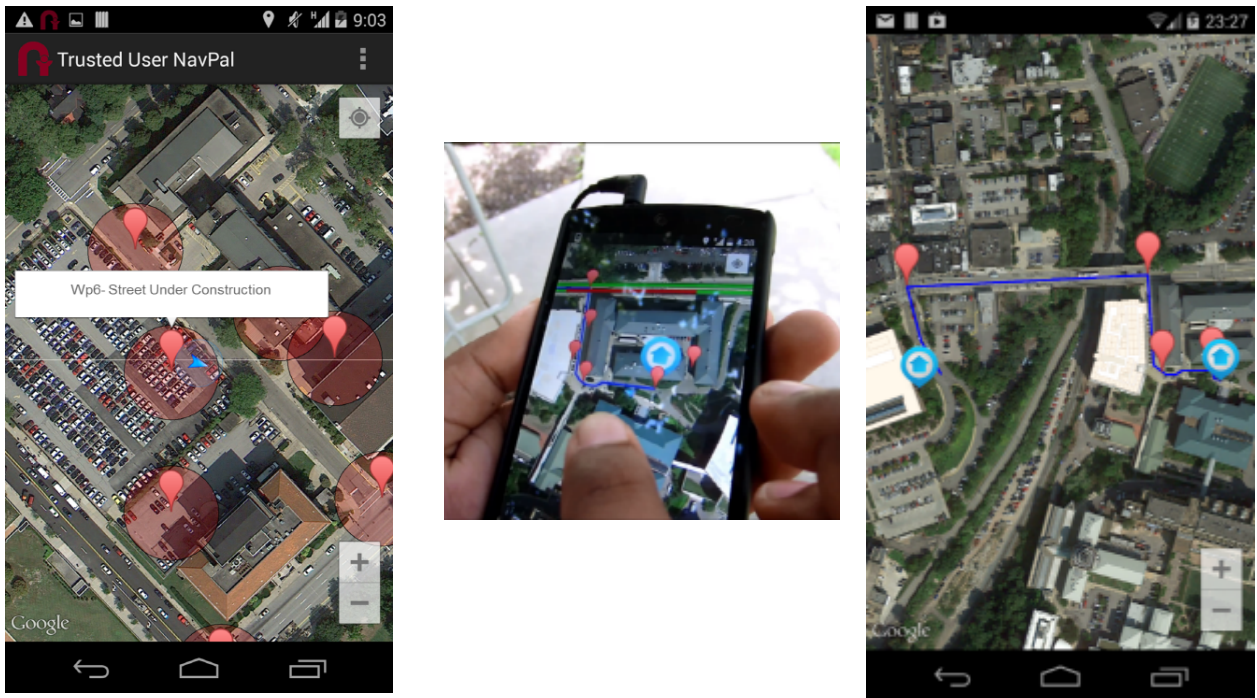


Figure 1. Screenshots of an early prototype

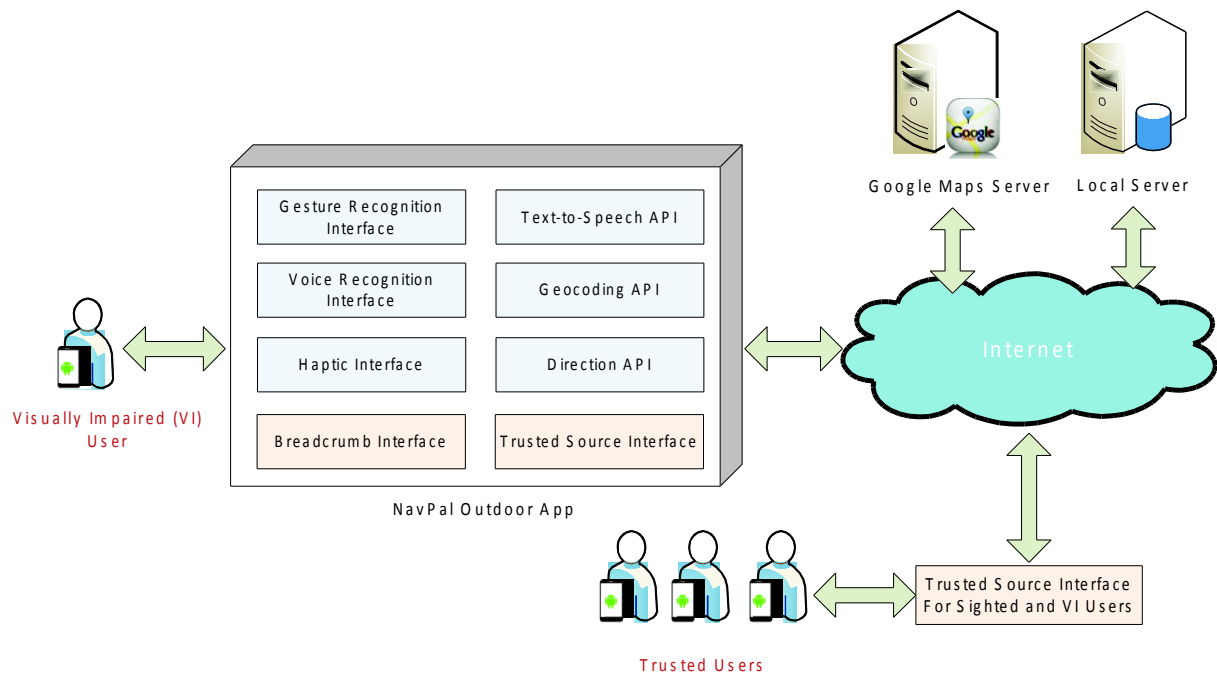


Figure 2. System architecture

As it is often crucial for B/VI travelers to be informed about dynamic changes especially when traveling in unfamiliar environments and to record their observation on the changes for future trips, we developed a framework for incorporating information from trusted sources, and user annotations. The underlying concept of the trusted source interface is that trusted individuals can share their observations about dynamic changes in the environment with B/VI

travelers for navigating safely and independently. For example, if a street is under renovation and a trusted individual traveling via this route observes this dynamic change that could be a potential risk to B/VI travelers, then he/she can record the dynamic information through the trusted source interface. B/VI travelers who have added that individual to their list of trusted sources are then alerted of this dynamic change, and can choose to avoid the street under renovation and take an alternative path to reach their destination safely. Examples of trusted individuals could be government officers in the locality, property managers (e.g., a building manager), orientation and mobility experts, friends of the B/VI traveler, or B/VI travelers themselves. B/VI users play an important role in this methodology since the system enables them to share their personal navigational experience with other B/VI users. Many B/VI people prefer obtaining navigational information from other B/VI persons due to having the same, or very similar, situational and informational awareness, and because of the types of descriptions and landmarks used in common.

We developed two interfaces for this prototype tool: 1) for B/VI trusted sources, and 2) for sighted trusted individuals. The B/VI interface of the prototyped tool is made accessible via on-screen gestures, voice commands, and audio output. Locations of interest to the user can be stored as phone contacts and effective routes between destinations (and from the current location) can be calculated via Google Maps. While navigating with this tool, the user is given audible navigational instructions at waypoint intervals, e.g., "Head north for 20 meters and then turn left." In addition, the street name and user's direction of travel are announced at intersections. The nearby points of interest are also automatically announced to the user for better localization and orientation. If the user deviates from the desired path at a given setting, e.g., 10 meters, the app informs the user to stop and re-routes a new path to the destination.

Since on-screen gestures are a commonly used input modality for B/VI users when interacting with a touchscreen smartphone, we adopted these gestures as part of our accessible interface. We first conducted a small usability study with a few B/VI users from our partner networks to determine which gestures are more effective for our tool. We also evaluated accessibility and ease of operation of our smartphone tool through this small usability study.

For the annotation component, a B/VI user can verbally record his or her navigational experience and refer to it for future trips using our "breadcrumb" interface which allows a user to record messages tied to specific locations on a route that will automatically be played when they encounter those waypoints in the future. Message examples include any potential hazards, a waypoint name, and orientation information for future trips.

For sighted trusted users, we developed an additional app where they can simply tap the map on the screen and annotate any observed dynamic changes. Trusted users can specify attributes for the data such as 1) characterization of traversability of the waypoint, 2) the proximity of this waypoint to a key landmark, and 3) an estimated lifetime for this data to exist. The users can define a fixed lifetime in hours and minutes or can leave it as an unknown lifetime.

Trusted sources data, either from B/VI users themselves or sighted users, are then directly sent to the local server for storing. The data will be retrieved by the NavPal app depending on the trusted sources selected by B/VI users. The trusted user interface allows B/VI users to designate trusted sources for navigation aids from their contact list. This feature is vital because it enables B/VI travelers to prioritize trusted users and sources and also prevents retrieval of excessive and unhelpful information. This list is stored in the user's Android internal memory and can be edited through the setting option of this interface. Finally, B/VI users can be informed of dynamic changes by retrieving the user-designated trusted sources. This initial prototype helped us to develop limited functionality and get some useful user feedback which confirmed the significance of its potential impact in improving safety for B/VI travelers.

Approach

Based on the feedback received from the initial prototype, the research team focused on re-designing the NavPal app to enhance its robustness and user interface, and to allow for seamless integration of both indoor and outdoor navigation.

Enhanced NavPal App

NavPal is an Android app which aims to help blind or visually impaired users to navigate in public spaces. It has several components, all of which follow a similar modular structure, localization, address decoding, and path finding. This app was entirely re-implemented with a more modular design that enhances robustness and extensibility to easily add new features in the future. The flowchart for the enhanced NavPal app is illustrated in Figure 3. The key innovation added was enabling the app to seamlessly navigate in both indoor and outdoor environments and detect these transitions to alert the users as needed.

For each of the NavPal app components, there are several separate modules which perform their task to the best of their ability and then pass their results to a centralized aggregator which combines each modules estimate to produce the final output used by NavPal. For example, there are currently two path finding modules, one for indoors, one for outdoors, so if the user wants to navigate from a bus stop to a particular room, the outdoor module generates a path to the front door of the building, and the indoor module generates a path from the front door to the room, then these two paths are passed to the aggregator which combines them and returns the mixture back to the overall NavPal system.

This same system is used for localization. There are numerous modules that perform localization separately. They then send their best guess about the user's position, as well as how certain they are of this guess, to the localization aggregator which can compare them and previous locations to generate a more realistic position estimate.

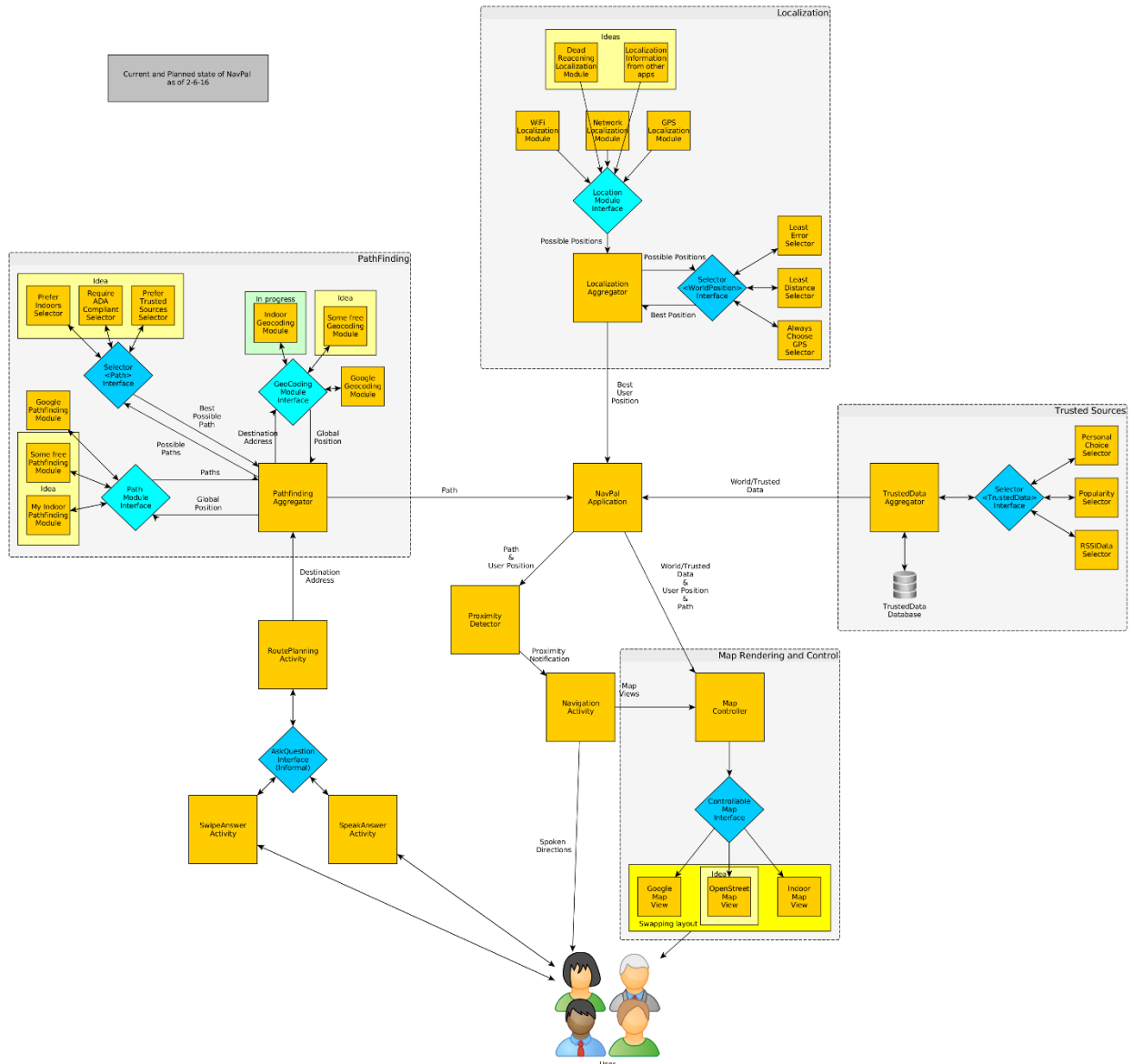


Figure 3. NavPal app flowchart

NavPal can also take advantage of Android's broadcast system to allow other 3rd party applications to receive data from NavPal and contribute to NavPal. This would allow an ecosystem of context-aware accessible applications. For example, a public transit system could implement an app that would allow users to connect to the bus they are riding and receive location information from it, this would allow the user to turn their GPS off to save their phone's battery. The transit app could even look at the user's current navigation, see what stop they need to get off at, and notify them and the bus driver when they reach the stop.

NavPal also features a database which encodes every building that has been mapped as a graph allowing fast search for destinations, like a specific room or the nearest bathroom or water fountain. This database is also designed to store other information that would be of interest to a blind or visually impaired individual such

as warnings about a step on a sidewalk, or information to enhance their experience like telling them when they will pass a vending machine or kitchen so that they can tell by the sounds/smells that they are still on the right path.

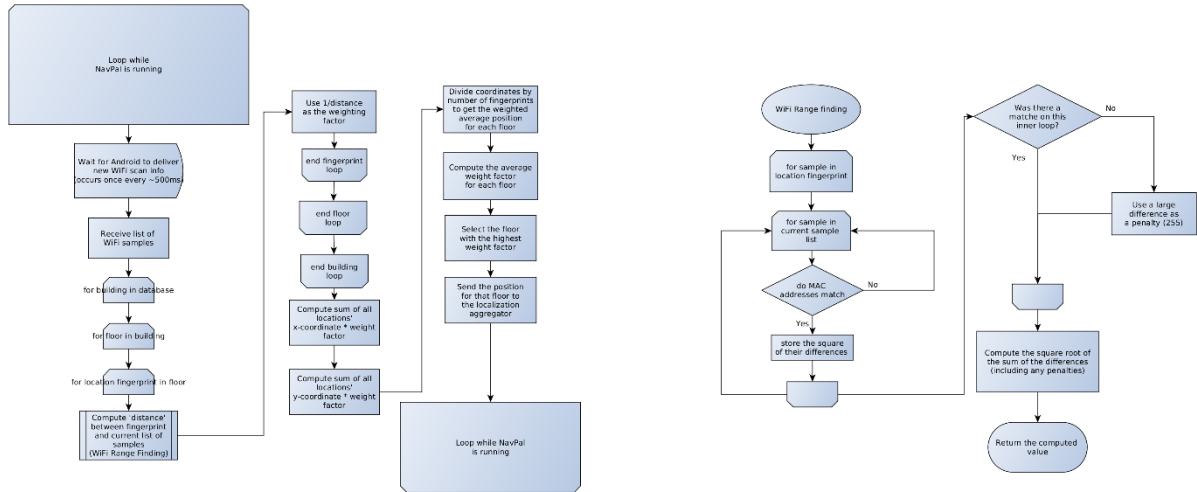


Figure 4. RSSI Algorithm used in latest NavPal app implementation

NavPal includes an indoor localization module which takes advantage of existing Wi-Fi network infrastructure. This is done by first 'fingerprinting' the building by recording Wi-Fi RSSI data at approximately one meter intervals down each corridor. Then, when NavPal has reason to believe that the user could be in that building it performs another RSSI scan and calculates the Pythagorean distance between that scan and all of the previously scanned positions. Then a weighted average of all of those positions is computed using the inverse of the distance as the weighting factor, i.e. positions with a lower distance receive a higher weight. This average is then returned as the Wi-Fi localization module's estimate. The RSSI algorithm used by NavPal is illustrated in Figure 4.

User Interface

Along with the enhanced app implementation, we also explored enhancements to the user interface for NavPal. The primary consideration when designing an interactive User Interface for this application was ease of use. As such, the interface was designed to require only simple operations by the user. It also interacts with the user through audio and haptic feedback.

Input Method

While designing the User Interface, careful consideration was given to choosing the type of input. For example, different types of input by a user would be through text, audio, swipe, tap etc. Even though we ruled out text, we had to choose an effective means of input between tap and swipe.

The user input is taken through the following methods:

- Swipe gestures

- Tap
- Audio Input

Within the tapping medium of input, there are several methods:

- Single tap
- Double tap
- Long press

Similarly, the swipe gestures fall under the category of multi-touch events. As such, we can choose between inputs by a simple swipe in different directions, to using two-fingered pinch. As Kane discussed in his paper **Error! Reference source not found.**, swipe gestures prove to be the easiest of input gestures for people with visual impairment. Therefore, we decided to use simple swipe gestures as the main input mode for the User Interface of this application.

Swipe Gestures

This application is designed to be compatible with NavPal application. As such, the User Interface for this application is designed to allow the user to select/ change multiple options. For example, using this application, the user would be able to add/delete a destination. Since the application has multiple tasks like these, the user input needs to be flexible enough so the application decodes it accordingly. One idea was to create large buttons on the screen and give auditory feedback whenever the user taps a button. The second idea was to divide the screen into two halves. And each half would be an input screen. The user can perform multiple swipe inputs on each half and each gesture would be linked to action. The latter idea provides much more flexibility and options to use. We decided to go with a User Interface that would take different swipe gestures as user input, and to use simple gestures like swiping up, down, left or right.

Hierarchy

The second way of improving ease of use for users with visual impairment is to reduce hierarchy in navigation of the application. We wanted to minimize the number of “activity screens” the user has to navigate between. Each “activity screen” corresponds to a set of choice that the user can choose.

1. **Start activity Screen (Select Destination):** The application launches this screen by default. Since the application is primarily used to select a destination and navigate to it, this is chosen as the default screen. In this screen, the user can swipe up/ down to scroll through a list of destinations that are stored. To confirm one of the destinations, the user can swipe to the right. There is auditory feedback instructing the user to do so when the application launches. Upon confirming the destination, the auditory feedback informs the user that the destination is selected.
2. **Menu Options Screen:** The user can access the menu options screen by swiping to the left from anywhere in the application. In this screen, the user can

again swipe up/down to scroll between different options. The options available are: add a destination, delete a destination, or select a destination. The user can select an option by scrolling through the right again. This lands them into the screen of adding, deleting, or selecting a destination (the start screen).

3. **Adding a Destination Screen:** When the user chooses to add a destination from menu options, this screen is launched. The auditory feedback instructs the user to tap the screen, record the name of the destination, and tap it again to finish the recording. Once the recording is finished, the user can swipe to the right to confirm the recorded destination or swipe left to go back to the menu options. The user can also tap again to record it again. Once the recording is confirmed, the user is redirected to the menu options screen.
4. **Deleting a Destination Screen:** When the user chooses to delete a destination from menu options, this screen is launched. The user can scroll up/down to select a destination and swipe right to delete it. The auditory feedback asks the user to confirm deletion before removing the destination completely. Once again, after confirming, the user is redirected to the menu options page.

Methodology

Once the NavPal prototype app and User Interface was built, the components were tested separately with potential end users. To separate feedback of the user interface from the navigation component, user feedback was solicited separately for the two components, and the components were not integrated into a single app for the purpose of the user test. The purpose of user testing was to determine the components' effectiveness and solicit feedback for improvement.

Participants

The user study was limited to stakeholders residing in the greater Pittsburgh area in Pennsylvania, USA. Participants were recruited from relevant community organizations, and the study was designed and executed in compliance with Carnegie Mellon University's Institutional Review Board (IRB) protocols (IRB number HS15-422). Four travelers voluntarily participated in the study – two were completely blind and two were visually impaired with varying degrees of vision. Each user study lasted approximately one hour and took place at Carnegie Mellon University.

Activities

For the NavPal prototype part of the user study, participants were provided with an Android smartphone (Sony Xperia Z3 compact) loaded with the app. After a quick training to become familiar with the app and its features, participants were asked to follow NavPal's navigational instructions for two routes: (1) an outdoor to indoor route and (2) and indoor to outdoor route. The first route originated at a bus stop just outside Carnegie Mellon University and ended at a lab in a nearby university building. The second route originated at an office in Carnegie Mellon University and

ended at a popular accessible pickup spot just outside the building. Each route was less than a quarter of a mile. One researcher took notes on the prototype app's accuracy and another researcher ensured the participants' safety at all times. Afterwards, participants returned to the office where they answered questions about their experience navigating with the NavPal app.

Participants then proceeded to the User Interface part of the study. A preliminary training was conducted where researcher explained about the User Interface and what each gesture means. Furthermore, the researcher explained to participants that this part of the user study was strictly to evaluate the User Interface and not the navigation. After training, each participant was given three scenarios: (1) to select a destination, (2) to add a destination, and (3) to delete a destination. For each scenario, notes were taken on intuitiveness of the interface and if the user was able to navigate to various functionalities or if they faced any difficulties. After all three scenarios were completed, the participants were asked a set of follow up questions to obtain their feedback on the User Interface in general, design preferences, and thoughts for improvement.

Findings

NavPal Prototype App

All participants found the app to be useful and liked at least one feature. All participants thought that the instructions/directions were clear and easy to follow and that it enhanced their navigation experience. Two participants were completely blind and also did not personally own a smartphone. It was easy for them to learn the swiping gestures during training and liked the app's swiping feature.

In terms of recommendations to improve the prototype app, all participants wanted it to update them on their progress when following directions. For example, to inform them that they are headed in the right direction, or when a turn is coming up. Three out of four participants recommended that the app have a feature to repeat directions for reasons such as ambient noise, they ran into someone they know, or if they got distracted. Participants gave useful suggestions for what information they would like to receive from the app, such as potential obstructions, steps, doorways, staircases, lavatories, water fountains, etc. One participant who had some vision, suggested that we use more audio cues than visual descriptors in our directions. For example, instead of saying, "you are approaching a cafeteria," the app can say, "you are approaching a cafeteria where you will hear a loud common space." All had different preferences for verbosity. This highlights the importance of an app that allows the user to customize their interaction experience with the app. For example, verbosity could increase in new locations and decrease in a more familiar locations. Overall, the participants were impressed that the prototype app worked indoors as well as outdoors. One participant who had a technical background commended the researchers on the seamless transition between indoor and outdoor and vice versa. Participants said they would use such an app for their navigation needs.

User Interface

Results confirmed the potential for the developed User Interface to be effective in a navigation app. However, there is room for improvement, such as adding more features and customizing the feedback users receive from the User Interface. Using gestures for input was seen as a good decision as it provides the users a stable way of input even while walking. All users specified that they would benefit from using an app while navigating, especially to new destinations. Future work will further develop a User Interface that can be customized according to user's needs as well as integrating the interface with the NavPal prototype app. More detailed results are listed below.

Selecting a destination

During this task, the users were able to swipe up/ down and a select a destination. They are then able to confirm it by swiping to the right without any errors. One user, however, swiped diagonally. When the application did not give the user any feedback about it, the user did not know that it was not the correct gesture. Therefore, future iterations will alert users when the performed swipe gesture is not recognized by the app.

Deleting a destination

During this task, the users had to swipe to the left to go to the menu options and then choose the option of deleting a destination. The users were able to go to the menu options screen. However two users swiped left again instead of right and this brought them back to the start screen. After correction, all users were able to successfully select the option of deleting a destination. They were also then able to delete the destination successfully.

Adding a destination

After deleting a destination, the users are automatically brought back to the menu options screen by the application. One user missed the audio feedback about that change and therefore was unsure of how to proceed from there. After some guidance, all users were able to select the option of adding a destination. Future versions of the user interface will incorporate more help features to enable users to figure out where they are in the app menu and how to proceed to the functionality they wish to use.

Once the option is selected, the app lets the user record the name of the destination and confirm it. This is the section of the application where the user taps the screen to start recording and tap again to stop the recording. While tapping the screen, the application sometimes detects the tap as a swipe. Three users faced this problem and therefore needed extra guidance.

After the destination name is said, two users did not tap the screen. When the application did not give any feedback, the users were unsure of the next step. This is the second area where the users were given extra guidance.

Clearly, future versions of the user interface will need to improve guidance and feedback throughout the interaction, and better distinguishing between taps and swipes.

User Questions

After the users completed all three tasks, they were asked a set of questions based on their interactions. Findings are summarized below:

- In general, all the users found that the ease of use for the User Interface was average.
- The audio instructions were easy to understand and the gestures were simple to use.
- Two users mentioned that they would like the application to give them feedback about incorrect gestures.
- All four users mentioned that they would use this interface for a navigational application.
- One user wanted the ability to interrupt audio feedback. When the users are familiar with different gestures, they would not want audio feedback for commonly used features to continue.
- All four users wanted to maintain the simplicity of the User Interface but would like to see more features added in.
- All four users mentioned that since the User Interface is based on swipe, it will be easier to use even while walking and using a cane.

Conclusions

Our work this year focused on re-designing the NavPal app to enhance its robustness and user interface, and to incorporate seamless integration of both indoor and outdoor navigation. We continued to explore a combination of WiFi and GPS-based indoor and outdoor localization techniques, as well as our trusted sources framework for categorizing and utilizing accessible landmarks to enhance navigation. Thus, we continued our tradition of designing a human-machine solution to address this problem. Our team conducted initial user testing of our component technology prototypes with four blind and visually impaired participants at Carnegie Mellon University and received positive feedback. Initial testing by our team was also conducted at the campus of the Western Pennsylvania School for Blind Children.

Findings from this work continue to impact several fields in useful ways. The trusted sources framework continues to receive interest from groups spanning non-profits and industry, and our prototype solution contributes to the state of the art in assistive technology research.

While our focus is in the discipline of robotics, and more specifically in assistive technology, the outcomes of this work will also have impact in the fields of orientation and mobility (the specialists who train blind and visually impaired people to navigate), accessible transportation, and human-computer interaction. Orientation and mobility experts continue to show interest in how our work can assist them to further enhance the independence and safety of blind and visually impaired people. Transportation groups such as Port Authority in Pittsburgh are

interested in how this work can be used to improve the services they offer to riders with disabilities. Human-computer interaction researchers who focus on interface design are interested in what we learn about accessible interfaces to technology tools.

Recommendations

The following set of ten design guidelines will be informative to other researchers working in the area of assistive navigation technology for B/VI users.

1. **Include users in the design process:** The most important guideline for effective work in this area is to include B/VI users and O&M specialists in an iterative design and testing process. Testing conducted with blindfolded sighted users does not yield the same result.
2. **Keep the user in the loop:** It is important to appreciate the orientation and mobility training of the B/VI users. Navigation assistance tools that keep the B/VI user in the loop and incorporate their input effectively will produce more robust and useful guidance.
3. **Pay attention to affordability:** Employment and purchasing power can be low among the B/VI community so assistive tools must be affordable in order to be useful.
4. **Reliability is extremely important:** Because the failure of these tools could jeopardize the safety of B/VI users, the tools must operate reliably to gain the trust of the users. Reliability can be addressed practically by predictable behavior in all scenarios, and graceful degradation in difficult environments. If users can predict failure conditions and how the tool will respond to these conditions, users can detect these situations and be prepared to overcome these limitations of the technology.
5. **Build practical tools:** It is important to ensure that B/VI users will be able to learn to use the technology in a reasonable timeframe, and that the usage scenario of the tool is practical. For example, practical considerations such as theft of expensive technology or the inability of a user to carry and use many/heavy/poorly shaped devices must be taken into account when designing these tools.
6. **Do not overwhelm the user:** Because the B/VI users must pay attention to their surroundings and keep track of a variety of things when navigating, it is important to design assistive tools that do not overwhelm or monopolize the attention of the user. Interfaces should be as simple as possible and allow for customization since the user will often need to multitask, and will want different levels of assistance from the assistive device depending on the specific scenario.

7. **Environmental considerations are important:** In areas with high levels of competing sound, B/VI users often prefer less information from assistive tools so that they can focus on other inputs from the surroundings. In contrast, when navigating through a large empty space, the user may want much more detailed instructions. Furthermore, when a tool provides information that is read aloud, it is important to consider privacy issues and whether this output is generating distracting levels of background noise.
8. **Expect and adapt to dynamics:** Effective assistive tools will provide mechanisms for recognizing changes in the environment and adapt to those changes in a timely manner that is beneficial to the B/VI user. Distinctions should be made between temporary changes and permanent infrastructural changes for optimal performance.
9. **Make the most of existing resources:** Understanding how B/VI users navigate without technology, and employing universal design principals to harness resources useful to sighted people can contribute significantly to the success of assistive tools for the B/VI community.
10. **Understand the bigger picture:** Understanding procedures, policies, and laws relevant to accessibility can significantly contribute to successful design decisions for assistive tools.

Acknowledgments

We thank our partners for their dedicated support of our project. We also thank all of the participants who volunteered their time for user testing.

This work is funded in part by Carnegie Mellon University's Traffic21 Initiative and Technologies for Safe and Efficient Transportation, The National USDOT University Transportation Center for Safety (T-SET UTC) which is sponsored by the US Department of Transportation. This work is also funded in part by a grant from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR grant number 90RE5011-01-00). NIDILRR is a Center within the Administration for Community Living (ACL), Department of Health and Human Services (HHS).

References

- [1] S. K. Kane, J. O. Wobbrock, and R. E. Ladner, "Usable Gestures for Blind People: Understanding Preference and Performance," in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New York, NY, USA, 2011, pp. 413–422.
- [2] Byung-Cheol Min, Suryansh Saxena, Aaron Steinfeld, and M Bernardine Dias, "Incorporating Information from Trusted Sources to Enhance Urban Navigation

for Blind Travelers," IEEE International Conference on Robotics and Automation (ICRA), March, 2015.

- [3] M. B. Dias, "NavPal: Technology Solutions for Enhancing Urban Navigation for Blind Travelers," tech. report CMU-RI-TR-21, Robotics Institute, Carnegie Mellon University, Sep. 2014.
- [4] B. Kannan, N. Kothari, C. Gnegy, H. Gedaway, M. F. Dias, and M. B. Dias, "Localization, Route Planning, and Smartphone Interface for Indoor Navigation," in Cooperative Robots and Sensor Networks, A. Kouba and A. Khelil, Eds. Springer Berlin Heidelberg, 2014, pp. 39-59.
- [5] G. Galatas, C. McMurrough, G. L. Mariottini, and F. Makedon, "eyeDog:
- [6] P. Narasimhan, R. Gandhi, and D. Rossi, "Smartphone-based Assistive Technologies for the Blind," in Proceedings of the 2009 International Conference on Compilers, Architecture, and Synthesis for Embedded Systems, New York, NY, USA, 2009, pp. 223-232.
- [7] N. Kothari, B. Kannan, E. D. Glasgwow, and M. B. Dias, "Robust Indoor Localization on a Commercial Smart Phone," Procedia Computer Science, vol. 10, pp. 1114-1120, 2012.
- [8] J. A. Hesch and S. I. Roumeliotis, "An Indoor Localization Aid for the Visually Impaired," in 2007 IEEE International Conference on Robotics and Automation, 2007, pp. 3545-3551.
- [9] Hend K. Gedawy, "Designing an Interface and Path Translator for a Smart Phone-Based Indoor Navigation System for Visually Impaired Users." tech. report CMU-CS-11-125, Computer Science, Carnegie Mellon University in Qatar, Dec. 2011.
- [10] J. M. Coughlan and H. Shen, "Crosswatch: a System for Providing Guidance to Visually Impaired Travelers at Traffic Intersections," Journal of Assistive Technology, vol. 7, no. 2, Apr. 2013.
- [11] V. Kulyukin and J. Marston, "The Blind Leading the Blind: Toward Collaborative Online Route Information Management by Individuals with Visual Impairments," AAAI Spring Symposium: Social Information Processing, pp. 54-59, 2008.
- [12] H. A. Karimi, B. Zimmerman, A. Ozcelik, and D. Roongpiboonsopit, "SoNavNet: a framework for social navigation networks." Proceedings of the 2009 International Workshop on Location Based Social Networks. ACM, pp. 81-87, 2009.
- [13] D. McGookin, S. Brewster, and W. Jiang. "Investigating touchscreen accessibility for people with visual impairments." Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges. ACM, pp. 298-307, 2008.

- [14] J. Balata, J. Franc, Z. Mikovec, and P. Slavik, "Collaborative navigation of visually impaired," *Journal of Multimodal User Interfaces*, vol. 8, no.2, pp. 175-185, Jun. 2014.