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# Towards Safe Urban Navigation for Visually Impaired Travelers

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## Disclaimer

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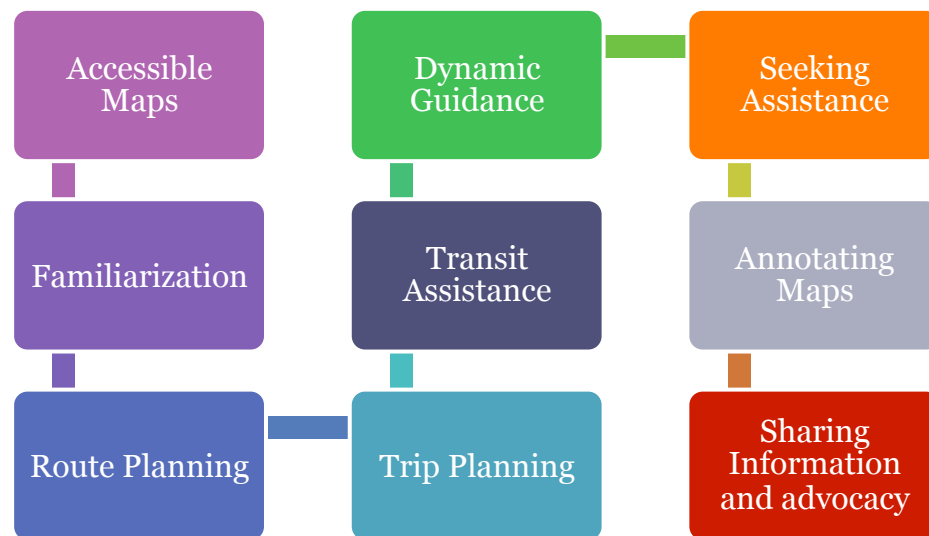
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## Motivation

Safety is a primary concern for the visually impaired when navigating unfamiliar urban environments. The recent White House Technology Showcase celebrating 20 years of the Americans with Disabilities Act (ADA) highlighted the need for using technology to enable Americans with disabilities to participate fully, both in their personal and professional lives. A critical component of this envisioned independence for people with disabilities is their ability to navigate urban environments. For people with visual impairments urban navigation can be sufficiently daunting that they avoid unfamiliar environments if possible. Since most environments are constructed to be easily navigated by sighted people, people with disabilities have to often seek help and use secondary cues to navigate many urban environments safely. Day-to-day activities such as using transit systems remain challenging tasks for people with visual impairments. This work aims to start addressing this safety problem by understanding the problem in greater context and exploring a variety of approaches that can enhance the safety of blind adults navigating the Carnegie Mellon campus and its connections to the surrounding community.

## The Urban Navigation Problem

Before we can solve the urban navigation challenge for people with disabilities, we must understand the key components of this challenge which include many elements including outdoor navigation, indoor navigation, transit system use, and emergency evacuation. Any solution to this challenge must therefore address all of these elements.



**Figure 1: Elements of urban navigation and wayfinding**

This means that urban navigation aids must incorporate accessible interfaces that allow people with disabilities to both receive and convey information, and must be customizable to accommodate individual preferences. These tools must also be capable of indoor and outdoor localization at the resolution

necessary for visually impaired travelers. For example, a sighted person is typically able to locate a place of interest if they are provided guidance to within a few meters to that location. This resolution of guidance is often insufficient for blind travelers. Access to maps and other information in a variety of forms will also be critical so that routes that adhere to sensory and ambulatory constraints can accordingly be planned. Finally, to truly empower people with disabilities, these aids, should provide mechanisms for advocacy to improve accessibility within the larger framework of the city infrastructure.

## **Scope of Work**

This short-duration project explores a variety of avenues to make the Carnegie Mellon University campus in Pittsburgh safely and independently navigable by visually impaired adults. The project thereby aims to contribute to methods that enhance safety for blind travelers traversing indoor and outdoor components of the campus, and also explores some aspects of safer navigation to and from campus (ex. connections to public transit). The project focuses mostly on increasing the understanding of the urban navigation challenge for visually impaired adults, and exploring initial concepts for potential technology solutions.

## **Approach**

Visually impaired adults have several concerns when navigating unfamiliar environments. First, they 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 to and from the location(s) 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. We employ a combination of surveys, interviews, and observations to enhance the understanding of these challenges, and explore ideas for a suite of tools accessible via ubiquitous smartphones and personal computers that can assist visually impaired navigators with all of the components relevant to the urban navigation problem.

## ***Community Partners***

- Blind and Vision Rehabilitation Services of Pittsburgh (BVRS)
  - We recruited blind and visually impaired adults from BVRS to inform our work
- Western Pennsylvania School for Blind Children (WPSBC)
  - We also benefited from the experience and expertise of the WPSBC staff in carrying out this work

## Understanding Challenges

In order to develop solutions that most effectively serve the navigation needs and preferences of visually impaired people, we conducted needs assessment to gain a better understanding of the nature, scope, complexity, and diversity of their current navigation methods and challenges. While examining existing navigation solutions, the research team also gathered information and feedback from partner organizations to inform and guide our work.

The needs assessment was conducted in six phases:

- Phase 1 surveyed existing assistive indoor navigation technology solutions for visually impaired.
- Phase 2 included:
  - Passive observations of visually impaired navigation lessons and an emergency building evacuation from partner organizations,
  - Initial interviews with visually impaired individuals and Orientation and Mobility (O&M) experts from partner organizations.
- Phase 3 included:
  - Examination of online blog posts written by deafblind individuals about their navigation experiences, and
  - Examination of instruction models and narrative maps provided in other navigation projects for the blind.
- Phase 4 included detailed surveys and interviews with visually impaired people or people who worked closely with visually impaired individuals from partner organizations.
- Phase 5 included:
  - Interviews and surveys with building managers to understand their challenges in making buildings accessible to visually impaired visitors,
  - Interviews and surveys with visually impaired travelers and orientation and mobility experts to understand challenges encountered during transit.
- Phase 6 exposed several members of the research team to the methodology of orientation and mobility training experts impart to visually impaired people

## **Assistive Indoor Navigation Technology for Visually Impaired People**

Making indoor navigation easier and safer for visually impaired people has been considered for decades. Any routing technology for the visually impaired requires different components and many technologies (both commercial and research) have been developed to assist people with disabilities to address these different components. While our principal interest is in technology to assist visually impaired people, we also investigated some technology developed to assist people with ambulatory disabilities so that we benefited from this additional knowledge.

People with disabilities have to overcome numerous challenges in their lives to perform basic day-to-day activities. In recent times, assistive technology (AT), generically defined as the set of technological tools that includes assistive, adaptive, and rehabilitative devices for people with disabilities, has promoted greater independence by enabling people to perform tasks that they were previously unable to accomplish on their own. One example is augmenting white canes with a variety of sensors such as laser emitting diodes, magnetic field probes, RFID [11-16], ultrasonic devices [17], and cameras [17-22]. Drishti [23] is an example of one such technological system that uses a precise position measurement system, a wireless connection, a wearable computer, and a vocal communication interface to guide blind users and help them travel in familiar and unfamiliar environments independently and safely. Outdoors, it uses DGPS as its location system to keep the user as close as possible to the central line of sidewalks of campus and downtown areas, and provides the user with an optimal route by means of its dynamic routing and rerouting ability. Some of the drawbacks to Drishti include the need for expensive additional equipment for positioning, and reliance on DGPS. In urban cities, GPS coverage cannot always be guaranteed. As a consequence any solution that relies purely on GPS is unreliable. Additionally, the lack of individual customization leads to a generic solution that is not suitable for all.

Assistive devices for enabling independent navigation for blind people have been explored for over a decade [24]. Recent work on navigational assistance for indoor environments includes BlindAid: An Electronic Travel Aid for the Blind [25]. In this system, the user carries an RFID reader on a cellular phone, and uses a network of inexpensive RFID tags in the building to navigate. This solution uses previously prepared map data to localize the user and specify desired routes through a voice interface or using buttons on the device. This solution does not translate well to outdoors. A core necessity of the system, installing RFID tags, is not practical and can get expensive when considered at a city wide scale. Furthermore, robustness will depend on how well the tagging of the environment is maintained. Other solutions have examined the combination of crowdsourcing, mobile phones, and Braille input devices to enhance the experience of blind and deafblind users using public transit systems [26]. Crowdsourcing is an increasingly popular mechanism to empower blind people in a variety of tasks [27-29], and when



combined with other perception, planning, and interface solutions, has strong potential for enhancing the experience of visually impaired people navigating urban environments.

In the area of assistive technology for ambulatory disabilities, advancements in engineering have transformed wheelchairs to be highly mobile forms of individualistic self-expression. Techniques of computer modeling [30], rapid-prototyping and robotics [31] are being applied to wheelchairs to create electric powered mobility and manipulation devices. The Drive-Safe System (DSS) [32] is one such addition, distributed, shared-control navigation assistance system for power wheelchairs intended to provide safe and independent mobility for people with ambulatory disabilities. The DSS is a human-machine system in which the user is responsible for high-level control of the wheelchair, such as choosing the destination, path planning, and basic navigation actions, while the DSS overrides unsafe maneuvers through autonomous collision avoidance, wall following, and door crossing. The drawback to DSS is that it is a low-level reactive solution that leaves all the high-level decision making to the user. Further, DSS requires a relatively large number of sensors for effective performance, including five ultrasonic range finders (URs), five infrared range finders (IRs), two bumper inputs, one speaker, and three status light-emitting diodes. Finally, such solutions require modifications to the operating environment including eliminating or obstructing glass walls and doors, widening doorways, and more.

In summary, despite the widespread research in assistive technology and the strong demand for assistive navigation tools [33], currently there exist no low-cost, accessible and user-friendly navigational aids to enable travelers with disabilities to safely navigate local neighborhoods and effectively utilize existing transportation options.

## **Initial Observations and Interviews**

### ***Passive Observations***

Researchers observed indoor navigation lessons for students as well as a fire drill evacuation process at one of our partner locations. The navigation lessons consisted of two hours of passive observation of the two activities inside the main school building: (1) navigation training session for a person with limited vision who also uses a wheelchair and (2) navigation training session with a young child who is totally blind but is able to move without a wheelchair and use a white cane to navigate. In these two sessions the teacher took each student around the building to different areas, reminding him/her of the different tactics and guides he/she should follow to safely and correctly navigate and localize himself/herself in the building. Finally, researchers were able to observe a fire drill evacuation process to better understand navigation challenges in an emergency scenario.

These observations helped in understanding landmarks of interest to potential assistive technology users. First, the lessons with students had techniques about orientation, safety, and obstacle avoidance. Second, the students had a mental map of the school so they were navigating smoothly (this highlighted the importance of mental maps). Third, the school had adaptations and landmarks in the environment that do not usually exist in all buildings. Some of the landmarks, however, were common in other buildings and the users used them during navigation lessons. These observations, therefore, were useful for understanding some landmarks that traveler with disabilities may pay attention to during navigation.

### ***Initial Interviews***

Researchers interviewed three visually impaired staff members to learn about their navigation experiences and their interaction with technologies. Four experts in the Orientation and Mobility (O&M) field were interviewed to learn more about what instructions they used to describe routes to visually impaired people. During the interviews, researchers also asked several questions related to navigation needs and interface input/output modalities that work for the target user. These initial interviews focused on learning about the following aspects:

- *Interfaces of successful technological interventions adopted by the visually impaired community.* Researchers concentrated on those interventions that could be directly related to the navigation domain or mobile devices.
- *Learning and familiarization processes related to the use of mobile technology.* Researchers were interested in learning experiences that provided cues as to how visually impaired users could adopt mobile navigation aids.
- *Type of interfaces preferred or rejected by visually impaired users who were already familiar*

with mobile devices. This aspect included input and output modalities applicable to navigation systems, as well as features related only to the information given by navigation aids, for example, level of verbosity.

- *Type of activity for which a visually impaired user would like to get navigation assistance.* For example, shopping, emergency evacuation, etc.
- *Impediments for the adoption of electronic travel aids.* For example, trust levels in current technology, fears about being lost or confused, independence, lack of motivations, etc.

During these initial interviews, visually impaired interviewees reported the adoption of different technologies, which ranged from using conventional mobile phones to using smart phones. These interviewees also indicated they used different technologies such as: GPS devices, mp3 players, Mobile Speak screen reader, barcode readers, “Pen Friend” for labeling, a personal digital assistant (PDA) called “Freedom Scientific” with a braille display, a scanner with optical character recognition (OCR) technology, a braille printer (“Braille Embosser”), and Text-To-Speech (TTS) technologies. One of the participants indicated preferring to use headphones because of trouble using TTS in loud environments.

### ***Input/Output Format Preference***

The interviewees also clarified their preferred input/output interaction method with technologies. All of the visually impaired interviewees mentioned importance of audio feedback for navigating menu items. Some recommended sound notifications as simple alerts. One participant indicated a preference for buttons as input modality, expressing the reluctance to learn particular gestures for each task. On the contrary, one participant found gestures very useful, because they save a lot of effort with navigating menus or using keyboards. Another participant highlighted the problems of voice recognition in crowded and noisy areas. There was interest from the interviewees towards systems with different levels of verbosity. Different levels of verbosity could be used by a navigation aid depending on the position of a person with respect to the route. Further, the value of using context sensitive information was highlighted by the different participants. When using travel aids, one participant wanted to know where the elevators are located, where the front desk is, what the sizes of the steps were, etc. Other landmarks mentioned during the interviews include fire alarms, doors, walls, corners and tables. This interest was also highlighted by a number of other participants during the testing phase. Table 1 summarizes these interviewees’ input/output preferences.

**Table 1. Preferred Input/Output Modalities by participants (P)**

<b>Preferred Input/Output Format</b>	<b>Audio feedback</b>	<b>Vibration patterns feedback</b>	<b>Voice input</b>	<b>Buttons input</b>	<b>Gestures input</b>
<b>Participants</b>	All	P2	P2	P1	P2

### ***Barriers for Adopting Technology Solution***

Different barriers, including price, portability and how much they block the users’ other senses, make the adoption of electronic travel aids difficult. One participant noted that data plans for the latest generation

mobile devices are expensive, while another emphasized the expense of GPS and color identification devices. An interesting issue raised by all was the lack of standardization with regards to navigation application. Further, the ease of use is another strong barrier for adoption. One participant recalled situations where using guide dogs and technology aids at the same time, make it difficult to navigate cluttered environments. The weather was yet another barrier for using mobile devices and navigation aids. That participant liked the small size of mobile devices because they could be put in a pocket if the weather conditions required it. Visually impaired individuals need to pay attention to their surrounding environment. A good option to avoid blocking their hearing capabilities is to place electronic aids near one of their ears. Bluetooth speakers are a good alternative according to that participant. Another participant expressed interest in knowing how the environment looks, especially indoors. Table 2 summarizes all the barriers that participants mentioned.

**Table 2. Barriers that keep participants (P) from adopting new assistive technologies**

<b>Barrier</b>	Price	portability	Blocking other senses	Not following same guidelines	Size of Device
<b>Participants</b>	P1	P1, P2	P1	P2	P1

## Examining Blog Posts and Narrative Maps

### ***Online Blog Posts***

In order to understand the extreme cases of visual impairment, the research team read online blogs written by deafblind people. While written from the deafblind perspective, most of the information still applied generally to visually impaired people. Entries included information about what deafblind people pay attention to during navigation, such as landmarks and environmental cues. The blog entries also provided some insight to some of their challenges. The quotes include:

- “I moved around a couple corners, down the hall, past two doors... I kept my hand on the wall so I would know what I was passing”[34]
- “Unfortunately I wasn't able to mentally map the layout of the building. I was too busy trying to find a familiar landmark”[34]
- “... I realized I was not where I should be. The approach was wrong. So was the angle of the door handle”[35]
- “The rubber mat felt right...I followed the edge of the mat with my cane ..... But the mat ended too soon”[35]
- “The feel of the rubber mat tells me that I am nearing the bulletin board and need to be ready to cross the hall”[35]
- “Every time I go to class, I walk down that hall and pass that location. And every time I do, I smell coffee right before I hit the rubber mat”[35]
- “I know the campus does deep cleaning during breaks... The halls can be a mess. It makes it extra hard for me to get around .... The mess covered up all my landmarks” [36]
- “But the wind was also interfering with my ability to use scent and touch ... Because of the constant wind against my skin, I couldn't feel the displacement of air as people moved past me...” [37]
- “I'm mostly deaf. I only hear environmental sounds with my old cochlear implant. I can't understand speech.... I can hear the chatter of people, the rustling of papers and the sound of doors being slammed shut. Or I can hear the silence” [37]
- “I can smell the scent of people... Sometimes I smell food, as someone eats a snack near me. I can often determine my location by scent, as well. Hallways smell bland and stale. I can smell coffee near the snack room.” [37]
- “Touch and the displacement of air give me more useful clues. There is a slight movement in the air when people walk past... Or I can feel a "whoosh" of cold or fresh air when someone opens the building doors.” [37]

Table 3 summarizes the information deafblind and visually impaired people pay attention to, based on information from the blogs.

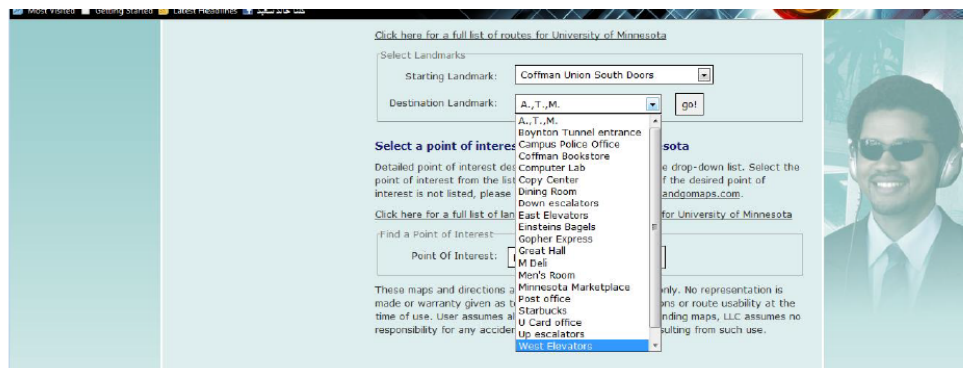
**Table 3. Clues and information visually impaired people pay attention to during navigation**

Landmarks						Mental Map for layout of building	Counts	
Feeling of the floor	Size of the mat	Bulletin board	Smells (coffee, scents, food, ...)	Feeling displacement of air	Environmental sounds		Number of corners	Number of Doors

### ***Instruction Models and Narrative Maps***

Different instruction models are used in previous navigation technologies. However, most instruction models are missing landmarks and other information that give visually impaired people more context about the environment. The “ClickAndGo” way finding maps service [38] provides very detailed and high quality narrative maps for indoor and outdoor routes. Narrative maps are “a verbal or text-based description that provides the way finding instructions required following and maintaining orientation along a walking route” [38]. These instructions are manually prepared by specialists. According to the founder of the ClickAndGo service, he/she would go around each route in person, videotape it and record routing directions for it. The instructions can then be downloaded from the website in text format. This format can be used in devices that support Text-To-Speech and Text-To-Braille. The instructions can also be downloaded as mp3 files that are compatible with portable audio devices. There is also a voice service where the user can have a free call to ask for routing directions from one location to another.

Manually creating these routes takes a lot of time and effort, making it difficult to scale this system to many places or buildings. However, the ClickAndGo advantage over other service or technologies is the quality of the instructions it provides. Based on testimonials provided in the ClickAndGo website, users find the instructions outstanding and provide very good environmental cues. We reviewed twenty ClickAndGo indoor narrative map instructions.



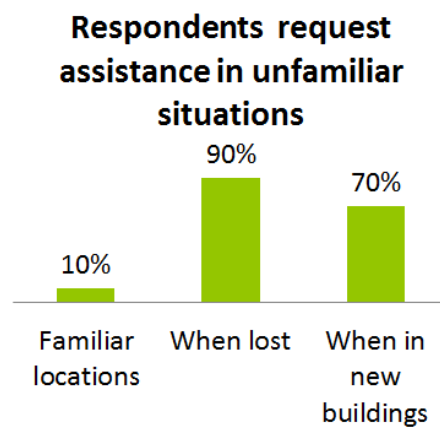
**Figure 2: 20 indoor narrative maps examined**

## **Detailed Surveys and Interviews**

Researchers conducted online surveys and phone interviews with 20 participants from partner organizations. 18 of the participants were visually impaired and the remaining 2 participants had no vision or hearing impairments but worked closely with blind and deafblind individuals. The goal of this phase was to learn more about end user's navigation and localization experiences, as well as identify features that are most important to potential users of assistive navigation aids.

### ***There is a need for a navigation aid***

In familiar settings, most respondents navigate independently, but when lost or in a new building, asking for help is the most popular strategy of finding one's way. Most respondents indicated they get lost occasionally, while the rest said they rarely become lost. This shows that there is much more of a need for navigation assistance in unfamiliar locations than in familiar locations. In unfamiliar environments where there is no one around to help, blind and deafblind people may be at a serious—and perhaps even dangerous—loss.



**Figure 3: Survey responses on requesting assistance**

### ***Speech is most popular method of phone interaction***

The most popular method of phone interaction was speech, followed by tactile buttons, then touch screen. A few respondents also mentioned the use of a screen reader. Thus, current phone use reveals a preference for speech-enabled features. Many respondents did not specify whether they use both input and output, however, a few did express some problems with speech input.

### Current Input

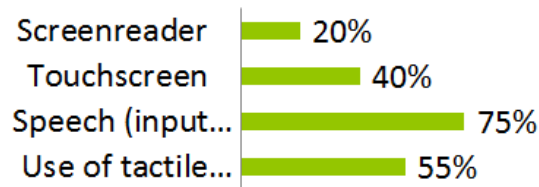


Figure 4: Survey responses on current input modalities

### ***Audio, tactile, and braille are preferred methods of interaction***

The majority of respondents always use environmental sound cues while navigating, while the remainder only use them occasionally. As a result, sound output from a navigation device is important, but it is very important that users be able to adjust and customize sound output and verbosity according to their individual needs and preferences. Survey results show that 50% of participants thought that sound would not interfere with navigation and the remainder thought sound would interfere.

Participants were also split on output modality. 50% of participants preferred audio, while 42% preferred a combination of vibration and audio. The remainder preferred a combination of vibration, audio, and braille. These results indicate a preference for a device with both vibratory and audio feedback, with options to turn off audio or vibrations, as preferred or needed. In terms of potential headphone use with the device, most users utilize both speakers and headphones with their devices, depending on the situation. However, several commented that headphones could only be used with a navigation device if used in just one ear, because they cannot be totally cut off from environmental sound cues.

### Preferred Output

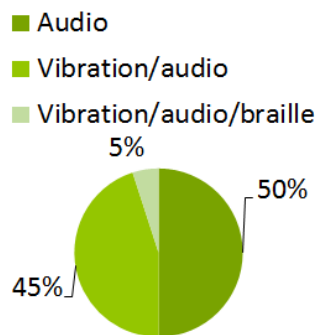


Figure 5: Survey responses on preferred output modalities



### ***Many respondents comfortable using touch screens***

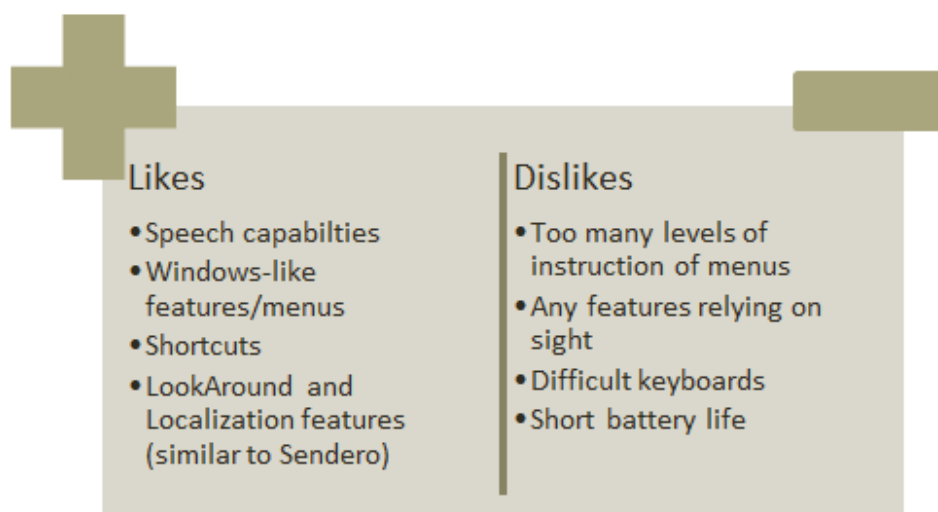
60% of participants have smartphones, while 35% have regular phones and the remainder did not report the use of a cell phone. Also notable, is that 50% of participants who have smart phones have an iPhone, while no respondents reported use of the Android. However, one respondent currently uses an iPhone, but feels quite limited and would like to “make the jump” to an Android, suggesting that the Android may have many appealing features for blind users. Furthermore, most participants indicated they would be comfortable drawing gestures on a touchscreen. However, one respondent indicated that it might be difficult knowing where to draw the gestures.

### ***Most respondents want control over the modes of instructions, levels of directions, and handling of errors***

The majority of respondents thought there should be different modes of instruction based on familiarity of the environment. While 44% preferred landmark-based level of detail, 56% said there should either be a combination of methods or that the user should be able to choose. When it came to frequency of directions, answers ran the spectrum. Roughly 50% said there should be some sort of combination of high-level, periodic, and/or on-request instructions, stating that there should be either different options or different modes. 32% preferred on-request, 16% preferred periodic, and 2% preferred high-level instructions. Again, this variety of responses further speaks to the need for customization.

### ***Technology use and preferences vary widely, and clearly demonstrate importance of customizability***

Respondents expressed a wide variety of likes and dislikes in currently available technologies, highlighting the need for customizability and user control when feasible, as summarized below.



**Figure 6: Survey responses on technology use and preferences**

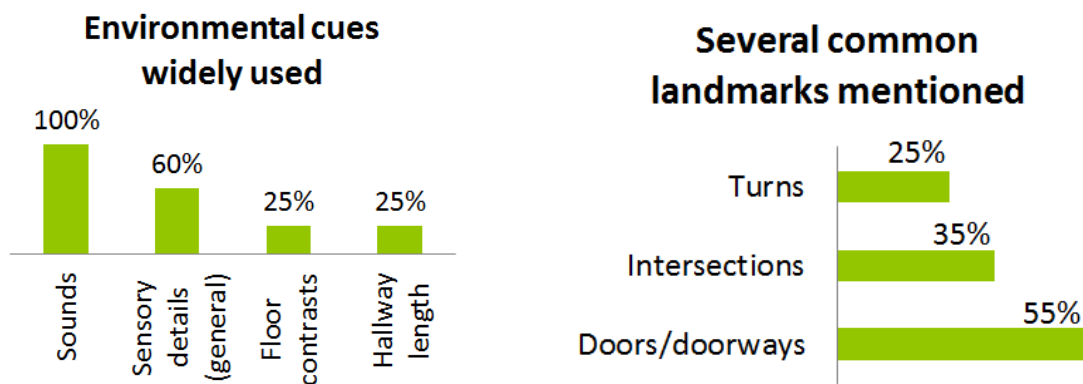
### ***Relatively high comfort levels with technology***

All respondents use electronic devices, including at least a computer, as well as a host of other technologies, from digital readers, to scanners, to CCTVs, to notetakers, to GPS. All respondents are comfortable using menus, using their current electronic devices, and listening to and following instructions carefully. While 37% indicated they use their phones exclusively for phone calls, the remaining 63% are comfortable using their phones for many different purposes, with more than half using their phones for navigation in some form.

Needs for training varies greatly by the individual and the technology in question, but 78% took multiple days to learn more complex technologies (from several days to weeks, to ongoing). Meanwhile, 72% said they could learn more simple technologies in less than a day. While 33% of participants usually use personal training or assistance with new technologies, 61% do not. Respondents said they learn new technologies most quickly when directions and layout are clear and intuitive, and when they have access to braille instructions.

### ***Environmental cues and landmarks very important***

All respondents said environmental cues (sounds, smells, tactile clues, etc.) are very important. Respondents might make note of certain smells or sounds, and will also use wall marking, braille, raised signs, and floor contrasts to help them orient themselves and navigate. Furthermore, 60% said they use environmental cues to orient themselves, with 55% actually preferring to orient themselves in this manner. Although several mentioned that they currently request help from others, no respondents indicated this as a preferred method of orientation.



**Figure 7: Survey responses on environmental cues and landmarks used for navigation**

Within buildings, all but one participant use landmarks. Landmarks were also very popular as a navigation strategy outdoors. Reported landmarks include intersections and turns (outdoors), doorways and one respondent also mentioned stairwells. Common indoor landmarks in the survey sample include vending machines, water fountains, elevators, entrances, and information desks. Furthermore, 70% of respondents use counting methods (i.e. counting the number of doorways or intersections).

### ***Speed of navigation and frequency of orientation vary***

56% of participants move at roughly the same pace, though several pointed out that this pace will generally be slower than the average sighted person's walking speed. 33% also reported a wide variation in speed, and several said that it would depend on the familiarity of the location and other environmental factors. In unfamiliar buildings, 39% of participants said they are "always" orienting themselves, 33% said they orient themselves every 30 seconds. Meanwhile, in known buildings, while 30% reported they orient themselves only at the beginning of the trip, 15% said every 30 seconds, and 40% reported "other," ranging from constant alertness or orientation in some sense, to seeking only main landmarks, or not even seeking cues at all.

### ***Preparedness and prior knowledge in emergencies important***

In emergency situations, 65% of respondents rely on previous knowledge to determine the closest safe exit. This knowledge may have come through personal inquiry, meetings, practice drills, or online materials. Many respondents take it upon themselves to find out about emergency procedures in new buildings, and one respondent stressed that this practice was out "of habit," and was not a result of their vision impairment. In referring to unfamiliar locales, such as a new hotel, responses were markedly "murkier." Some said they would just follow the crowd. One respondent said they would not know what to do in an unfamiliar situation. Thus, based on these results, there may be a need for additional assistance in unfamiliar situations in which individuals cannot rely on prior knowledge.

### ***Technology use in emergency evacuation is sparse***

Only 10% of respondents use any type of technology during emergency evacuations, which include a smartphone app for tornado warnings and TTS during emergency situations. Interestingly, the lack of technology in emergency evacuation may indicate a gap that can be filled by technology, particularly for unfamiliar locations such as hotels or large public buildings.

To summarize this phase of the needs assessment, the key takeaways were (1) users figure out where they are through environmental cues, and when lost, they ask others for help. (2) In getting to where they want to go, users create a mental map of their environment and use landmark and counting techniques to track their progress. (3) Regarding user interfaces, visually impaired people are comfortable drawing simple gestures on touchscreens, prefer a combination of audio and vibration feedback, and desire customization.

## **Building Manager Challenges and Transit Challenges for Visually Impaired Travelers**

This section is based primarily on the feedback from needs assessment survey interviews conducted in the summer of 2013.

### ***Goals***

1. To obtain information about visually impaired adults and what their needs and challenges are while using transit systems and traveling outdoors.
2. To obtain building managers' perspectives on how visually impaired people are expected to navigate through their building, discover some of the common aids that are present, as well as some of the safety hazards that visually impaired people might face.

### ***Questions***

The following questions were included in these surveys:

#### ***Users***

- What types of transportation do you commonly use?
- In what ways do you pre-plan how you are going to navigate to your destination? What methods for pre-planning have been most helpful to you?
- What do you think are the main navigational challenges faced by people with vision impairments when trying to go to unfamiliar locations?
- If you need assistance when traveling alone, how do you get help in unfamiliar situations in familiar locations, when lost, and/or when in unfamiliar locations?
- When traveling alone, how difficult is it for you to navigate from a public transit stop to an unfamiliar destination you are trying to reach?
- Have you ever used smartphone apps such as Tiramisu (which lets bus riders of Pittsburgh's Port Authority transit system know when the next bus is scheduled to arrive)?
- What landmarks/sounds/other features do you use to navigate indoor and outdoor environments?
- Have you ever heard of human echolocation?
- Would you be interested in navigation tools that would help you navigate outdoors as well as indoors?
- How has your technology access or use changed in recent years?

#### ***Building Managers***

- What are some of the most common access and entry points to your location for the public?

- What resources are available if anyone needs help getting around your building (or campus more generally) to find their intended location?
- How do you alert visitors to your building about obstacles?
- How do you inform visitors to your building about what to do in the case of an emergency evacuation?
- Have you had any past experiences with people with vision impairments in your building (or on campus more generally)?
  - a. If so, please describe some of those experiences.
  - b. Were there particular challenges that made it difficult for them to visit your location and navigate your building?
- Are there safety hazards that concern you about your building (or on campus more generally) that people with vision impairments might have a hard time dealing with?
- Do you have or plan to have landmarks, indicators, or other accessibility elements that are specifically intended to help people with vision impairments navigate your building?
- Are there any specific protocols in emergency situations or evacuations that would help alert people with vision impairments in your building (or campus more generally)?
- How often do you update floor plans for buildings?
- How do you alert visitors to your building(s) of any areas where access is restricted?
  - a. What is the procedure for handling the situation where there is an unauthorized entry into a restricted space in your building?
- Do you think a tool similar to what is envisioned in the video will be useful to you?
- If you could easily classify different spaces on your building map(s), which of the following categories are you likely to use (as appropriate)?
- If you could easily annotate a map of your building(s), what from the following list would you choose to annotate?
- Are there other technology tools you wish you had that would help make your building(s) more accessible to visitors with vision impairments?

### ***Survey Details***

The research team used surveys to conduct the needs assessment for both visually impaired and building managers. This analysis is based on a sample pool of 18 interview/survey respondents, 12 of whom are visually impaired, 1 who is an expert, and 5 of whom are building managers. All the survey questions in the needs assessment were separated into four categories that were named at the beginning of each section. Of the 12 users that were interviewed, all of them had some form of visual impairment. The one expert was able to provide details of what it is like to work with those who are visually impaired. Lastly, out of the five building managers that were interviewed, we obtained a wide variety of responses. Survey respondents were self-selected, so we might expect respondents to have higher incentives for participation, such as keen interest in assistive technologies, than the average blind individual. Each user

participant from the sample population responded to a series of questions in one survey with four categories. The survey breakdown is as follows:

### *Users*

1. Planning for Navigation, 6 Questions
2. Navigating Transitions and Unfamiliar Environments, 4 Questions
3. Understanding/Visualizing an Environment, 12 Questions
4. Technology Features, 10 Questions

### *Building Managers*

1. Questions About the General Public, 4 Questions
2. Questions Specific to Visually Impaired, 4 Questions
3. Building Floor Plans, 4 Questions
4. Floor Plan Creator Tool Feedback, 6 Questions

The surveys consisted of multiple choice, yes/no, and open answer questions. The research team's contacts at local organizations – Blind & Vision Rehabilitation Services of Pittsburgh (BVRS), The Western Pennsylvania School for Blind Children (WPSBC), and previous participants for other projects – were the primary conduits for obtaining survey participants. The research team required that survey participants be 18 years of age or older, and be visually impaired, or a building manager at an institution. Surveys could be conducted online, via phone, or in person. Many respondents opted for phone and in-person interviews, and the other participants chose to participate online. Phone and in person interviews generally took about 1-1.5 hours to complete.

For the building managers, all of the interviews were done in person. The purpose of these interviews with the building managers was to better understand how they view people coming into their building and to better understand their role as building managers.

There were a total of 18 participants, 5 of which were building managers and 12 were users. Of the 12 users, 2 were in-person interviews, 6 were phone interviews, and 4 answered the questions through an online survey. Unfortunately, not all of the questions were answered on the online surveys; there were 9 completed interviews/surveys and 3 that were partially complete. We were, however, able to obtain very helpful information about what visually impaired adults look for while navigating in indoor and outdoor environments. The five building managers were a mix of for-profit and nonprofit organizations to give us a better picture of the variety of difficulties that can arise in buildings. In order to preserve the privacy of the survey and interview participants, all of our answers have been recorded anonymously.

The surveys were administered through our research group's online LimeSurvey account. Respondents that opted for online surveys inputted their responses directly into the online system. For the phone interviews, the research team members conducting a given survey typed notes into the online system; interviewers generally did not take word-for-word notes, but strove to capture the essence of the responses to the best of their abilities.

## ***Results***

### ***Summary of Results***

#### **Users**

Types of Transportation mostly used

- Walking
- Bus
- Train (Subway)

Types of pre-planning techniques

- Websites
- Smartphone Apps
- Help from a friend
- Calling the location beforehand

Types of navigational apps used

- Google Maps
- Sendero (LookAround)
- Ariadne
- Around Me
- BlindSquare

#### **Building Managers**

Features to include in assistive navigation tools

- Voice indicators for indoor navigation
- Directional signage with braille
- Multi-extension floor plan file manipulator tool

Elements to avoid

- Multi-targeted audience
- Having too much information within the floor plan app

## Suggested future steps

- Concentrate on a specific set of audiences
- Talk to other organizations about notices and precaution warning for visitors

## *Important findings of the needs assessment analysis:*

### Users

- The most important thing that visually impaired people are striving for is independence while navigating.
- Many users are interested in a navigational device that not only navigates outdoors, but indoors as well.
- The way that a visually impaired person navigates may depend on when that person actually lost their vision.
- Buses can be the worst type of transportation while navigating to a destination because a visually impaired person may not be aware of where exactly the bus is going to stop and when their bus will be there.
- Sighted people are not aware of how a visually impaired person needs to receive directions to get to a destination; they only think of a way that a sighted person would visualize a route.
- Speech is a very popular method of phone interaction.
- Customizability of the interface is very important.

### Building Mangers

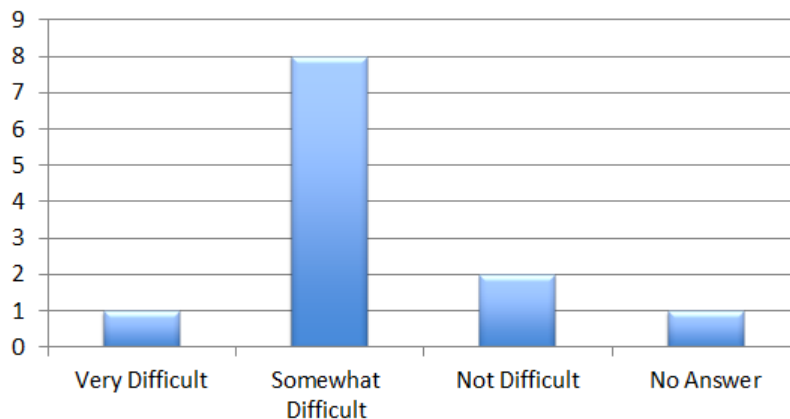
- Most building managers would like to be able to classify rooms, halls, and doors, as well as what types of doors are on a floor.
- Building managers would also like to be able to annotate doors, regular exits as well as emergency exits, and elevators.
- Building managers seem to have a controversy about fire extinguishers, some want it on the floor plan and some do not because of safety reasons.
- There are a lot of variations on when the floor plans are updated; they range from daily to never updating due to funding constraints.
- All the buildings have Wi-Fi capabilities but all of them required login credential and if you are a scheduled visitor you can get access to Wi-Fi.
- Most managers are willing give us access to any safety or security policies related to building/campus access.



## Detailed findings

### Users

While navigating from public transportation to an unfamiliar location, users stated their level of difficulty:



**Figure 8: Survey responses on difficulty experienced using transit options**

The survey participants mostly found it to be somewhat difficult to navigate from public transportation to an unfamiliar location. The reason for this is possibly because the public transportation method that they chose to use is not always reliable. However, once the user has gotten off and on the public transportation, they usually are able to reach their desired location with little difficulty because most of them usually pre-plan their route. When asking the users what types of transportation they use and which types they prefer to use, most stated that they prefer to walk or take the bus. The reason that most prefer those two is because they are the cheapest methods and some stated that they do not like to take a taxi because it is very expensive. Those who are visually impaired prefer to navigate on their own because it is a way to develop their independence. They do not want to have to rely on others to pick them up and drive them to their destination nor to ask someone on the street unless they necessarily have to because they are completely lost.

A major difficulty while trying to use the bus as a transportation method is that it is not very reliable. Most users that prefer to use the bus stated that the bus does not come when it is supposed to and they do not stop exactly in front of the bus stop sign which completely throws the visually impaired person off. With the bus not coming when it is supposed to and not stopping at its exact location, the visually impaired person will most likely miss the bus and not even know it. Also, if they miss their bus, they most likely have no idea of when the next bus that they would be able to take will come.

The navigational devices that users have stated that they currently or previously use have different reviews for each type. For example, Sendero (<http://www.senderogroup.com/>) is a very popular navigational device that the visually impaired users stated that they use, but it is not always reliable. This device may be incorrect in its directions for where the user actually needs to turn and they may end up

running into something or getting completely lost. Once a user is lost, it may be very difficult to find exactly where they were before so that they can continue their route to their destination.

The types of pre-planning methods that the users stated that they use varied. One of the main difficulties with calling the location ahead of time to get some sort of directions is that the person who is giving directions is not sure how to give directions that make sense to someone who is visually impaired. For example, a visually impaired person needs to receive directions such as walk 10 feet then turn left, walk another 30 feet then turn right. The directions do not necessarily have to be that detailed, but if there are any navigational cues that the person who is giving directions could think of to make it easier on the visually impaired person, then that alone would be very helpful.

### Building Managers

Most buildings only have front and rear entrances, so they mainly have a front desk attendant available to help and make sure visitors get to where they need to be as well as keep unauthorized visitors out. Most of the desk attendants warn visitors about obstacles that a visitor might have a hard time dealing with during the check in process unless the visitor is escorted by someone else that works in that particular building. All of the buildings have signage to help guide people to their destinations, emergency exit plans, emergency evacuation procedures, as well as have braille underneath door number signs. However, none of the buildings have braille directional signs for the visually impaired.

Most of the building managers have had experiences with visually impaired people, but they all agree that spontaneous events, unannounced constructions, as well as abnormal building structures can make it difficult for visually impaired people to get around. Some of these abnormal building structures include: half floors (random half dozen set of steps on the same floor), low walls, sides of helix stairs, air bridges that connects two buildings, and activities on campus. There are some limitations between different building managers because some non-profit organizations have a hard time keeping their floor plans up-to-date due to a lack of funding.

Most visually impaired people are expected to be able to navigate their way around by themselves in most buildings. There are some indicators along the walls along with high contrast floors, but it's difficult to measure how effective these methods really are to people with different degrees of visual impairment. Most building managers do not want to offend people that are visually impaired and make them feel inadequate to be a part of society, so they try to let them be as independent as possible. Thus their interaction/knowledge about the difficulties with the visually impaired people is somewhat limited.

There is also a wide range of precaution for restricted areas between buildings. Some of the most common precaution methods are human interaction (someone telling you verbally where not to go), discovering for

yourself through signs, testing a door to simply see if it is locked, or just getting notices prior to entering the building. Most of these buildings are dependent on security round checks to ensure people that aren't authorized stay out of the area because they do not use security camera.

All of the managers believe that a tool such as the Floorplan Creator Tool would be useful to them. Most of them stated that it will be useful in helping them keep/get their floor plans up-to-date. Some of them mentioned additional features that might make it easier for both parties if we have a multi-extension file importer tool for different types of drawing files and voice navigation within the application for the visually impaired.

### ***Summary Findings***

The summarized findings of this survey highlight the following features important to visually impaired travelers when using assistive technology aids to navigate urban environments:

- Giving options for the direction mode/depth of instructions
- Allowing users to customize features, instructions, and output/input options
- Using landmarks in direction, but also giving options for turn-by-turn instructions
- Having the ability to go back to same location that they were in before
- Asking where exactly they are
- Providing clear instructions of where to navigate
- Able to provide information about exactly when the a bus is coming and where to stand

The summarized findings of this survey highlight the following features important to building managers seeking to make their localities more accessible to visually impaired visitors:

- Focus on specific set of visually impaired people (degree of visually impairment)
- Multi-extension floor plan import tool
- Tie-in to Smartphone indoor navigation app
- Voice indicator within the navigation application
- Being able to annotate doors, regular exits as well as emergency exits, and elevators
- Being able to classify rooms, halls, and doors, as well as what types of doors

## **Experiencing Orientation and Mobility Training**

A final component of the work we did to enhance our understanding of the challenges faced by visually impaired travelers during urban navigation was to recruit the help of an orientation and mobility (O&M) expert to help us experience and understand the O&M training that is provided to visually impaired people when they learn to navigate urban environments. For this component of our work, we were fortunate to benefit from the expertise of Dr. George Zimmerman, Associate Professor and Coordinator of the Vision Studies Program at the University of Pittsburgh. The information in the rest of this section was provided by Dr Zimmerman for our information and education on the topic.



**Figure 9: Research team introduction to Orientation and Mobility training**

Through Dr. Zimmerman, we learned that orientation is the cognitive process of receiving and processing sensory information to identify/determine a specific spatial location within an environment. The term mobility is the ability to move from one location to another using human, cane, and/or dog guide techniques for protection. O&M for individuals who are blind or visually impaired implies the use of orientation/sensory information combined with the use of mobility protective techniques to travel safely, independently, and efficiently within a familiar or novel environment.

The field of O&M began during WW II when soldiers who suffered visual impairment were sent to Valley Forge VA hospital. The federal government decided that rehabilitation of all injured soldiers should become a priority to returning the war wounded to civilian life, so a program of independent travel using a long cane and human guide skills was developed. This program is the basis of the current O&M skills taught to and used by children and adults who are blind or visually impaired today.

### ***Spatial landmarks and clues***

Visually impaired individuals use all available sensory information to remain oriented while traveling, but also use time/distance/rate of travel to anticipate sensory landmark locations. A landmark is defined as any unique single datum or multiple sensory data consistently experienced in a given environment. So a single sensory experience, such as a change in kinesthesia/proprioception caused by an uprooted slab of concrete can be used to identify that specific location in the overall environment, but that landmark must be unique and it must be experienced each time the individual travels that route. A clue is any sensory information that is not unique or consistently experienced in a given environment. In other words, while the smells from a coffee shop are unique to a specific environment, the traveler, because of weather or the shop being closed, may not perceive it, or in the example of the uprooted slab, there may be more than one uprooted slab on a given sidewalk, thus not making that sensory experience unique.

### ***Sequence of Instruction and Familiarization***

Orientation and Mobility is based on a developmental curriculum model of instruction. Less complex skills of human guide and various other indoor safety skills and techniques are introduced before introducing more advanced complex outdoor skills and techniques (e.g., subway travel). However, even the most adept travelers have need of indoor and/or outdoor familiarization services from an O&M Specialist. The standard O&M familiarization service includes an initial human guided walk through of the route being learned pointing out various sensory landmarks or clues that are particularly useful for orientation purposes. Depending upon the traveler's ability and/or complexity of the route being learned, there may need to be multiple guided walks, but each walk would allow the traveler the opportunity to establish the time/distance/rate for the entire route. The O&M Specialist may use a map to provide the traveler with a tactile aerial perspective of the entire spatial layout of the environment, and then the specific route(s) within that environment. Once the traveler feels more comfortable with his or her spatial understanding of the route, the O&M Specialist will take the traveler to the starting point and allow the traveler to use his or her cane or dog guide, while the O&M Specialist walks along in close proximity, reinforcing the sensory landmarks and clues. The O&M Specialist's proximity to the traveler, especially at complex street crossings, is critical during this phase of familiarization. Finally, the O&M Specialist will fade back a distance from the traveler and allow the individual to travel the route "independently," only intervening if necessary.

## Towards Accessible Maps

Informed by our needs assessment data, our research team also explored some options for providing visually impaired adults with a technology aids to enhance their safety during urban navigation. One option explored was providing a virtual navigation experience to orient visually impaired adults in unfamiliar environments prior to a trip. This solution must include a safe and practical means for facilities managers to make accessible maps of their campuses that can be made available to blind travelers, an accessible interface, content management system, and customizable route planning mechanism that blind travelers can use to explore these maps and plan their trips, and a framework for keeping this map and navigation content up to date. We developed initial prototypes for a floorplan creation and management tool that can better equip building managers to create and maintain accessible maps of their buildings and surroundings, and a virtual exploration mockup for a Carnegie Mellon campus location.

# NavPal Floorplan Creator

Help the visually impaired navigate your building

## User Input

What we need from building owners.

### Upload a Floorplan



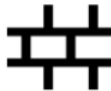
Upload floor plans of public spaces that you have the rights to

### Label Spaces



Label closed off areas as either room, hallway, staircase or elevator.

### Define Boundaries



Close off all rooms, hallways, staircases and other features

### Pin Landmarks



Pin points of interest such as bathrooms, drinking fountains, etc.

### Mark Entranceways



Select the portions of walls that are doorways, entrances or exits

### Connect Floors



Connect the floors of your building with staircases and elevators

**Figure 10: Initial prototype of floorplan creation and management tool**

Next, we created a simple web-tool to allow visually impaired travelers using screen readers to pre-plan routes within indoor environments. Eventually, users will be allowed to download these pre-planned routes to a smartphone-based location-aware app that can guide the travelers to their destinations.

**NavPal** - - - - -  
A smart phone-based navigation aid for blind and deafblind users

HOME ROUTES RESEARCH TEAM PUBLICATIONS MEDIA

### Instructions

Starting landmark: Hunt Library  
Destination landmark: Wean Hall

There are 3 directional steps to go from Hunt Library front entrance to Wean Hall entrance.

1. Take a left from the front entrance of Hunt Library.
2. Walk straight until you observe Porter Hall on your left.
3. Take a right turn to walk straight into Wean Hall.

You are at the destination now. Please note that these directions are fictitious for the purpose of this activity.

To enter a new starting landmark and destination landmark within Carnegie Mellon University Pittsburgh, please use the following drop-down menus. Click on the Get Route button after you have entered your preferences. To get directions in another location, select [list of places](#).

Starting Landmark:

Destination Landmark:

**Carnegie Mellon**

**Research Labs:**

**TECHBRIDGEWORLD**

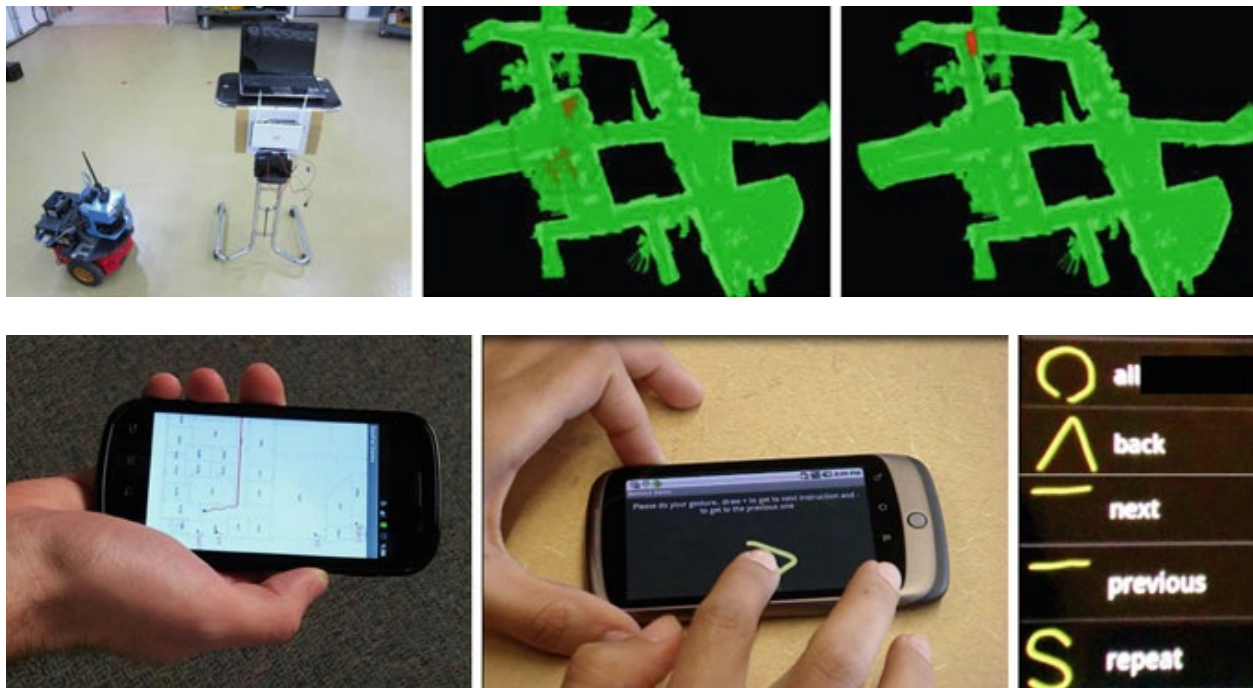
**rCommerce Laboratory**

**Sponsors:**

**Figure 11: Initial prototype of accessible route planning tool for indoor environments**

Location-aware applications can use GPS tracking to provide directions and locate places of interest. However, these systems suffer from their dependency on GPS and can therefore only function accurately when there is a clear view of the requisite number of satellites. In the absence of GPS, achieving sufficient localization accuracy on a consumer device is extremely challenging. Several GPS-free localization techniques have been studied, including inertial sensors, ultrasound, radio, and others [1-9]. These systems have been able to demonstrate relatively high accuracy, but suffer from being impractical to deploy in the mass consumer market. The inertial systems use expensive and bulky tactical-grade IMUs which are not available to most. Similarly, ultrasound and require installation and use of custom hardware. The challenge remains to develop a location-aware system that will reach mass consumer

adoption. The smartphone is one of the most promising solutions due to its ubiquity, available sensing and processing power, and broad social acceptance.



**Figure 12: Initial prototype of navigation app on a smartphone**

Some of our prior work [39] with the NavPal project (<http://www.cs.cmu.edu/~navpal/>) led to an initial prototype that addressed some of the above components. The localization component of this initial work used a robot to roam a building and build a Wi-Fi signal strength map that corresponds to the building map generated by the robot's sensors. The interface component of this initial work used simple on-screen gestures and a combination of voice and vibration feedback to allow visually impaired users to interact with the app. In this work, we improved the integration of the localization and interface components of this initial prototype and also did a long-term study of how Wi-Fi signals vary over time in different locations on the Carnegie Mellon University campus and the Western Pennsylvania for Blind Children campus. Our findings were that the Wi-Fi fingerprinting alone would be insufficient to robustly localize without frequent updates to the building map of Wi-Fi signal strengths. We also explored an initial crowdsourcing approach for coarse indoor mapping of Wi-Fi signal strengths in buildings. This approach showed some promise for low-cost, yet frequent updating of these maps. This prototype work is however still at an early stage and will require further development to produce robust tools that are useful in a variety of urban environments.



## ***Future Plans***

To address localization using commercial smartphones, we plan to combine multiple complimentary approaches including GPS when available, the smartphone inertial system, Wi-Fi fingerprinting, GSM triangulation, and other modalities such as fixed location informational kiosks. The smartphone onboard inertial system detects movement using the accelerometer, and tracks heading using the compass sensor. Wi-Fi localization has the advantage of bounded error and the ability to localize in a global context. It works by examining the identities and signal strengths of nearby Wi-Fi access points to determine a coarse location. GSM, the protocol for mobile telephony, can also provide a coarse location estimate from the identities of nearby mobile phone towers. These localization techniques must allow for seamless use of available methodologies so that travelers can navigate both indoors and outdoors (and handle the transitions) in a variety of environments without disruption. We also plan to explore additional modalities to achieve localization with sufficient robustness and resolution. These include crowdsourcing methods [10], using location information broadcast from stationary kiosks at key locations, and methods for seeking help from sighted people in the vicinity.

Solving the urban navigation challenge for visually impaired travelers also requires advances in route planning algorithms that can accommodate constraints and objectives specific to the blind, and can also efficiently operate on a variety of smartphones. Furthermore, these tools and services will require advances in accessible interface design for users with a range of visual impairments. Another important aspect is connecting with both trusted sources and sighted/informed people in the locality to enhance the availability of dynamic information and to enable visually impaired travelers to get help when they are in unsafe or difficult situations. Finally, we will explore practical ways in which blind travelers can annotate their routes and maps, record other information that will be useful for future trips to the same location, and share this customized information with others where applicable.

We have recently secured research funding from both the National Science Foundation and the Department of Education to enhance this initial work and advance the state of the art in accessible technology tools that enhance the safety and independence of visually impaired travelers navigating urban environments. The proposed solutions range from smartphone apps to assistive robots.

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