RFID Navigation System for the Visually Impaired

A Major Qualifying Project submitted to the faculty of Worcester Polytechnic Institute for the Degree of Bachelor of Science

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APRIL 25th, 2012

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ABSTRACT

Visually impaired people face unique challenges navigating in unfamiliar public locations. Twenty-five percent of the visually impaired people travel through public locations without assistance other than a walking stick[1]. A visually impaired person can obtain a sense of where they are based on their proximity to walls, doors, and other obstacles through the use of a walking stick. While this can help navigate to a destination, this can lead to longer routes and wasted time. Using a walking stick relies on trial and error, particularly in unfamiliar locations. Current navigation tools for the visually impaired focus on travelling from one location to another. This project focuses on designing a device for visually impaired people that is comfortable to use and can help with travelling independently. Our solution is a checkpoint system for the visually impaired that seamlessly integrates into a blind persons' walking stick and can be installed into public building infrastructure without major upkeep. The results from our user testing indicated our device succeeded in helping users navigate to their destinations.

[1] Lighthouse International. (n.d.). Lighthouse International - Use of Assistive Equipment. Retrieved April 18, 2012, from Lighthouse International: http://www.lighthouse.org/research/statistics-on-vision-impairment/use-of-assistive-equipment/

EXECUTIVE SUMMARY

This project developed an indoor navigation system to improve travel within public locations such as train stations and shopping malls for visually impaired people. The system helps users to determine the quickest route to a specified destination from their current location. The hardware consists of a RFID receiver embedded into a walking stick. A MYSQL database was configured to associate RFID tag identification codes with location names. A software suite was written in Java to perform route calculations using the identification code passed from the receiver.

The pre-survey, administered to visually impaired individuals, aimed to understand their current behaviors in public spaces. The results lead to the conclusion that visually impaired users that relied solely on a walking stick for navigation travelled to unfamiliar public spaces about once or twice a month. Half of the users surveyed rated their level of comfort when travelling alone as "slightly uncomfortable", while the other half rated their level of comfort as "slightly comfortable."

We evaluated our device in a classroom with locations tagged to mimic a public space. Testing the navigational system consisted of subjects directing themselves from one checkpoint to another. At each checkpoint, subjects were told their current location along with where they needed to go in terms of direction, distance, and final destination. The average time to navigate the course from point C to point J was 148 seconds; the longest time was 166 seconds, and the shortest time was 121 seconds. The overall distance they travelled was 110 steps. The return trip was from checkpoint J to checkpoint E, a distance of 100 steps. The average time to navigate this course was 83.25 seconds; the longest time was 100 seconds, and the shortest time was 65 seconds.

The post survey requested information regarding their interactions with the navigational system. Half of the users said they found the system useful, and would use it in the future. The other half said the system was not helpful and they would not use it in its current design. Two subjects found the system difficult to use, one user felt it was easy to use, and one had no opinion.

Based on the results from our study, we recommend the use of passive RFID receivers in conjunction with antenna-embedded tags placed into the floors of public buildings. The receivers and tags should optimally have a detection range of at least one foot in order for the visually impaired to successfully utilize the navigational system.

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1. INTRODUCTION

There are 285 million people worldwide that have some level of visual impairment. Visual function can be classified by four tiers: normal vision, moderate visual impairment, severe impairment, and complete blindness[2]. Legally blind refers to a person who has less than 20/200 vision in either eye, or a limited field of vision[3]. While not all visually impaired individuals are completely blind, many use walking sticks and guide dogs to navigate from place to place and to gain a sense of their surroundings.

For this visually impaired population, the goal is often to complete tasks in the least obstructive method, rather than the most efficient method, including the use of guide dogs and walking sticks. A guide dog is trained to steer its users away from objects and barriers. When a visually impaired person is using a walking stick, they gain a sense of their surroundings by waving their walking stick and striking obstacles ahead of them.

Public locations, such as a crowded shopping malls, airports, train stations, and bus stations, can be difficult to navigate and can be become disorienting for those with visual impairments. Imagine having to navigate to a terminal at an airport without the ability to see. After checking in bags and getting through security, one would still need to walk to the terminal listed on their ticket. Without asking others for help, these tasks can be difficult. These public spaces contain various sensory distractions such as traffic noise and other people. For a visually impaired person, it can become difficult to determine what direction to travel without some form of guidance. Navigating through unfamiliar public locations has

[2] World Health Organization. (2011, October). WHO | Visual impairment and blindness. Retrieved April 18, 2012, from World Health Organization: http://www.who.int/mediacentre/factsheets/fs282/en/

[3] National Dissemination Center for Children with Disabilities. (2004). Blindness/ Visual Impairment. Retrieved April 18, 2012, from National Dissemination Center for Children with Disabilities: http://nichcy.org/disability/specific/visualimpairment

long been a source of difficulty for the blind. The goal of this project is to provide a technological solution for the visually impaired to travel through public locations easily.

The use of technology in assisting the visually impaired has increased over the years. Various groups have researched ways to improve the accessibility of public locations for individuals with disabilities. Only recently has there been increased interest in assistive technology for those with visual impairments. Utilizing the project team's programming experience; the team designed a technical solution to visually impaired navigation in public places.

The navigational aid created is a radio frequency identification (RFID) antenna embedded into a walking stick. Combining RFID technology and the walking stick used by many visually impaired individuals, a navigational system was developed that can be integrated into the life of a visually impaired individual without the need for learning a new device. The user holds a walking stick with an embedded RFID receiver. Scanning tags with the receiver provides location data to the program for which the user can input a command. Once a RFID reader picks up a tag, the user will be able to receive their current location and also directions to a new location within the layout of RFID tags. This paper describes how this solution was implemented, from conception to design, design, testing, and results.

Our first step was to identify an issue for visually impaired people which has not been well addressed. Originally, we were going to design a smart house designed to integrate appliances into a home for easy accessibility by blind and visually impaired people. We were planning on integrating electronic household appliances into a centralized system. However, we began work on designing our system, we wanted to get feedback from our target audience.

Visually Impaired Blind User Group (V.I.B.U.G.), an organization that meets at The Massachusetts Institute of Technology to test the usability of blind accessibility devices, agreed to evaluate project ideas and to test the final result. In visiting V.I.B.U.G. for the first time, the team presented their project followed by a discussion. We asked the members to fill out a survey helping us to identify any concerns or ideas we missed. We obtained contact information which we used to schedule meetings with some V.I.B.U.G. members to test our final product in April. The feedback obtained from the surveys and the question and answer session helped us form the project idea that we pushed forward with.

1.1 VISION STATEMENT

Illustrating an ideal solution, a visually impaired individual would be able to successfully navigate within unfamiliar public location. A visually impaired person would enter a public building with the walking stick we designed with an embedded RFID reader at the bottom of the walking stick. At the entrance of the building, the walking stick would come into the range of an RFID tag located on the floor. This returns an auditory message announcing that they have arrived at a particular public location and instructions to a menu. The menu gives the user the option to hear more information on their current location, identify nearby locations, and receive directions from their current location to another part of the public space. The user would be able to pick a menu option by pressing a button located on the walking stick. In this way, they would be able to navigate through a public location until they would be ready to leave.

The project, nicknamed "Project In-Sight," was designed to create a system that would help a visually impaired person navigate through a public place. While designing this project, we identified an area of assistive technology that has not been fully addressed, particularly indoor navigation in public locations. We believe that this project accomplished the vision statement described above, considering timing and budget constraints.

2. BACKGROUND

2.1 RELATED TECHNOLOGIES

There are number of systems for indoor navigation currently available on the market. Current systems use a variety of technologies including Bluetooth, Wi-Fi, and RFID. These navigational systems typically consist of a hand held device containing a receiver connected to a network of tags. The issue with systems using this design is that they require users to become accustomed to using an extra hand held device such as a smart phone or RFID receiver.

One such system is "Ways4all[4]," which uses a system of smart phones and Bluetooth connected RFID receivers and tags to direct users along predefined paths. This system places RFID tags at intersections, hallways, and doors to indicate boundaries. The smart phone connects the RFID receiver to a database. Researchers focused on developing a system that downloaded planned trips to the smart phone and then downloading the building layouts. There are other navigational modules that use similar RFID tracking technology.

2.2 BLUETOOTH

The first wireless technology considered was Bluetooth. Bluetooth is useful for short-distance device-to-device communication. The most basic form of Bluetooth connectivity exists in the form of the master and slave. A master Bluetooth device is connected and communicates with a number of slave devices in the network. At any moment, the master device can transmit data to one other device. The master device can switch rapidly between the slave devices in the network to increase efficiency. Also, the role

[4] Kiers, M. (2011, June 27). Ways4all: Indoor navigation for visually impaired and blind people. Retrieved April 18, 2012, from http://www.stadtentwicklung.berlin.de/internationales_eu/staedte_regionen/download/projekte/eurocities/4bca_vienna_2011/presentation_martijn_kiers.pdf

of master in the network can be assigned to any of the other of the slave devices. Bluetooth has several strengths, such as the ability to determine distance between two devices, the ability to create a virtual "network" of devices through a Bluetooth network, and most handheld devices (such as phones) have Bluetooth integrated. Bluetooth, however, has a couple faults. Firstly, the Bluetooth transmitters, or beacons, would have to be set to "discoverable" at all times in order for our receivers to find them. When the Bluetooth transmitter is in discoverable mode, it broadcasts its ID for any Bluetooth device nearby to read. This creates a security hole for our system. A malicious user could change their Bluetooth device name to match a transmitter's name in our system to take over the network and provide false information or directions. Secondly, in order to gain access to the Bluetooth transmitter's virtual network map, the receiver would have to be manually paired with each transmitter, which requires constant work on the visually impaired user's part to pair with the devices. Another factor to consider is the cost of maintenance for such a system. Bluetooth devices need to be optimized to use their batteries efficiently; otherwise the cost of battery replacement would make this option unfeasible. We decided that the faults outweighed the benefits and chose not to use Bluetooth technology for the project.

2.3 WI-FI

Wi-Fi is another technology we considered using to locate the user. Using Wi-Fi triangulation, we would pinpoint the user's location based on signal strength. Wi-Fi triangulation works by mapping received signal strength indicator (RSSI) into a distance. Although this can find where the user is, Wi-Fi signals are subject to interference from walls, ceilings, furniture, as well as other people. This technology would not be feasible in public locations such as train stations and shopping malls where the number of objects that can interfere with the Wi-Fi connection would fluctuate over the course of a day or night. Another issue we encountered is that a Wi-FI implementation would require a publicly accessible Wi-Fi connection, which may not always be readily available. NaviMe[5] is an indoor navigation system designed and built by Nokia that incorporates Bluetooth technology and Wi-Fi with a cell phone (Nokia N95) to help navigate a user through a map. Maps of school buildings, offices, bus terminals, etc can be downloaded to the user's cell phone. The issues the NaviMe project ran into surrounded the systems maintainability and also the inevitability of varying signal strengths caused by interfering devices. The system uses both Wi-Fi and Bluetooth requiring the user must connect to both networks when entering a building to determine their location in the building.

2.4 RADIO-FREQUENCY IDENTIFICATION

Radio-frequency identification (RFID) is a wireless technology that uses low frequency radio fields to transfer small bits of data between RFID devices, usually consisting of chips attached to tags and a receiver with an antenna. RFID is a popular technology that is being used in a variety of fields, such as retail. RFID devices can be compared to bar codes or magnetic strips on credit cards, where each bar code or strip is a unique identifier represented by a number. And, similar to bar codes and magnetic strips, the device must be scanned by the receiver to obtain information from the RFID chip. One benefit to RFID technology over previously mentioned forms of identification is that RFID devices operate by proximity rather than swiping or scanning. Usually RFID devices can be read or scanned from as far as 100 meters to as little as a few centimeters depending on the type and range of the readers and chips. Since RFID technology is susceptible to reader and tag collision, the exact frequencies of RFID tags are variable and can be configured to minimize interference from other electronics, including other RFID systems.

[5] Le, M. H., Saragas, D., & Webb, N. (2009, October 22). Indoor Navigation System for Handheld Devices. Retrieved April 17, 2012, from Worcester Polytechnic Institute: http://www.wpi.edu/Pubs/E-project/Available/E-project-102209-164024/unrestricted/Indoor_Navigation_System_for_Handheld_Devices.pdf

Early use of RFID technology can be traced to the 1940s[6]. A predecessor to RFID devices and receivers was originally used as an espionage tool for the Soviet Union to identify friendly or foe fighter planes as they landed on runways. This technology was crude, but it functioned similarly to passive RFID: once activated the tag would retransmit the radio waves containing the plane's information to another device. The modern form of RFID technology was developed by Mario Cardullo in 1973[7]. He designed a passive RFID system with memory. Early potential uses were in automotive identification, banking, highway tolls, and medical sciences. As RFID matured, different types of tags and receivers emerged. There are multiple types of RFID devices: active, semi-passive, and passive RFID. Active RFID chips have an internal battery and actively broadcasts their signals and are often used for applications such as management, money transactions, product tracking, access control, promotion tracking, etc. Semi-passive RFID chips also use internal batteries to power their circuits however unlike active chips which actively broadcast their signal, these chips rely on the receiver to supply power to broadcast the signal. Due to the costs of both the battery and advanced internal hardware, both these types of RFID technology are typically expensive and are reserved for more advanced forms of asset management. The project initially used active RFID tags and receivers to approximate the current position of the user. However, due to the financial limitations, a cheaper solution was implemented.

Passive RFID is a more budget friendly alternative to active and semi passive RFID. Passive chips or tags do not have internal batteries; therefore the cost of maintenance is drastically lowered since there is no need for replacement batteries. Instead, the circuits obtain power when they are scanned by the receiver. The passive chips do not broadcast their frequencies and must be within a few centimeters to be scanned by the receiver. This

[6] Roberti, M. (n.d.). The History of RFID Technology - RFID Journal. Retrieved April 17, 2012, from RFID Journal: http://www.rfidjournal.com/article/view/1338
[7] I.B.I.D.

has its benefits and draw backs as well. While the ranges of the tags are fairly small, there is a smaller chance of frequency collision. Table 1: Pros and Cons of Wireless Technologies below summarizes the details of each technology we considered.

	Active RFID	**Passive RFID**	**Bluetooth**	**Wi-Fi**
Average Cost of 12 transmitters	$660 ($55/ea)	$24 ($2 ea)		$360 ($30/ea)
Average Cost of 1 Receiver	$45	$25		$25
Able to detect distance	Yes	No	Yes	Yes
Able to track target's location	Yes	No	Limited* *can track while receiver is in range of transmitter manually	Yes
Connection	Automatically in range	Automatically in range	Pair with transmitter when in range	Automatically in range

TABLE 1: PROS AND CONS OF WIRELESS TECHNOLOGIES

3. DESIGN

There are three major components to the navigational system. The first component is the database. The second is the RFID embedded walking stick. The third component is the software and user interface associated with it. The system utilizes a MYSQL database to keep track of relational data associated with tags. For example, the RFID tag with the identification code 4500BE8B95E5 was associated with the location named “Bravo.” The database had one main table, which contained one row for each RFID tag. These rows had columns for the RFID tag’s identification string, the description of the location, the tag’s neighbors (if any), inter-tag distances, and the directions to those neighbors from the tag.

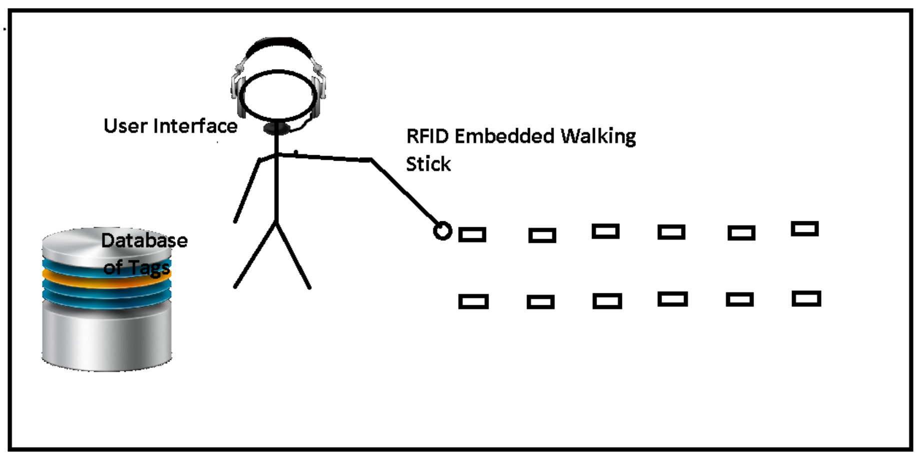

FIGURE 1: SYSTEM COMPONENTS

The software suite, written in Java, was designed to handle route calculations and allow for user input and auditory feedback. The software first connected to the database and cached the relational data from the table. Then, the user was asked to scan the nearest RFID tag to allow the system to determine their location. Once the user had scanned a tag, the user was presented with a menu containing possible commands, such as “What is close to me?” and “Navigate to location.” The former command told the users what tags are nearest to their location. The latter command calculated a turn-by-turn route to a destination.

RFID technology was used to keep track of the user's current location in the navigational system. There are two components to RFID: a reader, which is embedded into the walking stick, and tags. RFID tags were placed on the floor to represent particular points of interest in a public location. For example, an RFID tag would be placed outside each store in a mall. The reader was attached to a walking stick and covered in a shell to prevent damage to the reader. The user would move the cane in a downwards sweeping motion in front of them to allow the reader to synchronize with RFID tags on the floor.

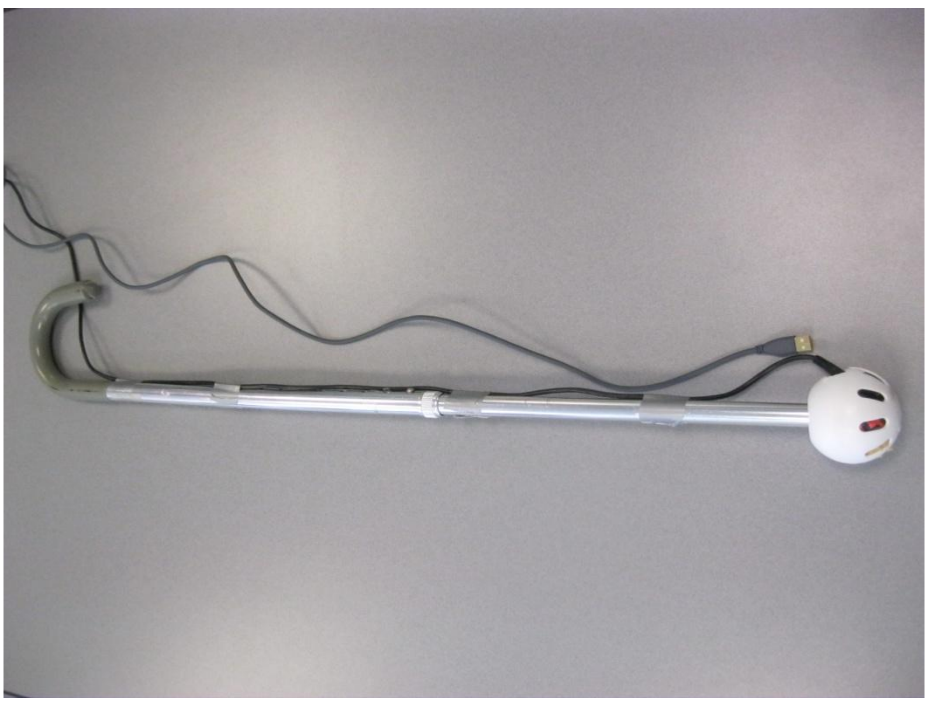

FIGURE 2: PROTOTYPE WALKING STICK

There are notable differences between the walking stick used for this project and an actual implementation of this system. The first difference is the design of the walking stick. A blind person's walking stick is a piece of engineering in itself; it is precisely balanced and designed to provide tactile feedback to the user. In an actual implementation, the embedded RFID receiver and protective shell would not affect the weight distribution and balance of the walking stick. Another key difference is how a user would input commands to the device. In the project experiment, commands were manually inputted by a project member into the navigational program via a laptop. This would return a text response. The text is vocalized using FreeTTS, an open source text to speech Java API. In an actual implementation, the user would be wearing an ear piece with a microphone that is connected to the walking stick. The walking stick would have an analog button that the user would press to get the program ready to receive a command. User command would be inputted by voice to a microphone. For instance, a user would press the analog button, then say, "Destination: Coffee World," and the device would respond by giving directions to that location into an ear piece.

3.1 IMPLEMENTATION

We wanted to design a system to assist the visually impaired people navigate public spaces. Based on feedback from V.I.B.U.G., we concluded that a major problem area for visually impaired people was finding places, such as stores or terminals in a public area. We set out to design an indoor navigation system tailored specifically to visually impaired people, which would help to identify and navigate to stores in a mall, or terminals at an airport.

The next step was to break down the goal into smaller tasks and milestones. We needed to analyze and determine what resources would be required to accomplish those tasks. The tasks were identifying locations, calculating shortest route to another location, keeping track of the user's progress, providing feedback to the user, and reading user input.

After analyzing these elements, we determined that we needed a database, a software suite, beacons, and readers for the beacons.

3.2 EXPERIMENTATION

Once the system was designed, it was time to test it. Two team members, Punit and Ben, created a brand new layout. The third member, Devin, was unaware of how the new layout was structured. To simulate a visually impaired user navigating a public place, Devin was blindfolded and taken to a classroom. RFID tags were arranged on the floor of the classroom in a pattern which Devin was unfamiliar with. Punit and Ben asked him to navigate from one point of the map to the other using the prototype. While he was able to successfully navigate from one point to another three times, we had identified a problem area: the reader was not detecting all of the tags. The RFID reader on the walking stick was covered in a protective wrap that was weakening the connection between the reader and the tags. The walking stick was remodeled and we tested the system again with greater success.

4. RESULTS

The project started with a number of goals in mind. Our goals are based on design aspects we hoped to hold throughout the project. Our first goal was a need to understand the ways people with visual impairment interact with current technologies and to design a system that is usable by visually impaired people. In order for us to succeed in doing so, we needed to have a user interface that a blind person can interact with. Our second goal was to determine possible solutions that are currently available on the market and determine what the best solution would be. Our final goal involved delivering a system that successfully navigates users throughout an absolute course mimicking a public building.

4.1 INITIAL SURVEY

We were able to interview seven visually impaired individuals. We were able contact the individuals by soliciting their contact information at a V.I.B.U.G. meeting held during the time of the project. We believed these individuals would provide useful insight into their visual impairment and would be able to provide helpful answers due to the V.I.B.U.G. presentations of assistive technological devices at each monthly meeting. All interviews were conducted over telephone and conversations last for 25 minutes.

One section of the survey aimed to collect general information about the individual. All individuals surveyed were:

- legally blind; their visual acuity measured at 20/200 or worse.
- blind for more than 10 years
- between the ages of 36-65

Four of the seven individuals considered themselves proficient in Braille, two had some experience, while one had no experience in the language. In terms of their individual confidence in computer use, three users considered themselves experts, while the remaining individuals considered themselves to be proficient.

Through our conversations, we were able to gather information about their interactions and uses of technological devices. In interacting with a computer, each of the individuals said they had prior experience in using a screen reader and keyboard. Four had said they had used a microphone in interacting with a computer.

One important question that was asked of each individual was whether they preferred to interact with a device by voice or touch. This was an important question going into the design phase of the project. If there was more preference for voice, our design should be able to receive input from the user by voice and be able to communicate a response audibly. Likewise, with touch, a user should be able to press buttons or control device responses based on hand gestures or movements. Out those surveyed, three responded that they would prefer a combination of both touch and voice. Another three said they would prefer touch over voice. One individual preferred voice over touch. It was clear from this question, that elements of both voice and touch should be considered in the design.

We also wanted to know if any of those surveyed owned a smartphone. The trend in assistive technology today has been leaning towards smartphones. With multiple applications being able to perform on a single device, a visually impaired individual could switch applications based on their current need. The smartphone's interactive touch screen and audio inputs/outputs make it very attractive to the visually impaired. But when respondents were asked whether they owned a smartphone, six out of seven expressed that they did not own a smartphone. In elaborating further why they did not own a smartphone, many cited the financial cost of owning a smartphone. The phone was also too complicated for some respondents to use.

Each of the individuals interviewed had agreed to being contacted again to participate in an experiment of the device created through this project. This was an encouraging sign that the participants wanted to help once the design phase was completed.

4.2 EXPERIMENT METHODOLOGY

Following the completion of our system implementation, the team conducted trials on visually impaired individuals to determine the effectiveness of the indoor navigation system. Subjects were recruited from the Visually Impaired and Blind User Group (V.I.B.U.G.). Individuals within the group met the following criteria for the trial:

- All individuals within the group had some form of visual impairment, 90% of whom were completely blind.
- The team presented and interviewed members of V.I.B.U.G. to gain an understanding of visual impairment and problems they faced. All individuals expressed interest in a follow-up in regards to a testing an indoor navigation system.

Subjects in the trial were asked to navigate from one location to another by locating RFID tags placed strategically around a room on the floor. The layout represented a scaled down version of a mall or other public building. The trials were recorded in order to analyze how subjects interacted with the system. The data we gathered was used to make modifications to the system and draw conclusions on the effectiveness of the design.

We originally planned to bring in as many as six subjects for our tests; however only four subjects participated in the trial. Even though we were looking to conduct trials on more individuals, we believe the information we collected was highly useful in determining how to improve our indoor navigation system. Overall, subjects expressed enthusiasm in the technological aspects of the system, but were concerned with the effectiveness of the physical aspects of the system. The following information and conclusions were collected from subjects during the trial and will be discussed further in the following section.

The team wanted to determine whether or not visually impaired individuals would find our indoor navigation system helpful in navigating an unfamiliar public location. All subjects who participated in the trial were over the age of 40 and were all visually impaired for more than 10 years. To navigate, three of the subjects relied primarily on a walking stick, while one relied primarily on a guide dog.

We used a classroom within the Massachusetts Institute of Technology to perform our experiment. A classroom at M.I.T. was determined as the best location for to conduct the trial because it is where the monthly V.I.B.U.G. meetings were held. The actual V.I.B.U.G. classroom could not be booked for the first day of trials, so a classroom one building over was used. The team instructed subjects to still meet at the V.I.B.U.G. and we then brought them to the test room.

The classroom was large enough to have two locations separated by five feet on average. In addition to simulating this layout, the area of the classroom in which the experimental procedure was conducted was cleared of desks and chairs. The distance between the two farthest tags was 20 feet.

Once the participants arrived, one team member read the consent form, shown in Appendix A, to them and administered a pre-survey. The process took approximately 15 minutes. Once these tasks were completed, a team member escorted the subject to the classroom where the experiment was taking place. In the walk-over with each subject, each visually impaired individual held on to the team member’s elbow. It allowed for faster navigation through the hallway and it did not require the visually impaired subject to depend on the team member's voice.

4.3 EXPERIMENTAL RESULTS

Table 2: Pre-Survey Results organizes pre-survey information which we collected from test subjects. All four subjects were between the ages of 36-65 and completely blind for more than 10 years. Additional questions revealed behaviors when travelling, particularly in public locations.

Subject	Travel in Unfamiliar Public Locations	Resources Utilized When Travelling	Comfort Level Travelling Alone
#1	Twice a month	Walking Stick, Person	2 - Slightly Uncomfortable
#2	Once a month	Walking Stick, Person	3 - Slightly Comfortable
#3	Once a week	Guide Dog	2 - Slightly Uncomfortable
#4	Once a month	Walking Stick	3 - Slightly Comfortable

TABLE 2: PRE-SURVEY RESULTS

The pre-survey showed that subjects did not travel to unfamiliar public locations frequently. Responses ranged from once a week to once a month. In travelling to these locations, subjects utilized either a walking stick or person to assist them in navigation. Subject #1 commented that locations the subject typically visited were based on "prior orientation". This meant that the subject would go to a new location with a sighted person first and rely on the instructions and directions the sighted person provides on future trips to the same location. Subject #3 maneuvered primarily with a guide dog.

Based on the responses from the pre-survey, it can be concluded that subjects were not comfortable acclimating to a new location. It reinforced the problem statement that visually impaired individuals have difficulty navigating in unfamiliar public locations.

Current solutions do not leave the visually impaired feeling comfortable travelling independently, especially to an unfamiliar location.

The next step in our experiment was to test the navigational device. The testing phase of the experiment involved two tasks: travelling from C to J and from J to E. C, J, and E represent locations within the layout. The locations were selected based on their long distance from each other and multi-turn directions that would be required in reaching the destination.

Table 3: Task #1 - Time Trial - Location C to Location J (in seconds) displays the results of the first task of the experiment. This required subjects to use the navigational system to direct themselves from location C to location J. The results for each subject are recorded in the table. The results display the time, in seconds, it took for each subject to reach one location to another, until the subject reached their final destination. The average of each directional interval is displayed in the final row. The final column displays the total time it took from location C to location J, along with the average total time of all subjects in the last row. Subject #4 took an alternate route to location Juliet but still traveled the same distance as the other three subjects.

Subject #	C to E - 10	E to F - 20	F to H - 30	H to G - 10	G to J – 40	Total Time
#1	14	26	35	47	44	166
#2	42	39	21	17	22	141
#3	24	46	62	11	21	164
	C to A - 10	A to B - 20	B to D - 10	D to G - 30	G to J – 40	
#4	14	18	24	35	30	121
Avg Time Per Interval	23.5	32.25	35.5	27.5	29.25	148

TABLE 3: TASK #1 - TIME TRIAL - LOCATION C TO LOCATION J (IN SECONDS)

Table 4: Task #2 - Time Trial - Location J to Location E (in seconds) displays the results of the second task of the experiment. This required subjects to use the navigational system to direct themselves from location J to location E. The results are displayed below. Subject #3 and Subject #4 took an alternate route to location J because going from location G to location F could route through either location D or location H and still travel the same distance.

Subject	J to G - 40	G to H - 10	H to F - 30	F to E - 20	Total Time
#1	24	25	21	30	100
#2	17	12	19	17	65
	J to G - 40	G to D - 30	D to F - 10	F to E - 20	
#3	19	14	15	21	69
#4	19	15	42	23	99
Avg Time Per Interval	19.75	16.5	24.25	22.75	83.25

TABLE 4: TASK #2 - TIME TRIAL - LOCATION J TO LOCATION E (IN SECONDS)

In reviewing the data collected, we noticed that there was a learning curve in gaining familiarity with the navigational system. The subjects' times reveal that it took a shorter time per 10 steps as subjects navigated to their destination. Or in other words, the subjects accelerated throughout the course which resulted from the users becoming comfortable with the device. For outlier time intervals, this was primarily caused by:

- Additional instructions provided by the experiment moderators when the subject was past the interval location.
- Technical difficulties in RFID tag linked with the RFID reader.
- Technical glitch in which the subject tagged the same location twice causing the system to input a message that the subject has scanned the wrong tag.

Table 5: Post-Survey Results displays information collected from subjects in the post-survey. All questions solicited their opinions on the navigational system.

Subject	Overall Difficulty	Comfort Level	Helpful	Would you use it?	Auditory Feedback
#1	Very Difficult	Very Comfortable	Yes	Yes	Easy to Understand
#2	Neutral	Comfortable	Yes	Yes	Slightly Easy to Understand
#3	Slightly Difficult	Slightly Comfortable	No	No	Slightly Difficult to Understand
#4	Easy	Very Comfortable	No	No	Slightly Difficult to Understand

TABLE 5: POST-SURVEY RESULTS

In reviewing the responses from the post-survey, subjects varied in how they rated the overall difficulty in completing both tasks. Subject #1 would have found the tasks very difficult to complete if the experiment moderators were not there to tell him when he had gone past a location interval. Subject #4 found the task and instructions easy to follow. By the end of the study, all subjects found the device comfortable to use. Three of the subjects listed a walking stick as a resource when travelling. Half the subjects found the device to be useful and something they would like to use in a public location. Half of the users found the auditory feedback, which was produced through a laptop to be slightly difficult to understand.

In discussing what the subjects liked about the device, they were generally pleased with the auditory feedback. The navigational system was interactive with the subject. One subject had mentioned that voice was familiar in screen readers. When in the range of an RFID tag, the subject was able to:

- Find out where they were currently located.
- What locations they were near.
- Get directions to another location based on their current location.

In critiquing the device, subjects wanted the distance metric to be a standard unit of measure. Units of measure most appropriately for this navigational system would be feet or meters. In this trial, we had used steps as our unit of measure between locations. We realized that steps were inaccurate and left users slightly off in reaching their target. As Subject #1 described it, the unit of measure was "subjective in nature." In discussing directional navigation, Subject #1 suggested that when the user received an instruction to turn a certain direction, it should include the amount of degrees of a circle they should turn before the subject should move straight forward.

Subjects were also concerned about the target in which the RFID reader had to be in range of the tag in order to receive an auditory response. Subjects had to place the reader very close, and at most times, touching the tag, in order for an auditory response to occur. The subject had small target to find as they navigated that if they walked past the tag, the subject was essentially off the grid and lost. Subjects recommended more tags and bigger targets for subjects to pass in order to receive an auditory message.

4.4 EVALUATION OF THE SOFTWARE SUITE

The software suite consisted of five main components: user input, reader input, audio output, database querying, and route calculations. Based on the subject's responses and our own software testing, we were able to draw conclusions about how well the software performed and what changes could be made in the future.

The first component we isolated was user input. For the purposes of our experiment, the experimenter entered the user input. At the main menu, the two choices a user could enter are "1," which corresponded to "where am I," and "2," which entered navigation mode. For each test subject, we began the experiment with a "1" Each time we selected "1," the software read to the user where they were in relation to other checkpoints. When entering "2," the software then asked the experimenter to enter the name of the checkpoint to navigate to.

All aspects of user input performed their tasks accurately, but we identified a few areas we could improve upon. Firstly, it was pointed out that checkpoints should be put into a numbered list so a visually impaired person could, for example, press "1" on a number pad to go to "Alfa" instead of typing out the full destination. Secondly, an option should be added that allows the user to repeat any output. Speech recognition would make inputting longer commands more easy; however speech recognition may be difficult and inaccurate when used in public locations with loud ambiance.

The second component was reader input. When the software was initialized, it entered a loop that constantly scanned for RFID tags. Whenever the receiver detected a tag, it successfully handled the event by relaying the tag's ID number to the software. We performed unit tests to test that the software processed tags correctly.

The third component was audio output. The Java text-to-speech engine we incorporated into the project read any output from the software to the users. The test subjects were able to understand most of the instructions, such as “walk 10 steps North to Alfa,” and “where would you like to go?” The users suggested that there should be options to limit how much the software verbalizes. A visually impaired person often tries to listen to their surroundings; too much auditory feedback from the software could become a distraction. One suggestion was to provide a setting to switch from verbal feedback to short tones to indicate when turns occur.

The fourth component was our database. The current database setup performs excellently for a small scale experiment. Larger implementations, however, would need a more effective system. Our current database setup requires the user to connect to the internet to download all information. This either requires the device to have built-in Wi-Fi, or have some other method of downloading the information from the database. If Wi-Fi was unavailable, this implementation would not work. Another possible implementation would be to create a docking station for the device that allows database information to be stored onto internal memory on the device.

The last component was route calculations. We used Dijkstra’s algorithm to calculate the shortest destination determined by distances, or weights, assigned to the paths on the graph. We created a symmetrical layout to represent an average mall. The symmetry unfortunately meant that there were potentially multiple ways to get to a destination and travel the same distance. This led to one user being directed on a different path than the other three users, while travelling the same distance. If the experiment were to be run again, the distances would be altered so there could only be one shortest path to a destination.

5. CONCLUSIONS

Conclusions were determined based on the responses received from test subjects during the experiment. The section is divided into hardware and software components. Conclusions are consistent in delivering an indoor navigational system for the visually impaired. The current prototype can be used as a basis for further implementations of this navigational system.

5.1 HARDWARE

The hardware component of the navigational system overall accomplished its main goal of assisting a visual impaired individual from getting from one location to another. Utilizing RFID technology allowed test subjects to consistently link the RFID reader to RFID tags placed in the experiment layout in reaching a destination. We believe that RFID can be continued in advanced implementations of the navigational system.

The number and range of the RFID tags utilized in this experiment limited the usability of the device. The tags, measuring 2.13 x 3.35 inches, contain a small RFID sensor. In order for the RFID reader connected to the walking stick to link with an RFID sensor contained within a tag, the reader needed to be on or nearly on the center of the tag. Each checkpoint contained one RFID tag, which created a small range in which the subject could link the reader to a tag. It can be concluded that a single RFID tag at each checkpoint was not sufficient in navigating to a destination.

The walking cane component of the system was familiar to a majority of subjects who used a walking stick of similar structure on a regular basis. The walking cane doubled both as a device to identify incoming obstacles like a walking stick but to also find and link with RFID tags placed on a walking route. The USB cord connected to the laptop did not interfere with the waving motion of test subjects as they navigated through the experiment layout. In tracking subject times between intervals, their learning curve during the test trial confirmed that a visually impaired could adjust to a full implementation of a similar navigational system.

5.2 SOFTWARE

In order for the device to be usable, the software and the user interface must be designed to be used for people with visual impairments. Because the device is to made for people with limited vision, there must be some way to interact with the software be it through analog buttons and voice command. A combination of analog buttons and voice command seems to be the best way to interact with the device. Through a headphone and microphone, the user would be able to use voice commands to navigate from tag to tag.

Input and output should be efficient and limit use of unnecessary words and/or noises. Visually impaired people use the noises in their immediate surroundings to gain a sense of position. Because of this, subjects during the experiment mentioned the issue of being overwhelmed with information from the device and also the surroundings.

6. RECOMMENDATIONS

While designing and implementing the project, we noticed several things that could have improved the system if we had more time and a larger budget. The team was able to create a list of recommendations that can be implemented in future projects, without considering financial limitations.

The biggest issue was the passive RFID technology. While passive RFID is affordable, it does not provide additional information that is essential for tracking. Active RFID would allow for the system to maintain real-time tracking information on the user. Real-time tracking would allow the system to provide additional and rapid responses, such as an early warning when the user is going in the wrong direction. We also explored Bluetooth technology and Wi-Fi technology. Both had their strengths, active RFID seemed to be the most useful.

Passive RFID navigation could have been improved with the use of a digital compass. Our system kept track of compass directions and instructed the user to head in those directions; however the user had to be told where the compass directions were by a tester. If a digital compass were integrated into the system, the system could have given the user early warnings if they were headed in the wrong direction. Instructions could also have been given as "turn left" or "turn right" instead of "head West" and "head East."

Java is not the best programming language to write this software in. While it accomplished our goals, it was not the most efficient. Java has difficulty natively reading hardware and connecting to databases. We recommend using C or C++ in the future.

The implementation we chose was to integrate the reader into a walking stick that the user held. Another possibility would be to integrate it into a mobile device, such as a cellular phone. While most cell phones do not come with integrated RFID, they do typically have Bluetooth and Wi-Fi, which could also be used in the system.

7. BIBLIOGRAPHY

1 Kiers, M. (2011, June 27). *Ways4all: Indoor navigation for visually impaired and blind people.* Retrieved April 18, 2012, from http://www.stadtentwicklung.berlin.de/internationales_eu/staedte_regionen/download/projekte/eurocities/4bca_vienna_2011/presentation_martijn_kiers.pdf

2 Le, M. H., Saragas, D., & Webb, N. (2009, October 22). *Indoor Navigation System for Handheld Devices.* Retrieved April 17, 2012, from Worcester Polytechnic Institute: http://www.wpi.edu/Pubs/E-project/Available/E-project-102209-164024/unrestricted/Indoor_Navigation_System_for_Handheld_Devices.pdf

3 Lighthouse International. (n.d.). *Lighthouse International - Use of Assistive Equipment*. Retrieved April 18, 2012, from Lighthouse International: http://www.lighthouse.org/research/statistics-on-vision-impairment/use-of-assistive-equipment/

4 National Dissemination Center for Children with Disabilities. (2004). *Blindness/ Visual Impairment*. Retrieved April 18, 2012, from National Dissemination Center for Children with Disabilities: http://nichcy.org/disability/specific/visualimpairment

5 Roberti, M. (n.d.). *The History of RFID Technology - RFID Journal*. Retrieved April 17, 2012, from RFID Journal: http://www.rfidjournal.com/article/view/1338

6 World Health Organization. (2011, October). *WHO | Visual impairment and blindness*. Retrieved April 18, 2012, from World Health Organization: http://www.who.int/mediacentre/factsheets/fs282/en/

8. APPENDICES

APPENDIX A. INFORMED CONSENT FORM

Informed Consent Agreement for Participation in a Research Study

We are a group of students from Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts advised by Professor Emmanuel Agu. We will be testing a prototype device designed to assist visually impaired individuals navigate independently through public locations such as train stations or shopping malls. This project is part of our core graduation requirements here at WPI. Our project is purely for academic purposes because we truly want to develop a device that could potentially benefit the visually impaired community. There is a RFID reader that would be attached to a walking stick that we would provide. The purpose of this receiver is read RFID tags placed on the floor that you will walk past. When the receiver gets in the range of a tag, you will hear a message indicating the name of the location you have arrived at. The RFID reader is connected by a cord to a laptop. We have created a layout in the room to simulate a public location, such as a mall. There are RFID tags installed in different parts of the room floor. Once you begin, we will provide you a task to complete with our device. This will involve you navigating around the room with our device. We are now ready to start the study.

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Ben Lipson, (631) 252-3141

Devin Thomas, (781) 325-3145

Title of Research Study: RFID Checkpoint System for the Visually Impaired

Sponsor: Worcester Polytechnic Institute, Project Advisor: Prof. Emmanuel Agu

Introduction:

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:

For this experiment, we will investigate the usability of a prototype navigation device around a public place that is catered specifically for a visually impaired individual. The device is able to read passive RFID tags. When the RFID reader gets in the range of a tag, the device will output your current location. We will ask subjects to complete a certain number of tasks using our device. The information will be used to analyze the prototype that we created in understanding areas of improvement upon the device and to see how useful could the device be in a real-life application. The findings of this experiment will be published in an academic report to be submitted to Worcester Polytechnic Institute.

Procedures to be followed:

On the test days, we will have a classroom set-up to conduct the experiment. The classroom will be located on a college campus to be determined by the project team. The room can be classified as a large classroom. Before we begin the experiment, we will have the room cleared of any sort of obstacles or objects that could obstruct our experiment and ensure the safety of those participating in the experiment. RFID tags will be placed around the room to mimic a layout of a public location such as a mall. The RFID tags will be taped to the floor. The RFID tags are thin enough, that when taped to the floor, they are safe to walk over or do not become an obstacle when navigating in a room. The RFID reader, for the purpose of this experiment, will be installed on a walking stick provided by the student investigators.

The RFID reader will be connected to a laptop by a USB cord, long enough to not obstruct the user during the experiment. A researcher will hold the laptop and guide the participant throughout the duration of the experiment. The researcher will also make sure that the cord will not obstruct the participant as they navigate through the room. Prior to the experiment we will have the participants complete a survey. Once the participant has signed the user agreement form, we will provide the walking stick which contains the RFID reader.

The researchers will then double check the room for safety, fill out date and age for the subject, and clear the test area for the participant to begin. Prior to the first run through, we will conduct a test run of the device to insure proper functionality and describe the lay out to the participants. We will position the subject at the first RFID location and ask the subject to begin walking around the room as normal. Throughout each run, there will be at least one researcher walking alongside the user to insure their safety. Once the user is within range of an RFID tag, they will hear an auditory response from the laptop announcing their current location. For example, they may walk over an RFID tag and that would receive a response from the RFID reader and to the laptop.

Once we believe the subject is comfortable and has an understanding of the device, the researcher will ask them to complete a number of tasks with the device. As they complete a task, the researcher will ask the subject to talk aloud in order to understand their thought process as they use the device. This information will be recorded and saved for post-analysis.

Tasks to complete by the subject include:

- Finding their current location.
- Get directions from the current location to another location, provided by the researcher.
- Navigation around the layout and see how many RFID tags they were able to accurately reach and receive auditory output from.

Once the experiment begins, a researcher will be tracking the time it takes for the subject to complete a particular task. Once a task is completed, we will provide a new task from their current location in the room.

Once the participant completes all necessary tasks, the participant will be escorted out of the testing area and asked to fill out a post-survey as the researchers prepare for the next participants trial.

Risks to study participants:

The risk factor for the participants in the project will be kept at a minimum. The entire process will be conducted in a classroom. The RFID reader attached to the walking stick will not have any risk of harm to the individual. We have a researcher who will make sure the room is void of obstacles, one to overview the entire experiment and tasks conducted by the subject, and one to follow the user and assist them through the course.

Benefits to research participants and others:

Research subjects would be able to test the usability of our navigation device that could potentially be implemented in public places.

Record keeping and confidentiality:

Records of user participation in this study will be held confidential so far as permitted by law. The study will involve the audio or video recording of the experiment with the student investigators. Neither your name nor any other identifying information will be associated with the audio or video recording or transcript. Only the research team will be able to listen or view any recordings. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify the user, by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury:

In the unlikely event of physical injury resulting from participation in the research, you understand that medical treatment may be billed for the cost of such treatment by your insurance provider. No compensation for medical care can be provided by WPI. You further understand that making such medical care available, or providing it, does not imply that such injury is the fault of the investigators. You do not give up any of your legal rights by signing this statement.

Cost/Payment:

There is no cost or payment for participating in this experiment.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

Prof. Emmanuel Agu, CS Department, WPI, 100 Institute Road, Worcester, MA (Tel. 1-508-831-5568). You may also contact the chair of the WPI Institutional Review Board (Prof. Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu) or WPI's University Compliance Officer (Michael J. Curley, Tel. 508-831-6919).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You have the right to stop participating in the experiment at any time. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit. Data obtained in this experiment will become the property of the investigators and WPI. If you withdraw from the study, data already collected from you will remain in the study.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

___________________________ Date:___________________

Study Participant Signature

____

Study Participant Name (Please print)

____________________________________ Date: ___________________

Signature of Person who explained this study

WPI RESEARCH SURVEY

We are a group of students from Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts. We are conducting a survey to visually impaired individuals to learn more about their interactions within products within their home, the public realm, and general technology in general.

We are currently working on a project advised by Professor Emmanuel Agu of WPI in regards to assistive technology/software for visually impaired people. This project is part of our core graduation requirements here at WPI. Called the Major Qualifying Project, it is a major-specific project using our college knowledge and applying it to a real-world problem. Our project is purely for academic purposes and because we truly want to develop something that potentially a visually impaired people could benefit from.

Your participation in this survey is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous. No names or identifying information will appear on any of the project reports or publications. Your participation is greatly appreciated. If interested, a copy of our results can be provided at the conclusion of the project.

For more information/questions, please email: eoa0019-team@wpi.edu

* Required

BACKGROUND

Name *First Name*

Email Address *Preferably list most often used.*

Phone Number *Optional*

Age ***Select one*
- 18 – 35
- 36 – 65
- 66 +

What is your level of visual impairment? ***Select one*
- Low Vision (20/70 or worse)
- Legally Blind (20/200 or worse)
- Complete Blindness

How long have you been visually impaired? ***Select one*
- 1 – 5 years
- 6 – 10 years
- more than 10 years

BEHAVIORAL QUESTIONS

List devices/appliances within your home catered to your visual impairment *List one device/appliance per line*

Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment? *Describe below*

Level of proficiency reading Braille ***Select one*

- None
- Some
- Proficient

How would you rate your computer expertise? ***Select one*

- Novice
- Proficient
- Expert

Which of the following input devices do you use to interact with your computer? ***Select all that apply*

- Joystick
- Keyboard
- Microphone
- Mouse
- Screen Reader
- Touch Screen
- Other:

Preferred method of input when using a computer ***Select all that apply*

- Joystick
- Keyboard
- Microphone
- Mouse
- Screen Reader
- Touch Screen
- Other:

Do you prefer to interact with a device by VOICE or TOUCH? ***Select one*

- Voice
- Touch
- Both

Do you own a smart phone? ***Select one*

- Yes
- No

SMART PHONE

If answered yes to previous question

Type of Smart Phone ***Select one*

- iPhone
- Android

- Windows
- Blackberry
- Other:

Application(s) most helpful on your smart phone and reason(s) for its usefulness? *List one application and description per line*

SMARTPHONE

If answered no to previous question

Other than financial reasons, is there a reason you do not own a smart phone?*Enter response below*

PUBLIC

What public place(s) would you benefit from an assistive technology device available to you? *List one per line*
What aspect of navigating public places do you have the most difficulty? *Enter response below*

OPEN ENDED

Do you have/heard of any creative ways in which technology can be used to assist visually impaired people? *Enter response below*

Would you be willing to participate in a follow-up survey?
- Yes
- No

Questions/Comments *Enter response below*

APPENDIX C. INITIAL SURVEY RESPONSES

INTERVIEW SUBJECT 1

1. **What is your level of visual impairment?**
   Legally Blind (20/200 or worse)

2. **How long have you been visually impaired?**
   More than 10 years

3. **List devices/appliances within your home catered to your visual impairment**
   Jaws software, cane, talking watch, clock, caller id

4. **Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment?**
   Reading/scanning the mail, food labels from grocery stores, getting information, how prepared is it on someone's website, plan trips very carefully, can't read street signs

5. **Level of proficiency reading Braille?**
   None

6. **How would you rate your computer expertise?**
   Proficient

7. **Which of the following input devices do you use to interact with your computer?**
   Keyboard, Microphone, Mouse, Screen Reader

8. **Preferred method of input when using a computer**
   Keyboard, Scanner/for items

9. **Do you prefer to interact with a device by VOICE or TOUCH?**
   Touch

10. **Do you own a smart phone?**
    No

11. **Type of Smart Phone**
    N/A

12. **Application(s) most helpful on your smart phone and reason(s) for its usefulness?**
    N/A

13. **Other than financial reasons, is there a reason you do not own a smart phone?**
    Free phone from Safelink, only need a cheap phone

14. **What public place(s) would you benefit from an assistive technology device available to you?**

Shopping mall, grocery stores, retail stores, finding seats in the fleet center, theatres

15. **What aspect of navigating public places do you have the most difficulty?**
    Locating rooms, elevators, stairs, bathrooms

16. **Do you have/heard of any creative ways in which technology can be used to assist visually impaired people?**
    Most of the touch interface is nailed down except the smart phone. If I got to turn off the light, I have to go to the light switch. Let the light switch turn off when I do not know whether it's on or not.

INTERVIEW SUBJECT 2

1. **What is your level of visual impairment?**
   Complete Blindness

2. **How long have you been visually impaired?**
   More than 10 years

3. **List devices/appliances within your home catered to your visual impairment**
   Computers with screen readers, Apex Braille note taker made by human ware, Icon Braille plus (note taker), ID Mate (bar code scanner), talking clocks, talking volt meter, audible light probe that makes a noise when there is a light, talking bathroom scale, talking clock/radio

4. **Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment?**
   Anything that requires a person to look at a visual display is very difficult for a blind person (i.e. DVR, lot of on-screen information that can't be recognized; appliances).

5. **Level of proficiency reading Braille?**
   Proficient

6. **How would you rate your computer expertise?**
   Expert

7. **Which of the following input devices do you use to interact with your computer?**
   Keyboard, Screen Reader

8. **Preferred method of input when using a computer**

9. **Do you prefer to interact with a device by VOICE or TOUCH?**
   Voice

10. **Do you own a smart phone?**
    No

11. **Type of Smart Phone**
    N/A

12. **Application(s) most helpful on your smart phone and reason(s) for its usefulness?**
    N/A

13. **Other than financial reasons, is there a reason you do not own a smart phone?**
    Didn't really like the smart phone experience too much, not as reliable as a screen reader

14. **What public place(s) would you benefit from an assistive technology device available to you?**
    Read public signs, knowing where the signs are and reading the signs

15. **What aspect of navigating public places do you have the most difficulty?**
    Knowing where public signs are and reading the signs

16. **Do you have/heard of any creative ways in which technology can be used to assist visually impaired people?**
    Use of infrared signs; Using a smart phone's camera to identify and say labels, app with text correspondence that would go to a screen reader; GPS for blind people that list labels for public buildings, go into a mall figure out where the directory and read the directory

INTERVIEW SUBJECT 3

1. **What is your level of visual impairment?**
   Legally Blind (20/200 or worse)

2. **How long have you been visually impaired?**
   More than 10 years

3. **List devices/appliances within your home catered to your visual impairment**
   Laptop, Perkins Braille, Braille labeler, Penfriend, Braille ruler, labeled microwave/oven/washing machine/thermostat, color identifier, handheld video magnifier, CCTV, talking scale/thermometer, slate, stylus, iPod Touch, Braille display, accessible MP3 player, digital talking book players, adapted cassette four-track player, money identifier, talking timer/alarm clock/HD digital radio, talking keychain watch, tactile watch, phone with talking caller ID, document scanner with OCR program

4. **Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment?**
   Accessing print material, especially what comes in the mail, sorting mine from others, junk from important, time spent scanning the text, often it does not read when scanned due to fonts and colors and layout, hard to find a sighted reader who can be hired to do this as a job

5. **Level of proficiency reading Braille?**
   Some

6. **How would you rate your computer expertise?**
   Expert

7. **Which of the following input devices do you use to interact with your computer?**
   Keyboard, screen reader, touch screen

8. **Preferred method of input when using a computer**
   Keyboard

9. **Do you prefer to interact with a device by VOICE or TOUCH?**
   Both

10. **Do you own a smart phone?**
    No

11. **Type of Smart Phone**
    N/A

12. **Application(s) most helpful on your smart phone and reason(s) for its usefulness?**
    N/A

13. **Other than financial reasons, is there a reason you do not own a smart phone?**
    I am not a frequent cell phone caller so prefer to use an IPod Touch.

14. **What public place(s) would you benefit from an assistive technology device available to you?**
    Commuter Rail Station

15. **What aspect of navigating public places do you have the most difficulty?**
    Finding entrance and exit that go to different areas in and out of large places (i.e. South Station, Boston); Imagine South Station and how to find the restroom, finding an accessible map and reading it, locating nearby amenities (i.e. coffee shop), learning/memorizing the layout of a place that I will visit often, overwhelmed when there is loud noises but need ears to navigate, knowing how to get to and from where I am

16. **Do you have/heard of any creative ways in which technology can be used to assist visually impaired people?**
    Having a handheld device that does as many things as possible as opposed to needing so many different items, especially those that need to be taken with you, so things for navigation or for being able to read the electronic digital messages on signs and on my appliances would be fantastic; the latter would be great for at home or the train station, especially at home with almost all appliances.

INTERVIEW SUBJECT 4

1. **What is your level of visual impairment?**
   Complete blindness

2. **How long have you been visually impaired?**
   More than 10 years

3. **List devices/appliances within your home catered to your visual impairment**
   Washing machine, dryer, label raised dots on certain places, dishwasher with raised buttons, stove, speaking VCR

4. **Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment?**
   Using DVD player and television (no access to the menu/program guide)

5. **Level of proficiency reading Braille?**
   Proficient

6. **How would you rate your computer expertise?**
   Proficient

7. **Which of the following input devices do you use to interact with your computer?**
   Keyboard, Microphone, Mouse, Screen Reader

8. **Preferred method of input when using a computer**
   Keyboard, Screen Reader

9. **Do you prefer to interact with a device by VOICE or TOUCH?**
   Both

10. **Do you own a smart phone?**
    No

11. **Type of Smart Phone**
    N/A

12. **Application(s) most helpful on your smart phone and reason(s) for its usefulness?**
    N/A

13. **Other than financial reasons, is there a reason you do not own a smart phone?**
    Basic cell phone with built-in speech, can text and make calls, no desire to do email or other advanced services on smart phone

14. **What public place(s) would you benefit from an assistive technology device available to you?**
    Mall

15. **What aspect of navigating public places do you have the most difficulty?**
    Finding particular places/buildings/addresses

16. **Do you have/heard of any creative ways in which technology can be used to assist visually impaired people?**
    GPS has great potential, yet expensive

INTERVIEW SUBJECT 5

1. **What is your level of visual impairment?**
   Complete blindness

2. **How long have you been visually impaired?**
   More than 10 years

3. **List devices/appliances within your home catered to your visual impairment**
   Computer, Braille note taking device, digital talking book player, Library of Congress tape player

4. **Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment?**
   Getting around the web, sites are bad to use, can't tell what's going on; microwave used minimally, getting the television to work

5. **Level of proficiency reading Braille?**
   Proficient

6. **How would you rate your computer expertise?**
   Proficient

7. **Which of the following input devices do you use to interact with your computer?**
   Keyboard, Microphone, Screen Reader

8. **Preferred method of input when using a computer**
   Keyboard, Screen Reader

9. **Do you prefer to interact with a device by VOICE or TOUCH?**
   Touch

10. **Do you own a smart phone?**
    No

11. **Type of Smart Phone**
    N/A

12. **Application(s) most helpful on your smart phone and reason(s) for its usefulness?**
    N/A

13. **Other than financial reasons, is there a reason you do not own a smart phone?**
    N/A

14. **What public place(s) would you benefit from an assistive technology device available to you?**
    Malls, big parking lots

15. **What aspect of navigating public places do you have the most difficulty?**
    Lack of useable signage of places unaware of

16. **Do you have/heard of any creative ways in which technology can be used to assist visually impaired people?**
    Can't use microwave because of touch screen interface, would be good to have a remote control

INTERVIEW SUBJECT 6

1. **What is your level of visual impairment?**
   Complete blindness

2. **How long have you been visually impaired?**
   More than 10 years

3. **List devices/appliances within your home catered to your visual impairment**
   Computer, Braille note taking device, digital talking book player, Library of Congress tape player

4. **Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment?**
   Laundry, find stains, discolorations in clothing

5. **Level of proficiency reading Braille?**
   Proficient

6. **How would you rate your computer expertise?**
   Proficient

7. **Which of the following input devices do you use to interact with your computer?**
   Keyboard, Screen Reader

8. **Preferred method of input when using a computer**
   Keyboard

9. **Do you prefer to interact with a device by VOICE or TOUCH?**
   Touch

10. **Do you own a smart phone?**
    No

11. **Type of Smart Phone**
    N/A

12. **Application(s) most helpful on your smart phone and reason(s) for its usefulness?**
    N/A

13. **Other than financial reasons, is there a reason you do not own a smart phone?**
    N/A

14. **What public place(s) would you benefit from an assistive technology device available to you?**
    Talking signs in public places (i.e. mall)

15. **What aspect of navigating public places do you have the most difficulty?**
    Parking lot navigation, navigating within a store

16. **Do you have/heard of any creative ways in which technology can be used to assist visually impaired people?**
    More manuals available, find products in the store (i.e.. supermarket)

INTERVIEW SUBJECT 7

1. **What is your level of visual impairment?**
   Complete blindness

2. **How long have you been visually impaired?**
   More than 10 years

3. **List devices/appliances within your home catered to your visual impairment**
   iPhone, computer, Victor screen reader (reading books and text files), national library service player

4. **Please list any daily task(s) that are time-consuming or difficult as a result of your visual impairment?**
   Cooking, doing laundry, reading printed material, watching television, XM radio, the oven, washing machine, dryer, dishwasher

5. **Level of proficiency reading Braille?**
   Some

6. **How would you rate your computer expertise?**
   Proficient

7. **Which of the following input devices do you use to interact with your computer?**
   Keyboard, Microphone, Screen Reader, Touch Screen

8. **Preferred method of input when using a computer**
   Keyboard

9. **Do you prefer to interact with a device by VOICE or TOUCH?**
   Both

10. **Do you own a smart phone?**
    Yes

11. **Type of Smart Phone**
    iPhone

12. **Application(s) most helpful on your smart phone and reason(s) for its usefulness?**
    E-Z news (gives your access to news sites), money reader

13. **Other than financial reasons, is there a reason you do not own a smart phone?**
    N/A

14. **What public place(s) would you benefit from an assistive technology device available to you?**
    Train/Bus/Subway Station

15. **What aspect of navigating public places do you have the most difficulty?**
    Not familiar with a location; getting out of bus station, not sure where foot traffic is going; Being in a line and not knowing how long the line is or whether its moving forward, If it's moving, have a proximity sensor tell you when the line is moving.

16. **Do you have/heard of any creative ways in which technology can be used to assist visually impaired people?**
    MIT developed this virtual map app to maneuver around and get a sense of the area

APPENDIX D. EXPERIMENT PRE-SURVEY

Age

- 18 – 35
- 36 – 65
- 66+

Level of visual impairment

- Low Vision (20/70 or worse)
- Legally blind (20/200 or worse)
- Complete blindness

How long have you been visually impaired for?

- 1 – 5 years
- 6 – 10 years
- more than 10 years

How often do you travel in a public location in a given week (mall, library, university building, etc.)?

- 0 – 5 times
- 6 – 10 times
- 10 or more times

Is there anything you use to assist you when navigating in a public place? Please describe.

How would you rate your comfort level navigating in an unfamiliar public location?

- Uncomfortable
- Slightly uncomfortable
- Slightly comfortable
- Comfortable
- Very comfortable

APPENDIX E. EXPERIMENT POST-SURVEY

Please rate the overall difficulty in completing the tasks assigned by the researcher?

- Very Difficult
- Slightly Difficult
- Easy
- Very easy

How would you rate your comfort level in using the device by the end of the study?

- Uncomfortable
- Slightly uncomfortable
- Slightly comfortable
- Comfortable
- Very comfortable

Did you find the device useful/helpful in navigating a new location?

- Yes
- No

What did you like about the device? Please describe.

What did you dislike/found difficult about the device? Please describe.

Could you imagine yourself using a similar device in navigating through a public location?

- Yes
- No

Please rate how well you could understand the auditory feedback?

- Very difficult to understand
- Slightly difficult to understand
- Slightly easy to understand
- Very easy to understand

Do you have any questions/comments about the study or device? This could entail ways in which we could improve the device or just questions of the study or project itself. Please describe.

APPENDIX F. EXPERIMENT LAYOUT