ITS INSTITUTE
Intelligent Transportation Systems

Development of Mobile Accessible Pedestrian Signals (MAPS) for Blind Pedestrians at Signalized Intersections

Final Report

Prepared by:

Chen-Fu Liao
Michael Rakauskas
Avanish Rayankula

Department of Civil Engineering
Minnesota Traffic Observatory
University of Minnesota

CTS 11-11

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
CTS 11-11		

4. Title and Subtitle	5. Report Date
Development of Mobile Accessible Pedestrian Signals (MAPS) for Blind Pedestrians at Signalized Intersections	June 2011
	6.
7. Author(s)	8. Performing Organization Report No.
Chen-Fu Liao, Michael Rakauskas, Avanish Rayankula	
9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Department of Civil Engineering University of Minnesota 500 Pillsbury Drive, SE Minneapolis, MN 55455	CTS Project #2010052
	11. Contract (C) or Grant (G) No.
12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Intelligent Transportation Systems Institute Center for Transportation Studies 200 Transportation and Safety Building 511 Washington Ave. SE Minneapolis, MN 55455	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes
http://www.its.umn.edu/Publications/ResearchReports/

16. Abstract (Limit: 250 words)

People with vision impairment have different perception and spatial cognition as compared to the sighted people. Blind pedestrians primarily rely on auditory, olfactory, or tactile feedback to determine spatial location and find their way. They generally have difficulty crossing intersections due to lack of traffic information at intersections. Among the intersection crossing sub-tasks, locating crosswalk, determining when to cross and maintaining alignment to crosswalk while crossing are the most difficult tasks for the blind and visually impaired. To understand how the blind pedestrians make safe crossing decisions, ten blind and low-vision individuals were interviewed. The purpose of these interviews was to understand the types of information they use while making safe intersection crossings and identify new information types that could assist them. A Mobile Accessible Pedestrian Signals (MAPS) prototype was developed to support decision making at signalized intersections. The MAPS integrates sensors on a Smartphone, Wi-Fi, and Bluetooth technologies, and traffic signal controllers were developed to provide intersection geometry information and Signal Phasing and Timing (SPaT) to pedestrians who are blind at signalized intersections. A single-tap command on the Smartphone screen allows users to request for intersection geometry information, such as street name, direction and number of lanes at a corner of an intersection. A double-tap input while pointing toward desired direction of crossing will confirm the crossing direction, request for pedestrian phase, and the Smartphone application will then wirelessly request for signal timing and phasing information from traffic signal controller.

17. Document Analysis/Descriptors	18. Availability Statement
Accessible Pedestrian Signal (APS), Crosswalks, Blindness, Visually impaired persons, Traffic, Traffic signal control systems, Smartphones	No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	135	

Development of Mobile Accessible Pedestrian Signals (MAPS) for Blind Pedestrians at Signalized Intersections

Final Report

Prepared by:

Chen-Fu Liao
Department of Civil Engineering
Minnesota Traffic Observatory Laboratory
University of Minnesota

Michael Rakauskas
Department of Mechanical Engineering
HumanFIRST Program
University of Minnesota

Avanish Rayankula
Department of Computer Science
University of Minnesota

June 2011

Published by:

Intelligent Transportation Systems Institute
Center for Transportation Studies
200 Transportation and Safety Building
511 Washington Avenue S.E.
Minneapolis, Minnesota 55455

ACKNOWLEDGEMENTS

We would like to thank the Intelligent Transportation Systems (ITS) Institute and Center for Transportation Studies (CTS), University of Minnesota, for supporting this project. The ITS Institute is a federally funded program administrated through the Research & Innovative Technology Administration (RITA). We also would like to recognize the following people and organizations for their invaluable assistance in making this research possible.

Linda Spaulding, Certified Orientation and Mobility Specialist (COMS)
Professor Gordon Legge, Department of Psychology
Professor Herbert Pick, Institute of Child Development
Michael Manser, Director, HumanFIRST, UMN
Professor Thomas Stoffregen, School of Kinesiology
Alec Gorjestani, Research Fellow, Intelligent Vehicle Laboratory, UMN
Minneapolis Vision Loss Resources (VLR)
Minnesota Traffic Observatory (MTO), UMN

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

ADA	American Disability Act
ACB	American Council of the Blind
AFB	American Foundation for the Blind
APS	Accessible Pedestrian Signal
ATC	Advanced Traffic Controller
COMS	Certified Orientation and Mobility Specialist
CTS	Center for Transportation Studies
CWA	Cognitive Work Analysis
DSRC	Dedicated Short Range Communications
DSS	Digital Sign System
EID	Ecological Interface Design
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HumanFIRST	Human Factors Interdisciplinary Research in Simulation and Transportation
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transportation Systems
O&M	Orientation and Mobility
LBS	Location Based Service
MAC	Media Access Control
MACD	Macular Degeneration
MAPS	Mobile Accessible Pedestrian Signal
MEMS	MicroElectroMechanical Systems
MTO	Minnesota Traffic Observatory
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NFB	National Federation of the Blind
PDR	Pedestrian Dead-Reckoning
POTS	Postural Orthostatic Tachycardia Syndrome
RFID	Radio Frequency Identification
RITA	Research & Innovative Technology Administration
SD	Standard Deviation
SPaT	Signal Phasing and Timing
STT	Speech To Text
TAD	Travel Assistance Device
TTS	Text To Speech
UI	User Interface
UMN	University of Minnesota
VLR	Vision Loss Resources
WDA	Work Domain Analysis
WHO	World Health Organization
WPS	Wi-Fi Positioning System

EXECUTIVE SUMMARY

According to the fact sheet published by the World Health Organization (WHO) in 2009, there are about 314 million people who are visually impaired worldwide, and 45 million of them are blind. People with vision impairment have different perception and spatial cognition as compared to the sighted people. Blind pedestrians primarily rely on auditory, olfactory, or tactile feedback to determine spatial location and find their way. They often travel in areas that are less familiar, partially due to limited spatial knowledge, with potential barriers mentally or physically. Movement barriers, such as bike parking racks, traffic sign poles, benches, lamp posts, and newspaper boxes on the sidewalk, may seem simple and trivial for sighted person to navigate. However, these obstacles create additional challenges to the blind people to find their way and further limit their transportation accessibility and mobility. People with vision impairment generally have difficulty crossing intersections due to lack of traffic information at intersections. Among the intersection crossing sub-tasks, locating crosswalk, determining when to cross and maintaining alignment to crosswalk while crossing are the most difficult tasks for the blind and visually impaired.

To understand how the blind pedestrians make safe crossing decisions, ten blind and low-vision individuals were interviewed. The purpose of these interviews was to understand the types of information they use while making safe intersection crossings and identify new information types that could assist them. The individuals were also asked about their interaction with technology and infrastructure-based Accessible Pedestrian Signals (APS) to see how amenable they would be to using new APS technology, specifically technology that could reside on a mobile device.

Based on the findings of these interviews, six high-level recommendations emerged for the design of mobile APS:

1. Auditory and tactile information should not interfere with the pedestrian's ability to use their cane or listen to traffic cues.
2. Tactile cues are recommended as warnings when pedestrians put themselves in a dangerous situation, in tandem with auditory instructions.
3. Output from the system should be primarily short auditory phrases.
4. A method to repeat warnings / output is necessary.
5. Present additional information about the intersection.
6. Allow for automatic activation of walk signal when a mobile APS is present at an intersection; or allow the user to activate the signal though the mobile APS interface.

A prototype of Mobile Accessible Pedestrian Signals (MAPS) was developed by integrating sensors on a Smartphone and incorporating user's need to provide appropriate decision support at intersection crossing. Wireless technologies (Bluetooth & Wi-Fi) and signal information, Signal Phasing and Timing (SPaT), from traffic signal controllers are integrated to provide environmental information and personalized signal information to the blind pedestrians. Two simple user input commands are developed for the blind users: (1) The single-tap command on the Smartphone screen allows users to request for intersection geometry information, such as street name, direction, and number of lanes, at a corner of an intersection, (2) The double-tap

input while pointing toward desired direction of crossing will confirm the crossing direction, request for pedestrian walk signal, and the Smartphone application will wirelessly request for signal timing and phasing information from traffic signal controller. Speech feedback to the blind pedestrians is broadcasted through the Text-To-Speech (TTS) interface available on Smartphone.

There are concerns over the noise, the pushbutton location, and the installation and maintenance costs associated with current APS systems. In the long term, the MAPS system has the potential and capability to enhance, if not replace, existing APS. Given the elimination of conduits carrying signals and power to the vibrotactile buttons located around the intersection, the MAPS system can be deployed on a larger scale and more cost-effective manner. Although the proposed MAPS system is primarily targeted toward the blind and the elderly, there are also potential benefits for people with low vision and sighted pedestrians that may be distracted (while for example talking or texting on their cell phone) at the intersection crossing.

The MAPS system can also address the non-rectangular intersection issue by providing intersection geometry information and direction of crosswalk through speech. However, it requires further investigation to study the effectiveness of this approach depending on the accuracy of sensors on the Smartphone. The MAPS aims to provide decision support for the blind pedestrians at signalized intersections. It does not replace the wayfinding skills that a blind pedestrian already learned. Future work will focus on usability test of the system and evaluate the effectiveness of the MAPS prototype as compared to existing APS, and development of veering alert algorithm using pedestrian dead-reckoning and image processing technique.

1. INTRODUCTION

Individuals who are blind or visually impaired use the auditory and limited visual information that they can gather to make safe crossing decisions often report being dissatisfied with a general lack of information while crossing intersections, as found by Ponchillia, Rak, Freeland, and LaGrow (2007). This may explain why a study of blind pedestrian behavior in three cities found that only 49% of the crossings started during the walk interval (Barlow, Bentzen, & Bond, 2005). They also found that 27% of all crossings (that did not involve outside assistance) ended after the onset of the perpendicular traffic stream.

At crossings where using a pushbutton was required, Barlow, et al. (2005) found that few (0% - 16% depending on the city sampled) looked for and found the button; they also began walking only 20% of the time during the walk signal compared to 72% of the time when the pedestrian phase was on recall (i.e., included in every cycle). This may be because searching for the button often requires the pedestrian to move from their path of travel, which is often used as an alignment cue to make sure they are crossing straight. This suggests that there is room for improvement in terms of the design and accessibility of both accessible pedestrian signals (APS) and non-APS crosswalk signals for blind and low-vision pedestrians.

In addition, Barlow et al. (2005) found that although 72% started with appropriate alignment, location, or both, 42% ended their crossing maneuver outside the crosswalk. To this end, Guth, Ashmead, Long, and Wall (2005) found that site-specific characteristics (e.g., treatments such as rumble strips or speed countermeasures) appeared to have a greater impact on reducing the number of conflicts between pedestrians and vehicles than did a mobility device (e.g., cane or seeing-eye dog). Therefore, enhancing pedestrians' ability to perceive useful cues at an intersection may be an effective method of reducing crash events.

Therefore, when considering the design of an APS for blind and low-vision pedestrians, it is first important to consider the types of information that they currently need to cross and orient to their destination. It is also important to understand how they identify when it is safe to enter the intersection and how they align themselves with traffic when crossing safely to the other side. Finally, mobile APS designers need to understand how the blind pedestrians interact with infrastructure-based APS, how they benefit from this interaction, and what information (that is not currently present) could improve their intersection-crossing experiences.

1.1 Research Objectives

The objective of this project is to design a decision support system for blind or visually impaired pedestrians at signalized intersections. User need analysis and survey are first conducted in order to understand current challenges and what information may be needed to improve mobility. A Smartphone-based system is then developed by incorporating the survey results to provide intersection geometry and traffic signal timing information to the users.

1.2 Brief History of Accessible Pedestrian Signals (APS)

The audible pedestrian signals first appeared in 1920 in U.S. However, it is not included in the US standard, Manual on Uniform Traffic Control Devices (MUTCD) until 2000. In mid 1970's, the audible signals were mounted on top of the pedestrian signal display (also called pedhead-mounted APS) using two different auditory tones to distinguish the north-south (Cuckoo sound) and east-west (Chirping sound) directions.The audible pedestrian signals were later integrated with pushbutton for requesting pedestrian signal in mid 1990's. The pedhead-mounted APS has several shortcomings. The indication of 'Walk' signal is ambiguous and it requires blind pedestrians to know their direction of travel all the times. The audible sound is active when the 'Walk' signal is on and there is no indication of pushbutton location if exists.

The new generation of APS system incorporates many of the shortcomings from the earlier system. It provides audible and vibrotactile indication of the 'Walk' signal. A pushbutton locator tone that repeats constantly at 1Hz is added to provide information about the presence and location of a pushbutton. As part of the pushbutton, a tactile arrow that points in the direction of travel on the crosswalk is included. Some of the APS system can also adjust the audible volume with respect to the ambient noise level.

Currently, each APS system costs over $6,000 per intersection plus labor. The repeating tone adds 5 decibels of noise within 6 to 12 feet of pushbutton. In US, there is no standard pushbutton location and it often requires additional stub for installing pushbutton station poles. Ongoing maintenance and Braille verification require additional effort. There are complaints about noise of APS from residents near the installations.

1.3 Literature Review

1.3.1 Navigation and Wayfinding for the Blind

It may be arguable that providing wayfinding technology for the blind and visually impaired may undermine the maintenance of their learned techniques. However, the application to improve safety and increase capability for the visually impaired is more likely to outweigh the overall cost (Loomis et al., 2007). Navigation and wayfinding involve with dynamically monitoring a person's position and orientation with respect to the immediate environment and destination (Klatzky et al., 1998, 1999; Aslan and Krüger, 2004; Rieser, 2007). Navigation usually implies that a user will follow a predetermined route or path between a specific origin and destination. Navigation is often referred to as an optimal path based on a specific goal, such as shortest time, distance, minimum cost, etc. However, wayfinding refers to the process of finding a path, not necessary traveled previously, between a pair of origin and destination. The wayfinding process is more adventurous and exploratory.

Starting in 1990, the American Disability Act (ADA) requires built environment accessible to people with disability (Bentzen, 2007). Blind people are more vulnerable to collision due to insufficient information (such as distant landmarks, heading and self-velocity) and time for planning detour around obstacle (Loomis et al., 2001, 2007). People with wayfinding difficulties, such as visually impaired (Golledge et al., 1996; Helal et al., 2001), elderly people (Rogers et al., 1998; Kirasic, 2002; Hess, 2005), dementia or Alzheimer's diseases (Uc et al., 2004; Rosenbaum et al., 2005; Pai 2006), can benefit from a personal navigation system for navigation and wayfinding assistance. There has been lots of research investigating Geographic Information System (GIS) and Global Positioning System (GPS) based navigation system for visually impaired pedestrian (Golledge, et al., 1991, 1996, 1998, 2004; Helal et al., 2001; Ponchillia et al., 2007; Blake, 2011). Several researchers also focused on the development of User Interface

(UI) with non-visual spatial displays, for example, haptic (Loomis et al., 2005 & 2007; Marston et al., 2007), auditory (Loomis et al., 1998; Kim et al., 2000; Marston et al., 2007), or virtual acoustic display (Kim and Song, 2007), to order to provide perceptual information about the surrounding environment.

Willis & Helal (2005) used programmed Radio Frequency Identification (RFID) tags to provide location and navigation information for the blind. However, the RFID information grid systems requires short range communication (7~15-cm or 2.75~6-in) and high density of tags (30-cm or 12-in apart) in order to provide navigational guidance. Kim et al. (2010) developed an electronic white cane with integrated camera, ZigBee wireless radio and RFID tag reader to provide route guidance information to the blind and visually impaired at transit transfer stations. Grierson et al. (2009) utilized a wearable tactile belt developed by Zelek & Holbein (2008) to assist people with wayfinding difficulties. The wearable belt is integrated with GPS, compass, inertial sensor, battery and small motors to provide direction relevant cues for wayfinding. The results indicated that older people generate more wayfinding errors than young people. The tactile wayfinding belt can provide effective navigational aid for healthy users. Wilson et al. (2007) developed a wearable audio navigation system to assist blind or visually impaired people getting from origin to destination. The system uses GPS, digital compass, cameras, and a light sensor to transmit 3D audio cues to guide the traveler along a path to destination.

1.3.2 Blind Pedestrian at Intersection Crossing

People with vision impairment use auditory and limited visual information that they can gather to make safe crossing decision at signal intersection. They generally have difficulty crossing intersections due to the lack of information available to them about the traffic and geometry at intersections (Ponchillia et al., 2007). A study of blind pedestrian's behavior in three cities found that only 49% of the crossings started during the walk interval (Barlow et al., 2005). The study also found that 27% of all crossings (that did not involve outside assistance) ended after the onset of the perpendicular traffic stream.

At crossings where using a pushbutton is required, Barlow, et al. (2005) found that few (0% - 16%) looked for and found the button; they also began walking only 20% of the time during the walk signal as compared to 72% of the time when the pedestrian phase was on recall. The reason may be because searching for the button often requires the pedestrian to move away from their path of travel, which is often used as an alignment cue for crossing. In addition, Barlow et al. (2005) found that although 72% of blind participants started with appropriate alignment, location, or both, 42% ended their crossing maneuver outside the crosswalk. Guth et al. (2007) found that site-specific characteristics (for example, treatments such as rumble strips or speed countermeasures) appeared to have a greater impact on reducing the number of conflicts between pedestrians and vehicles than did a mobility device (e.g., cane or guide dog). Therefore, enhancing pedestrians' ability to perceive useful cues at an intersection may be an effective method of reducing crash events. There is room for improvement in terms of the design and accessibility of both accessible pedestrian signals (APS) and non-APS crosswalk signals for blind and low-vision pedestrians.

Accessible Pedestrian Signal (APS), indicating the onset of the pedestrian phase at signalized intersection, have been deployed in selected intersections to assist blind people at intersection crossing. However, there is disagreement between two major blind communities. American Council of the Blind (ACB) supported use of APS to provide additional information at all intersections. National Federation of the Blind (NFB) opposed all use of APS. The City of Minneapolis has installed 14 APS systems to provide audible indication of the 'WALK' interval to blind pedestrians. Recently, the City of Minneapolis has obtained federal funding to install additional 14 APS systems. The APS transition plan was drafted under which all traffic signals will be evaluated and prioritized for APS installation over the next 10 years.

The APS system generates beeping cues continuously to help the blind pedestrian locate the pushbutton. After the APS pushbutton was activated, the APS system will announce an audio message ‘Walk sign is ON’ when the pedestrian signal head is in the ‘WALK’ phase. It will then vocally count down the remaining time (in seconds) to cross the intersection during the ‘DON’T WALK’ phase. There are several common problems with traditional APS including the volume of announced message, not knowing which street has the ‘WALK’ signal on and confusion of alerting tones with traffic noises (Bentzen et al. 2000). Respondents to a survey (NCHRP 117) indicated that “direction taking at the starting position” and “keeping direction while walking in the crosswalk” were a problem, even with an APS. The acoustic signals from the APS systems are often confusing (Tauchi et al. 1998). The pushbutton location of current APS system is difficult to locate (Barlow et al., 2005). The modern roundabout intersection design presented more challenges for pedestrian with vision impairment in maintaining alignment, determining walking direction, and selecting gaps between vehicles (Long, 2007).

1.3.3 Navigation Technology and Location Based Services (LBS) for the Blind

Development of travelling aids based on global positioning has a long history. The first satellite navigation system, used by US Navy, was first tested in 1960. The use of GPS to guide blind, visual impaired or elderly people has been researched extensively (Garaj, 2001; Gill, 1997; Helal et al., 2001). Tjan et al. (2005) designed and implemented a Digital Sign System (DSS) based on low-cost passive retro-reflective tags printed with specially designed patterns. Blind or visually impaired pedestrians can use a handheld camera and machine-vision system to identify and navigate through unfamiliar indoor environment. Bae et al. (2009) evaluated a location tracking system using IEEE 802.11b Wi-Fi system to analyze the requirements of location based services in an indoor environment.

Although there are many aids (such as electronic, Braille map, etc.) to assist wayfinding, blind people often tend to use their cognitive map and spatial knowledge as primary guidance (Golledge & Gärling, 2004). People with low vision, when taught to pay more attention to auditory cues for determining when to cross intersection, often increase their street crossing ability. Street crossing is an important yet challenging task for many vision impaired individuals. However, training and technology can complement each other to improve blind pedestrians’ mobility, safety and accessibility at intersections. Many environmental cues are available, yet reliable, to support their decision making on various components of the street crossing task. It is important to understand the challenges, identify what information is needed for the blind pedestrian and what is available. Decision making using auditory feedback for the visually impaired usually requires longer time than that based on visual information received by sighted people (Long, 2007).

Due to slightly difference in the length of legs, human tend to veer without guideline (visual feedback) to walk along or target to walk toward. Blind people tend to veer when crossing quiet streets (Guth, 2007) and the spatial characteristics of the veering tendency differ between and within individuals (Guth & LaDuke, 1995). Kallie et al. (2007) conducted a study of the veering of blind and blindfolded sighted participants and a study of the same participants' thresholds for detecting the curvature of paths they were guided along. For intersection crossing, pedestrians typically need to understand the relevance for crossing safety and then select strategy to cross with lower risk. Giudice and Legge (2008) review various technologies developed for blind navigation. Currently, there is no single technology alone can offer solution for blind navigation for both indoor and outdoor navigation and guidance. In addition, it is critical to gain more insight from perception and clear understanding of their cognitive demand associated interpreting the information received from blind people's sensory system. Furthermore, blind people's transportation choices are mostly limited to walk, taxi and transit. In order to improve their accessibility and level of confidence in using the system, it is important to remove not only the physical barrier but also mental barriers that potentially impede their mobility.

City of Stockholm together with other stakeholders started an e-Adept project (2009) to make the city most accessible in the world by 2010. A digital pedestrian network, consisting of pedestrian paths, sidewalks, signs, stairs and many detail features, was developed based on open platform to integrate pedestrian navigation technology in assisting visually impaired or disabled. The pedestrian navigation system includes digital map, GPS receiver, mobile phone, and inertia navigation module. The digital network integrates municipal data such as road geometry, facility, and traffic information, to provide personal navigation services to elderly and people with disability in both outdoor and indoor environment (Jonsson et al., 2007; Dawidson, 2009; Johnni, 2009).

The NOPPA (2009) project conducted by VTT Technical Research Centre of Finland is designed to provide public transport passenger information and pedestrian guidance through speech interface. The NOPPA system uses GPS, mobile phone and information server to provide door-to-door guidance for visually impaired or sighted users taking public transportation (Virtanen & Koshinen, 2004). Barbeau et al. (2010) developed a Travel Assistance Device (TAD) using a GPS-enabled Smartphone to assist transit riders, especially for those who are cognitively disabled.

The ASK-IT project (2009), partly funded by the European Commission under the 6th Framework Programme, uses personal profiling and web services to provide user with navigation, transportation and accessibility information. The ASK-IT architecture is designed to allow mobility impaired people to live more independently. Users will have access to relevant and real-time information through mobile device primarily for travelling but also for home, work and leisure services. The emphasis is on a seamless service provision and a device that is intelligent enough to address the personal needs and preferences of the user (Bekiaris et al., 2007; Edwards et al., 2007).

In France, the Mobiville project (Coldefy, 2009) aims to develop a real-time multimodal transportation information service and provide location based navigation service for pedestrian using GPS mobile phone. GeoVector developed an application called World SurferTM to allow compass-enabled GPS Smartphone users to point their phone in a particular direction and search for information about point of interest. This service allows travelers to utilize their Smartphone device as a personal travel guide (Markoff and Fackle, 2006).

1.3.4 Users Interface for the Blind

The touch screen interface on a smart phone is not accessible for the blind people. Commercial text-to-speech (TTS) applications developed to read message on computer or cell phone screen to users have been used to translate information for the blind and visually impaired. Mr. T.V. Raman, a blind scientist and engineer at Google is developing a touch-screen phone for the blind (Helft, 2009). He suggested that such a device, in addition for the blind people, could provide eyes-free access for drivers.

Navigation guidance using verbal description and instructions has been studied as an efficient way for people with visual impairment (Bentzen et al, 1999; Crandall et al., 1999; Gaunet & Briffault, 2005; Giudice & Tietz, 2008; Giudice et al., 2007, 2010). Marin-Lamellet and Aymond (2008) conducted an experiment in an underground transport station with two groups of visually impaired pedestrian using verbal guidance combined with tactile surface system and verbal guidance system alone. They reported that the group using combined guidance system completes the trip in shorter time and has less difficulty.

Li (2006) investigated the user information required at individual level for location based service focusing on the interaction among individuals, environment, and mobile devices. In wayfinding, user preferences on route and map information vary depending on spatial layout, level of confidence, and surrounding situations. Golledge et al. (2004) conducted a survey of preferences of visually impaired people (30 persons) for a possible personal navigation device. They found that the most preferred output device was a collar or shoulder mounted speech device and most preferred directional interface was a handheld device that users can scan the environment to get directional information.

Davies and Burns (2008) reviewed recent advances in Cognitive Work Analysis (CWA) and Ecological Interface Design (EID) for visual and auditory displays. Davies et al. (2006) developed a prototype design of an auditory interface based on the Work Domain Analysis (WDA) of EID for people who are visually impaired. Usability test of the prototype was performed to evaluate the effectiveness of object identification, direction of obstacle, and determining relative size and distance of an object (Davies et al., 2007). Sanderson et al. (2000) proposed additional hierarchy layer to extend EID for auditory design.

2. USER NEED ANALYSIS

The user need analysis involved conducting a small set of interviews with visually impaired and blind individuals. The purpose of these interviews was to gain a high level understanding of the user needs and potential user interface issues with navigating and orienting. Interviews allowed the design team to begin designing the mobile APS to meet the needs of visually impaired users, while future efforts will include actual usability testing.

2.1 Participants

Blind and low-vision participants were selected from age cohorts that are likely to adopt and use mobile APS technology. Ten individuals (5 female) between the ages of 59 and 19 were interviewed (M = 37.6 years, SD = 15.3). The five youngest participants reported being blind or having low vision conditions since birth. The five oldest participants reported becoming blind or having low vision conditions at least 6 years previous. No participants had walking-mobility issues. A summary of all ten participant's age, sex, and vision information are presented in Table 2-1.

Table 2-1 Vision information for each participant, ordered by age

Age	Category	Affected	Condition
19	Blind	Since birth	Bilateral Retinoblastoma, legally blind in right eye
20	Low-Vision	Since birth	20/400 in right eye, just see light/dark
21	Blind	Since birth	Dysautonomia / POTS (circulatory), "counting fingers" in left eye, 20/200 in right eye
29	Blind	Since birth	
30	Blind	Since birth	
46	Blind	10 years	Cone dystrophy, "allergic reaction" to chemotherapy
49	Blind	30 years	MACD, 20/600 in left eye; also have hearing aids in both ears (32 years)
51	Blind	11 years	Degenerative Azores (virus in eyes), 20/400 in right eye, 30% vision word by word
52	Low-Vision	6 years	Peripheral & night blind
59	Low-Vision	41 years (right) 7 years (left)	"Can see a little" in right eye

Three participants were classified as “Low Vision” while the other seven were classified as “Blind”. This was based on criteria used in the U.S. to determine eligibility for certain disability benefits from the Federal Government and also restrictions. These criteria were as follows:

> **Blind** (or Legally Blind): Visual acuity (<u>with best correction</u> in the better eye) worse than or equal to 20/200 or a visual field extent of <20° in diameter, and use of equipment primarily in the “Blind” category (e.g., talking technology, Braille devices, readers).
>
> **Low vision**: Having 20/70 or worse vision (with best correction in the better eye) or any limitation to the visual field, and use of equipment in either the “Blind” or “Low-vision” categories (e.g., magnifiers, monocular, closed circuit TV).

2.1.1 Mobility

As a general gauge of the ability of this sample to orient and navigate to their destinations, participants were asked to rate their proficiency at general travel skills using a 5-point scale (adapted from Golledge, Marston, Loomis, & Klatzky, 2004). The scaling procedure was explained and discussed with each participant before the participant answered any questions. The scale and results are presented in Table 2-2, in summary:

- All participants rated themselves as average, above average or well above average at “independent travel”, although their mean ratings for “general sense of direction” and “new environments” were just average.
  - These findings suggest that although there was a large amount of variability in their self-ratings in general and in new environments, all participants thought they were of at least average abilities in traveling independently.
- Participants mean rating for crossing both signalized and unsignalized intersections was above average.

Table 2-2 Participants’ self-ratings of mobility, rank ordered by mean rating

Mobility Task	Mean Rating	Well below average (1)	Below average (2)	Average (3)	Above average (4)	Well above average (5)
Independent travel	3.9	0	0	3	5	2
Signalized street crossings	3.9	0	1	1	6	2
Unsignalized (or stop sign) street crossings	3.8	0	1	1	6	1
New environment	3.1	1	0	6	3	0
General sense of direction	2.9	1	3	3	2	1

2.1.2 Potential Individual Differences

During the interviews it was brought to the researcher's attention that there are two "philosophies" in instructing blind and low vision individuals in orientation and mobility. Training by the Vision Loss Resources (VLR) center (1936 Lyndale Avenue South, Minneapolis, MN 55403), which constituted the training for 9 of the 10 participants, emphasizes the use of any information that is available to the pedestrian; specifically, an individual who is still losing their sight is instructed to use their declining vision whenever possible. On the contrary, training by the National Federation of the Blind emphasizes having the pedestrian use any non-visual information available only, to the extent that training involves wearing blindfolds even if the individual still has visual capabilities available. By the time this distinction was realized, there was not enough time to recruit equal samples from both groups and therefore differences between the two samples were not specifically identified in these results.

This is mentioned for two reasons:

- It should be noted that the opinions expressed in these interviews may closer-reflect individuals trained by VLR, where individuals are taught to actively seek assistance from other pedestrians and information in the environment.
- Future samples used to test these pedestrian assistive systems should take this distinction into account and sample from both populations.

2.2 Procedures

All the interviews were conducted in March, 2010. Eight of these were conducted at VLR, one was conducted in an office (ME L103) on the University of Minnesota campus, and one was conducted at a restaurant in downtown Minneapolis. The experimenter began each interview by reading the consent form (Appendix A) and answering any questions that the participant had, before having them sign the consent form. In one instance, the participant read a Braille version of the consent form. Participants were then given a large-print or Braille copy of the consent form to keep for their records.

Participants were asked a series of questions about their vision, their experiences navigating and orienting, and related technologies (Appendix B). This interview lasted approximately one hour. Participants then signed a participant reimbursement form and were compensated before being released.

2.3 Dependent Variables

The objective of this interview was to identify user needs and potential user interface issues for blind and visually impaired pedestrians while navigating and orienting. To understand these needs, participants were asked questions relating to six categories of dependent variables (measures), as also outlined in the interview questions (Appendix B):

A. **Vision Background –** Background information on visual acuity, visual ability, and identification of devices participants may use to assist their vision on a daily basis. This data is presented in section 3.1.

B. **Navigation & mobility –** Description of participants' proficiency in walking/navigating on their own, including what types of information they receive from the environment and any technology they use to assist their vision. These questions covered:
   a. Methods of assistance used, e.g., cane, dog.
   b. What types of information are used while orienting in general and when traveling to a new location (categorical responses, adapted from Golledge et al., 2004).

C. **Questions pertaining to intersection crossing –** The frequency, difficulty, and comfort of crossing intersections. These questions were also intended to help participants remember their past experiences of crossing intersections. These questions covered:
   a. Describing their trypical experience crossing an intersection, including the steps they take approaching the intersection, waiting to cross, and making a crossing decision.
   b. Rating the importance of different information they may use while crossing an intersection (scaled responses, adapted from Golledge et al., 2004).
   c. Questions about their experience crossing roundabout intersections, if applicable.

D. **Technology self-ratings –** Participants' likes, dislikes, and suggested improvements to their interactions with technology that is currently available. These questions covered:
   a. Their current mobile phone.
   b. Mobile navigation assistants / GPS.
   c. Current APS.

E. **Proposed mobile APS description –**Participants were read a description of the proposed mobile APS. They were then asked to report what they believe could make it better and their likes and dislikes about specific output modalities. This included:
   a. Acceptance of different warning types, e.g., audio, vibration (scaled responses, adapted from Golledge et al., 2004).
   b. Expectations for audio and tactile warnings.

F. **Demographic information –** Background information such as age, education, and income. This data is presented in section 3.1.

3. USER SURVEY RESULTS

For all reported measures, frequencies of responses across participants (count, *N* = 10) are presented. For scaled questions, the mean (*M*) of responses across all participants (*N* = 10) are presented, along with a table showing the distribution of responses. Implications for the design of mobile APS are explored for each category of question based on these trends in the data.

3.1 Navigation and Mobility

3.1.1 Methods of Assistance

All ten participants had been trained in using a cane. Eight participants reported the cane as their preferred method of assistance when navigating in familiar areas. These participants had been using canes for blind orienting and mobility for an average of 6.9 years (*range* = 0.5 to 20). Of the two participants who did not report using their cane regularly (one carried his only to let others know that he was low-vision, the other used a guide dog).

Participants were asked what methods of assistance (they could report more than one) they used while traveling in familiar and unfamiliar areas (Table 3-1). In summary:

- Most participants reported using the cane while traveling in familiar areas.
- There was more variability in responses when traveling to unfamiliar areas, although a majority reported using a combination of their cane and another method of identifying the new location.

Table 3-1 Methods of assistance reported by participants when traveling in familiar and unfamiliar areas, rank ordered by frequency of response

Traveling in Familiar Areas	Traveling in Unfamiliar Areas
8 Cane	6 Cane
1 Asking others	4 Asking others
1 Sighted-guide	2 Sighted-guide
1 Using low vision	2 Metro Transit
1 Guide dog	2 GPS (on phone or separate device)
1 No outside assistance	2 Google maps, look up online
	1 Guide dog

3.1.2 Types of Information Used while Orienting

Participants were asked what their preferred methods to assist with pre-trip planning were. Seven participants reported contacting Metro Transit (6 using the phone hotline, 1 using the website), three reported calling the destination, two used Google maps (street view, in particular), and one used a personal GPS device in virtual mode, and only one reported memorizing the steps to take.

Participants were also asked: "Imagine you are traveling from your residency to a physician's office in an unfamiliar part of town. Please describe the types of information you would need to make this trip successfully." Responses were grouped into six categories of information type, based on a measure from Golledge et al. (2004). Table 3-2 presents the number of participants mentioning an item in that category (multiple responses within a single category by a participant were combined). In summary:

- All participants reported using transit information, including calling the Metro Transit helpline for directions and assistance using bus routes.
  - Nine of these participants reported that the helpline and bus drivers were some of the easier information to locate/identify from their past experience, including informing them about bus schedules, stop and transfer locations, and directions from stops to their locations.
- Related to this, eight participants reported using street and destination information types to make their trip successfully.
  - Participants found it easier to identify locations by where they were located on the block as opposed to using more visual means (e.g., address, signs).
- Only six participants reported using route and landmark information types, likely because some (two participants) thought it was hard to remember and use cardinal directions (North/South/East/West) while traveling.

Table 3-2 Information types used when asked to travel to an unfamiliar location, rank ordered by frequency of response

Frequency (out of 10)	Category	Summary of Responses
10	Transit	Call Metro Transit for directions and information about bus routes (stops, direction of travel, transfers, which door to exit from). Call Metro Mobility for direct ride.
9	Street	Direction from bus stop. Knowing direction of travel on avenues vs. streets. Where on block or which corner the bus stop is located.
8	Destination	Address. Distance down a block, number of buildings/dips to pass. Corner that bus stop is on
6	Landmarks	Destination building appearance & location of entrance. Physical cues by entrance, e.g., potted plants, tables.
6	Route	North/South (cardinal) or general direction from bus stop Where to turn.
3	Building	Where in building, what floor- directions from entrance. Location of elevators/stairs, unique interior features.

3.1.3 Implications for Mobile APS Design

- Most blind individuals use a cane as their primary source of information for orientation and navigating. A mobile APS should not interfere with their ability to use a cane use; the design should consider hands-free implementation or the interface could be integrated into the cane itself.
- A mobile APS should also not interfere with the users' ability to interact with others (e.g., blocking their ability to hear or talk with others).
- A mobile APS could gain acceptance by users if it provides street and cardinal direction information.
- Because of the high frequency of public transit use, a mobile APS could gain acceptance by users if it could identify the relative direction and distance of bus stops near an intersection.

3.2 Questions Pertaining to Intersection Crossing

3.2.1 Intersection Crossing Process

Participants were told to "Please imagine that you are half a block from a signalized intersection that you must cross." They were then asked to step-by-step their process of safely approaching and crossing (directly across) that intersection. Participant responses were compiled and a single list of steps presenting the frequency which each step was mentioned (Table 3-3).

When approaching an intersection, four participants specifically mentioned listening for the general noise of the intersection (traffic, pedestrians) to guide them towards the corner. Upon their approach, nine out of ten participants mentioned seeking the ramp-like “dip” (i.e., slope, curve cut) and using this to line themselves up to cross. Five participants specifically mentioned waiting on the side of the dip, as this was a method to align themselves with the crosswalk.

Once they had reached a safe location, all ten participants reported using the sound of parallel traffic as their main information for when it would be safe to cross. This included listening for the engines to idol next to them, noting their direction of movement, and noting the “surge” of engine noise when they began to move. Four participants sought crosswalk buttons in the hopes of increasing the amount of time given for the crossing signal.

Specifically relating to their decision of when to cross, participants reported waiting a car length or short period of time after the parallel traffic surge to make sure traffic was in fact driving through the intersection. Related to this, four participants reported waiting at least one cycle to identify the traffic pattern, especially for the presence of right and left turn lanes which are difficult to detect.

Table 3-3 Steps involved in approaching and crossing an intersection, rank ordered by frequency of response

Frequency (out of 10)	Step-by-Step Process of Approaching and Crossing an Intersection
Approaching the intersection	
9	Feel for dip/slope of curve cut (cane, foot)- use to line up with the intersection
4	Listen for noise of intersection (cars, pedestrians), tells me I am approaching one
2	Differences between city and other (e.g., wind around buildings)
Waiting to cross	
10	Listen for parallel traffic (idol-ing, direction of movement, surge)
4	Seek button or light poles (infrastructure APS serves as beacon)
2	Listen for perpendicular traffic (idol-ing, direction of movement)
2	Use low-vision to line up with the intersection
Making a crossing decision	
5	Cross after parallel traffic begins moving (1 car, 5 seconds)
4	Wait to listen for pattern/length of cycle, or for presence of right/left turn lanes
2	Cross when traffic starts moving, close to surge beginning
2	If I don't hear traffic, safe to cross
2	Use low vision to know when safe to enter crosswalk

3.2.2 Importance of Intersection Information

Participants were asked to rate the importance of different information types they may use while crossing an intersection (adapted from Golledge et al., 2004). The scaling procedure was explained and discussed with each participant before the participant answered any questions. The scale and results are presented in Table 3-4. In summary:

- Knowing when it was safe to cross was rated as having the highest importance.
  - All participants reported this as important or very important.
- Information related to pedestrian alignment at the intersection and forming an understanding of accurate crossing direction (traffic alignment, crosswalk direction, crosswalk alignment, and type of intersection) were all rated as important.
  - All participants reported these neutral, important, or very important.
- Alignment with a remembered approach-path to the intersection and knowing that they were approaching the curb on the opposite side of the road were rated as important (on average), but less so than the previously mentioned information types.
- Participants had a neutral opinion about finding where the signal-button was located.
  - Most participants offered that this was because there is a lack of consistency in button location between intersections.

Table 3-4 Participants' self-ratings of intersection information importance, rank ordered by mean rating

Information Type	Mean Rating	Very un-important (1)	Un-important (2)	Neutral (3)	Important (4)	Very important (5)
Knowing when it is safe to cross a signalized intersection	4.7	0	0	0	3	7
Knowing your alignment relative to traffic	4.3	0	0	2	3	5
Knowing which direction to walk while crossing an intersection	4.2	0	0	3	2	5
Knowing your alignment relative to the crosswalk	4.2	0	0	2	4	4
Knowing type of intersection you are waiting at	4.1	0	0	2	5	3
Remembering your alignment relative to your walking approach to the intersection after searching for the apron/entrance to the crosswalk	3.8	0	2	2	2	4
Remembering your alignment relative to your walking approach to the intersection after searching for the crossing signal button	3.8	0	1	3	2	3
Knowing that you are approaching the curb on the opposite side of the road you are crossing	3.6	1	0	3	4	2
Finding the location of the crossing signal button	3.0	1	1	5	3	0

3.2.3 Roundabout Intersection Crossing

Only two out of the ten participants reported crossing a roundabout intersection. Because of this, there were not enough data to score the scaled responses. These are the open-ended comments from participants with experience crossing a roundabout as a pedestrian (note that all comments are paraphrased):

- An instructor was watching me the entire time, but I hated it. The entire experience scared the hell out of me. There were no landmarks and the traffic pattern was hard to understand. It was especially difficult to determine alignment, but also to know when to begin crossing. I think this could be accomplished with practice, though.
- You can't screw up crossing because the sidewalk guides you, there's only one way across. There was a tactile surface to stand on in the median area, which was helpful but there was no dip to help me line up. There might be a way to cross by listening for the pattern of traffic coming from the last light cycle of a neighboring intersection.

It is interesting to note that both of these participants who had experience felt that there *could* be a way for a pedestrian to safely cross a roundabout intersection, although the means to this end were different (practice vs. timing of traffic groups).

3.2.4 Implications for Mobile APS Design

- A mobile APS should enhance and not hinder pedestrian's ability to gather information that they normally use while crossing.
    - For example, pedestrians use the sound of parallel traffic to determine their alignment and the initial "surge" as a signal that it *may* be safe to begin crossing; a new system should not block their hearing so they can still use this information.
- A mobile APS would likely be used to confirm information they are already gathering, rather than using the mobile APS alone.
    - This would likely result in a more expedient crossing decision, whereas they currently may have to wait (at least) one full intersection cycle.
    - For example, when they hear a traffic surge they may use the information from the mobile APS to confirm that it is safe to cross. This would be useful because pedestrians sometimes are uncertain if there is a right or left turn lane, which are hard to distinguish from auditory information alone.
    - Similarly, although blind and low vision pedestrians prioritize their tactile alignment with the dip and auditory alignment with traffic, they could confirm this alignment and increase their confidence using directional information from an mobile APS.
- Pedestrians would be open to seeking crosswalk buttons if location was standardized or easier to find. Therefore, incorporating this functionality into a mobile APS would eliminate the need for seeking it out and increase the frequency of use.

3.3 Technology Self-Ratings

3.3.1 Experiences with Mobile Phones

All participants had a mobile phone, representing the following mobile networks:

4 Verizon (two Samsung, one HTC XV6800, and one LG enV3)
3 T-Mobile (two Samsung, one Nokia N-Gage)
1 Boost (Motorola i776)
1 AT&T (Nokia 9600), and 1 Sprint (LG)

Participants were asked what they used their phone for; in summary:

- All ten participants reported that they wished to use their phone for other features but they were limited by their interaction with the buttons and screen (for those who still had low-vision capabilities).
- Seven participants used and were generally satisfied with native (built-in) or installed text-to-speech capabilities that read off phone menu options, numbers as they are dialed, or contact names as calls were received.
  - One participant who did not have phones with text-to-speech capabilities specifically wished he could have "a phone that talks to me", and two did not like that the small text size made the screen difficult to read, even with a magnifier.
- Six participants used their phone only for calls and checking voicemail.
- Three participants reported texting occasionally.
- Only one phone would be considered a "Smartphone": an HTC XV6800 (on Verizon).
  - In terms of technology usage, this user was advanced: he had installed Note Taker and Mobile Speak software (a screen reader for mobile phones).
  - He also reported using many of the Windows Mobile applications, such as calendar, tasks, contacts, pocket Office (Word, Excel), internet, and infrequently voice commands.

Physical key layout and identification was an important factor specifically mentioned by two participants. One participant continued to use an older phone because of its unique design: this phone is meant for gaming, so the 5 and 7 keys are raised like game-pad buttons and it has a directional pad that is separated from the number keys. She also liked using it due to the distinct feel of each number key and the spread-out location of the call and end buttons. Similarly, another participant had added paint to two of the keys on her phone (Samsung flip phone on T-Mobile) so that she could identify the keys more easily.

3.3.2 Experiences with Mobile Navigation Assistants / GPS

Four participants had experience with a mobile navigation assistant or GPS systems for pedestrian use; each of their experiences are described separately below. Three participants who did not have a navigation assistant expressed interest in purchasing one (either as part of a mobile phone, or a separate unit, such as the examples in Appendix C) but expressed concern with the high price of many current options.

One participant currently used native (built-in) GPS capabilities on her mobile phone (LG enV3 on Verizon). With this phone, the participant used Verizon's subscription navigation software application, VZ Navigator, to obtain spoken turn-by-turn directions.

- She liked that it can determine directions on-the-fly from spoken commands.
- She did not like that she had to see the screen to confirm if it understood her correctly (potentially due to poor microphone sensitivity) and "wished it talked more."

One participant used Braille Note GPS (by Humanware, see Appendix C). This system uses a keyboard and outputs both auditory and on a tactile Braille keypad and requires wearing a Bluetooth GPS receiver on the user's collar.

- The participant liked the greater sense of independence and freedom from using this item, which was enhanced by having access to information such as a readout of the storefronts she is passing (a feature also used while riding a bus or in a car).
- However she also noted that one has to already be good with travel already because the system is not easy to use while traveling.

One participant had experience using a Garmin handheld unit, primarily for geocaching and not for mobility and orientation (as related to a mobile APS).

- He reported that he enjoyed the fast refresh rate of the system, especially in comparison to phone systems he had used.
- He did not like the small screen because he needed a magnifying glass to see the information adequately.

One participants had used a vehicle-based Garmin system (both in a car and while holding the system during a bus ride).

- She liked when the system announced street names as she passed them.
- She did not like how it interfered with the radio (in the car).

3.3.3 Experiences with APS

All ten participants had experience crossing an intersection with an infrastructure-based APS. Participants were asked to describe what they liked and disliked about using these signals. Participant responses were compiled and a single list of likes and dislikes was produced (Table 3-5). As expected, this list reflects features that are currently available in APS, specifically:

- Countdown of how much time is left to cross.
- Notification that it is safe to cross.
- Auditory information such as street names and sounds that served as beacons to locate the location of push buttons.

What is interesting are the dislikes of these systems because this informs us how blind and low-vision pedestrians' experience could be improved at intersections with or without an APS. In summary:

- Three participants responded that the typical feedback of signalized intersection buttons was poor, in relation to their primary task of crossing the intersection and knowing when it's safe to cross.
- Although only two participants specifically mentioned that finding the signal button was difficult, this was mentioned by most participants at some point throughout each interview.
- Two participants also found the noises made by APS to be an annoyance.
    - This seemed to be due to the perceived annoyance of other (sighted) individuals as compared to a personal distaste for the sounds.

Table 3-5 Likes and dislikes of deployed infrastructure APS, rank ordered by frequency of response

Frequency (out of 10)	Features of Currently-Deployed Infrastructure APS
Likes	
4	Gave a countdown of how much time is left to cross.
3	Told me when it was safe to walk.
3	Gave me information about the street name(s).
2	Provided a sound that oriented me to the other side (a beacon).
Dislikes	
3	Poor feedback of pressing the button. E.g., If you press the button at the end of a surge, it may not notify you of signal changes because it has gone into a standby-mode and you wouldn't know that it is doing this.
2	Difficult to find button location – "button poles" aren't in standard locations.
2	Noises are an annoyance to self and/or general public.

Participants were then asked, "If you could design a device that provided you with assistance approaching and crossing a signalized intersection, how would it work?" Participants then described features and information they would desire from an APS, which are summarized in Table 3-6.

Seven participants reported that they wanted notification of when it was safe to cross. Related to this, participants mentioned having difficulty detecting vehicles making right and left turns. This makes sense because these maneuvers are not part of the perpendicular/parallel traffic streams that they depend upon to make their crossing decision. Half of the participants also said they would like a countdown-type notification of how much time is left before the signal changes.

Half of the participants also wanted information that would direct them towards the opposite side of the intersection safely, including helping them maintain their position within the crosswalk. Although some current APS serve this function by playing a sound which can be used as a beacon, some limitations of this method were mentioned. One limitation is that participants reported it to be confusing when this sound is played at all four corners and recommended that it be specific to their direction-of-travel. To help alleviate confusion and provide an additional cue, one participant recommended differentiating between the sounds produced by streets versus avenues.

Recommendations were made by half the participants to facilitate activation of the crosswalk signal. This suggests that they would like to signal the crosswalk at most intersections but it is likely that the difficulty in finding the button keeps them from doing so currently.

Table 3-6 Desired information and features from APS, rank ordered by frequency of response

Frequency (out of 10)	Features of "A device that provided you with assistance approaching and crossing a signalized intersection"
7	Informs when it is safe to cross. Notify of vehicles in right/left turn lanes. Notify of vehicles behind pedestrian Notify of emergency vehicles approaching (changes to normal signal pattern)
5	Gives a countdown of how much time is left to cross. "Usefulness [of a countdown] depends on the size of the intersection."
5	Helps orient pedestrian towards the other side of the road "All four corners shouldn't sound the same… it's dangerous and confusing – I won't use a signal like that" "Separate voices for North/South direction from East/West direction so I can orient myself after I fall down."
5	Signal activation by non-traditional "button", e.g.: Using phone Remote button on a separate device (attached to cane) Motion sensor mounted at intersection Weight of person standing on curb dip (studded pad)
2	Gives information about street name(s)

3.3.4 *Implications for Mobile APS*

- Audio cues are most acceptable and expected by blind and low-vision pedestrians. They are familiar with text-to-speech functionality. New APS (including mobile APS) should take advantage of user-commands, usage conventions, and presentation styles that are currently available.
  - If audio is the primary interface mode, it should not require visual confirmation (e.g., as VZ navigator is reported to do).
  - In addition, limitations of audio interfaces that should be considered and accounted for, including:
    - Interference with the pedestrian listening to traffic information;
    - Volume in relation to hearing the information,
    - Volume in relation to annoying other people,
    - Ability to repeat and fast forward though information.
- If physical input into a device is needed, the buttons/means of entering this information should be clearly defined by tactile cues.
- Cost of purchasing a mobile APS device and/or software was an important consideration for most participants and would therefore have a large effect on device adoption. In addition, only one participant had a Smartphone already suggesting that a large percentage of blind and low vision individuals would require an upgrade in phone hardware to access a new mobile APS.

- A mobile APS has an opportunity to provide a number of information categories that are currently not available to pedestrians at many intersections. These include:
    - Infrastructure-based APS information, e.g., signal state, countdown of time remaining in the cycle.
    - Street names and presence of turn lanes.
    - The (cardinal) direction they are facing.
    - Location of infrastructure signal buttons and APS.
    - Nearby bus stops, storefronts, or landmarks.

3.4 Proposed System Description

3.4.1 Acceptance of Warning Types

Participants were asked to rate their acceptance of different warning types that could be part of a mobile APS (questions adapted from Golledge et al., 2004). The scaling procedure was explained and discussed with each participant before the participant answered any questions. One participant chose to not respond to these questions, so the mean results and frequencies are based on nine participants. The scale and results are presented in Table 3-7. In summary:

- There was an overall preference for presenting audio warnings over tactile warnings (vibrations), perhaps because this modality of warning is already familiar to these users.
    - Listening to warnings from the speaker of a cell phone, from speakers near the shoulder, or a single headphone received the highest mean acceptance ratings.
    - That said, the average rating for sensing vibrations from a phone in their pocket was also found to be acceptable.
- In general participants reported lower acceptance to warnings that interfered with the modalities which they normally received orientation and mobility information.
    - For example, there was a general dislike towards headphones worn over both ears or near the ears.
    - One participant even noted that wearing a stocking cap was already an issue in the winter and that covering either ear was unacceptable.
- They also reported it as less acceptable to hold a device in their hand
    - Three participants said they feared dropping a device while crossing in the middle of the intersection.
- Three participants also commented that cables were an issue to them and that wireless speakers would be a better solution for remote speakers.

Table 3-7 Participants' acceptance of warning types, rank ordered by mean rating.

Warning Type	Mean Rating	Very un-acceptable (1)	Un-acceptable (2)	Indifferent (3)	Acceptable (4)	Very acceptable (5)
Audio from cell phone speakers	4.3	1	0	0	2	6
Small clip-on shoulder or collar mounted speaker.	4.1	0	0	2	4	3
Single headphone worn over one ear	4.1	0	0	2	4	3
Sensing vibrations from a mobile phone in your pocket	3.7	0	2	1	4	2
Headphones worn near the ears (bone phone)	3.4	0	2	3	2	2
Sensing vibrations from a mobile phone held outward & aimed at the intersection to determine the correct direction of travel	3.3	1	2	1	3	2
Sensing vibrations from a mobile phone held in your hand	3.2	1	2	0	6	0
Stereo headphones worn over both ears	2.7	3	1	2	2	1

3.4.2 Expectations for Audio and Tactile Warnings

Participants were asked to imagine they were using a similar system to the one described (see section E of the survey, Appendix B) as they approached an intersection. One participant chose to not respond to these questions, so the frequencies are based on nine participants. Participants were first asked to describe the words they would expect the system to use to notify about each stage of this maneuver. Because there were general similarities in most responses, and we wanted to get a sense for what the whole sample of participants agreed would be a useful wording, Table 3-8 presents verbal responses that were *mentioned by two or more participants*.

The protocol originally had them report how the system would give tactile warnings (question 24, Appendix B), but this proved to be difficult for participants to understand and respond to. Instead, the stages were presented again and participants were asked to report whether they thought a vibrating (tactile) warning was appropriate at that time. For the tactile warnings, the raw frequency of participants who reported that they thought a vibrating warning was appropriate is reported in Table 3-8. In regards to tactile warnings, three participants reported that a combination of verbal and tactile warnings would also be appropriate. Three participants said they thought that tactile warnings would be confusing.

Table 3-8 Frequency of recommendations for verbal and tactile warnings during intersection approach and crossing stages

Stage	Verbal	Tactile
Approaching the intersection.	6 Approaching intersection of (road(s)) 2 …in (distance: feet, steps) 2 …(signalized/unsignalized)	
You have arrived at a location where it is safe to wait, but it is not safe to begin crossing.	5 Wait 2 Do not cross	
It is now safe to begin crossing.	5 Walk 2 Begin walking 2 Walk sign is on 2 Now safe	1
You begin crossing at a time when it is not safe to be in the crosswalk.	5 [warning sound] 2 Stop, do not walk/go	4
As you cross, the system determines you are walking outside of the crosswalk and it wants to direct you.	3 Veer (left/right) [to get back into crosswalk] 2 Go (left/right) [to get back into crosswalk] 2 (left/right) [to get back into crosswalk] 2 Too far (left/right) [*direction you have erred*]	7
You are approaching the opposite side of the street.	4 [say nothing–not necessary] 4 Approaching curve	

3.4.3 *Implications for Mobile APS Design*

- The combination of audio and tactile (vibration) warnings could produce a robust set of warnings. However if only one modality is available, an audio interface would be more informative than a tactile one.
- Interference with modalities they normally receive orientation and mobility information from should be avoided, e.g., placing headphones over the ears or having cables that could get snagged or interfere with their caning.

- Present additional information about the intersection that could assist pedestrians in crossing. For example:
    - The name of the streets that cross at the intersection.
    - The type of intersection (signalized/unsignalized).
    - Presence of turn lanes.
    - Warnings about geometry, especially at non-right-angle intersection angles
    - The number of lanes/distance across.
- When it was not safe to enter, pedestrians expected warnings to make a sound as opposed to a specific phrase. It would be appropriate to accompany this warning with a tactile alert.
- Vibrations were reported to be highly appropriate as a warning that they are walking outside the crosswalk boundaries.
    - It would be advisable to accompany this warning with an audio message of how to correct their path of travel (e.g., how to get back into crosswalk, “veer right”).

3.5 Recommendations for the Design of Mobile APS

Examination of the users’ informational needs while crossing intersections resulted in implications for the design of mobile APS for each set of questions. Because the purpose of this exercise was not to evaluate a specific interface, this section synthesizes the implications into general recommendations for the design of a mobile APS system. An attempt was made to rank recommendations in order of importance and criticality, based on how each recommendation could have an impact on pedestrian safety while crossing. This list of recommendations is followed by separate sections presenting summary points for each separate recommendation:

- Auditory and tactile information should not interfere with the pedestrian’s ability to use their cane or listen to traffic cues.
- Tactile cues are recommended as warnings when a pedestrian puts themselves in a dangerous situation, in tandem with auditory instructions.
- Output from the system should be primarily short auditory phrases.
- A method to repeat warnings / output is necessary.
- Present additional information about the intersection.
- Allow for automatic activation of walk signal when mobile APS is present at an intersection; or allow the user to activate the signal though the mobile APS interface.

3.5.1 Provide Intersection Information

Present additional information about the intersection.

- In addition to signal state and a countdown of time remaining in the walk cycle, other types of information that could be useful to present include:
    - Street names,
    - Presence of turn lanes,
    - The (cardinal) direction a pedestrian is facing,
    - Location of infrastructure signal buttons and APS,
    - Nearby landmarks (could include storefronts or bus stops at the corner).

- Users may find a mobile APS more useful and be more likely to use a new device if it presents information that they cannot currently get from their interaction (including from infrastructure-based APS).
- Future testing is recommended to identify what types of information would be most useful and how to optimize for information personalization.

3.5.2 Use Short Output Message

Output from the system should be primarily short auditory phrases.

- There was a preference and familiarity for audio system notifications and warnings while tactile warnings were largely thought to be ambiguous.
- The volume of output should be clearly audible to the user while simultaneously not constituting an annoyance to surrounding pedestrians.
- When it was not safe to enter, participants expected a warning sound as opposed to a specific phrase. Future testing is recommended to identify what sounds would be most appropriate during for this instance.

3.5.3 Avoid Interference

Auditory and tactile information should not interfere with a pedestrian's ability to use their cane or listen to traffic cues.

- Interfering with pedestrians' normal orienting methods interferes with their ability to verify the information from the mobile APS with their familiar information sources.
- Pedestrians are not likely to adopt new technology if they cannot verify the information or if they are forced to learn a separate / new method of orienting (e.g., using the mobile APS alone because headphones are covering both of their ears and they cannot hear traffic).

3.5.4 Use Tactile Cues for Warning

Tactile cues are recommended as warnings when a pedestrian puts themselves in a dangerous situation, in tandem with auditory instructions.

- Most participants thought vibrations would be appropriate to warn when they begin to walk outside the crosswalk boundaries. An audio message of how to correct their path of travel (e.g., how to get back into crosswalk, "veer right") should accompany this tactile warning.
- If audio is used as the primary mode of input, confirmation needs to be presented via an audio command (i.e., confirmation should not require visual/tactile confirmation).

3.5.5 User Override

Method to repeat or fast forward though output and warnings is necessary.

- Users may not always be able to prioritize the information presented by the system, e.g., if they need to attend to real-world information at the same time as a mobile APS notification is presented.
- Current devices allow users to speed up and slow down the presentation speed of auditory output, which allows blind and low-vision users to expediently find the information they are seeking; not including this functionality would negatively affect acceptance because it is expected.

3.5.6 Automatic Pedestrian Call

Allow for automatic activation of walk signal when mobile APS is present at an intersection; or allow the user to activate the signal though the mobile APS interface.

- Blind and low-vision pedestrians often expressed that they would like to signal the intersection of their presence in hopes of increasing the walk signal cycle time.
- Introducing the ability to interface with the infrastructure signal could eliminate the need for seeking out crosswalk buttons and could increase acceptance, frequency, and adoption of a mobile APS.

4. DEVELOPMENT OF SMARTPHONE APPLICATION

4.1 Introduction

One of the objectives is to develop a Smartphone application prototype that integrates available sensors on the phone to determine user location and orientation with respect to an intersection. The Smartphone application can wirelessly communicate with a traffic controller and receive near real-time signal timing and phasing updates. Corresponding signal phasing information can be sent to Smartphone according to the desired direction of crossing as confirmed by the user. After receiving confirmation from users, the system will then provide timing information of corresponding pedestrian phase to users. Warning signals such as '*Do not walk*' or '*Walk phase is on, x sec left*' will be broadcasted through Text-to-Speech (TTS) interface to support decision making at crossing. Automatic pedestrian call can also be sent to signal controller for registered blind, visually impaired, elderly or disabled pedestrians when they confirm the desired direction of crossing.

The prototype application was developed using an Android developer phone, HTC Magic, as shown in Figure 4-1. The application uses one external library backport-android because of unavailability of Bluetooth API on Android 1.6 which is currently installed on the phone. Other features in the phone used by the application include digital compass, GPS, Wi-Fi, and Text to Speech (TTS) interface.

Figure 4-1 HTC Magic Android Phone

4.2 Prototype Development

System design and development of the Mobile Accessible Pedestrian Signal (MAPS) is presented in this section. Performance of positioning accuracy of the GPS sensor and the heading accuracy of the digital compass are discussed as well.

4.2.1 System Design

The design architecture of the prototype system is illustrated in Figure 4-2. A roadside unit, a sniffer system, can be installed in the traffic signal controller cabinet to obtain signal timing and phasing information. The roadside data collection system, as shown in Figure 4-3, was developed by Professor Henry Liu and his research group in the department of civil engineering, University of Minnesota. The SMART-SIGNAL systems (Liu & Mar, ,2009; Liu et al., 2009) were deployed on over a dozen of actuated intersections in the Twin Cities area to collect traffic event data triggered by inductive loop detector, pedestrian calls and phasing changes. The roadside unit can eventually be eliminated when Advanced Traffic Controller (ATC) has the capability of broadcasting signal timing and phasing information wirelessly.

A digital map, containing intersection geometry, street name, number of lanes, and direction information is stored in a spatial database on the phone as navigational reference. The geospatial database is structured to identify each corner of an intersection and its neighboring nodes (intersection corners) in the vicinity. In order to handle the GPS positioning uncertainty, a Bluetooth device is included to help determining pedestrian location with respect to an intersection.

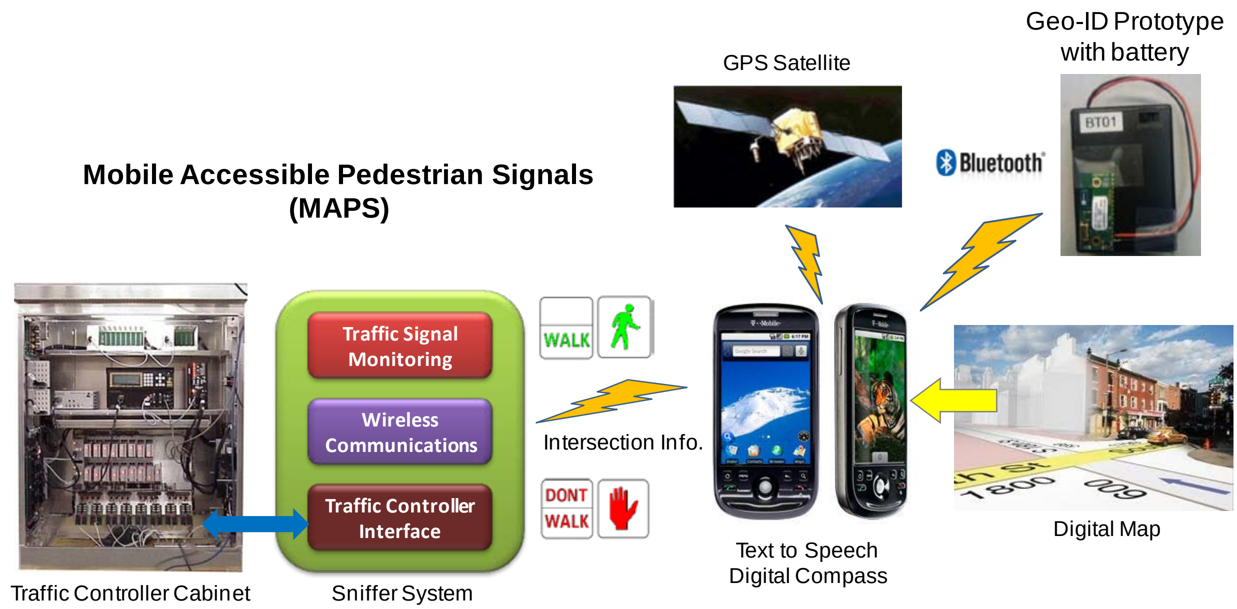

Figure 4-2 System Architecture of MAPS

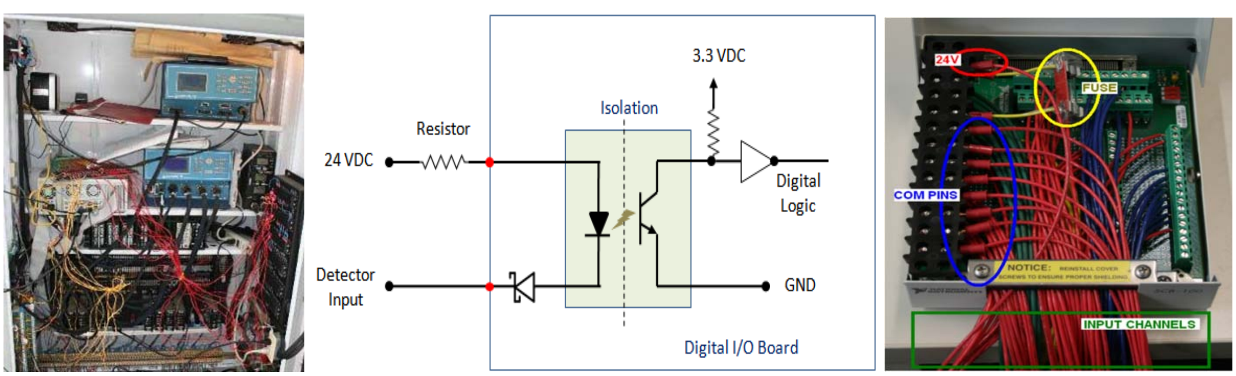

Figure 4-3 Controller Data Collection Interface of SMART-SIGNAL System

4.2.2   GPS

The GPS interface on the Google phone allows developers to use the positioning correction from Wi-Fi signal strength. Static position accuracy of the GPS receiver on the phone is within 10 meters at a relatively open space (for example, the Northrop mall area on UMN campus) as shown in Figure 4-4. However, the static positioning accuracy will vary depending on the constellation of the satellites at given time of the day. Figure 4-5 illustrates the positioning differences between the actual path (blue line) taken and the path recorded by the Smartphone GPS receiver (red line) while walking south two blocks from the civil engineering building to the intersection of Union and Washington Avenue then going eastward one block to Harvard street. The maximum position difference is about 40 meters. The maximum positioning error occurs in front of the Moos tower where fewer satellites are visible and multipath effect may also deteriorate the positioning solution.

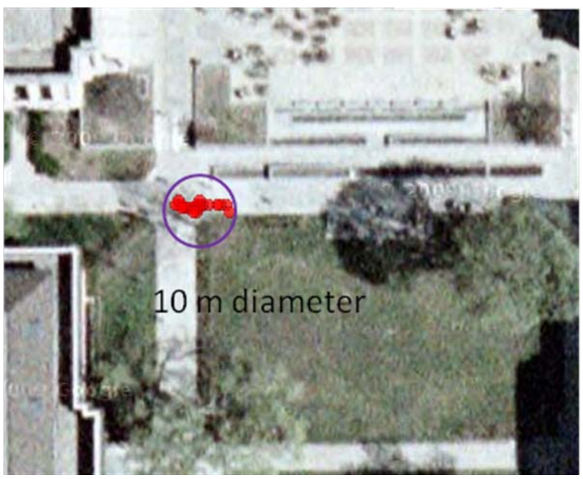

Figure 4-4 GPS Accuracy at a Fixed Location
(Background image from Google, Map Data © 2011 Google)

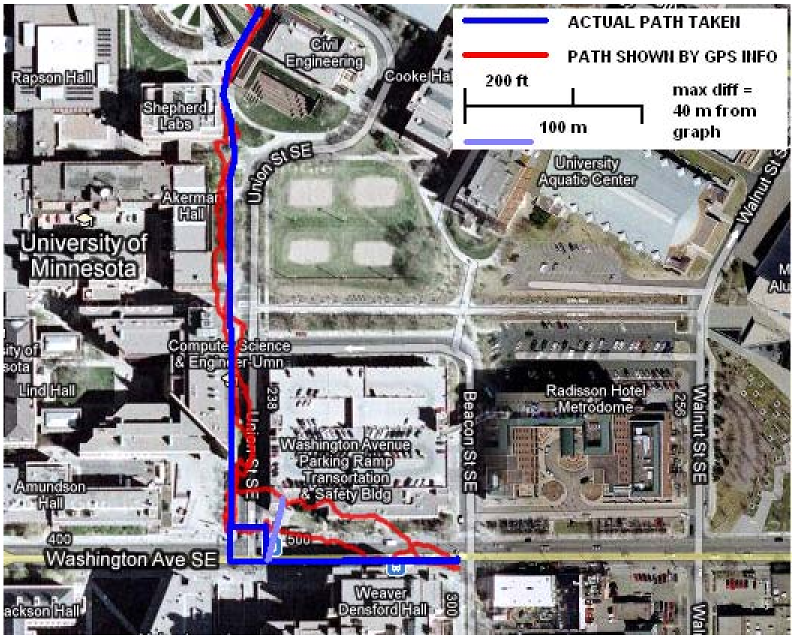

Figure 4-5 Comparison of Actual Path and Recorded GPS Data
(Background image from Google, Map Data © 2011 Google)

The Google Smartphone developer interface has the capability of generating positioning solution using Wi-Fi signal strength. Figure 4-6 compares the positioning accuracy of GPS and Wi-Fi Positioning System (WPS) provided by Skyhook (http://www.skyhookwireless.com/). Skyhook maintains a large global database of Wi-Fi access points and their precise locations. This data may then be used by a mobile electronic device to triangulate a user's position. Skyhook WPS claims their solution can provide 10 to 20 meters positioning accuracy. However, according to the result shown in Figure 4-6, the Wi-Fi based positioning is much worse than the GPS based solution at the test path described previously. A pseudo intersection at Northrop mall area on UMN campus is chosen for prototype testing. A walking path containing 7 sidewalk segments, as illustrated in Figure 4-7, is selected as reference for comparing GPS and Skyhook positioning solution. Positioning difference between the GPS and Skyhook data, shown in Figure 4-8, is within ±10 meters except at couple locations in segment 1 and 5 where the position difference in longitudinal direction (X) reaches up to 25 meters. The position difference in the latitudinal direction is within +5/-10 meters throughout the test period.

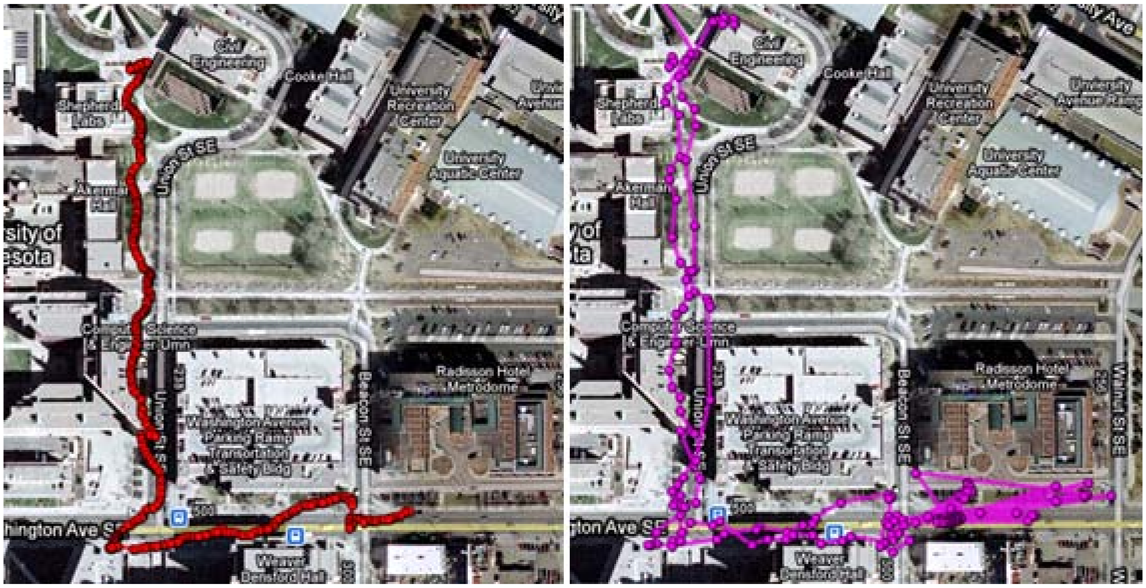

Figure 4-6 Comparison of GPS (Left) versus Skyhook (Right) WPS
(Background image from Google, Map Data © 2011 Google)

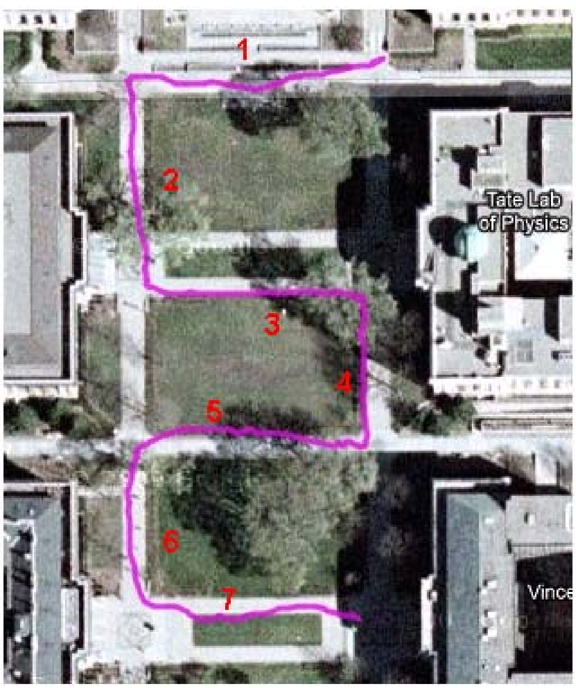

Figure 4-7 Pseudo Intersection at Northrop Mall on UMN Campus
(Background image from Google, Map Data © 2011 Google)

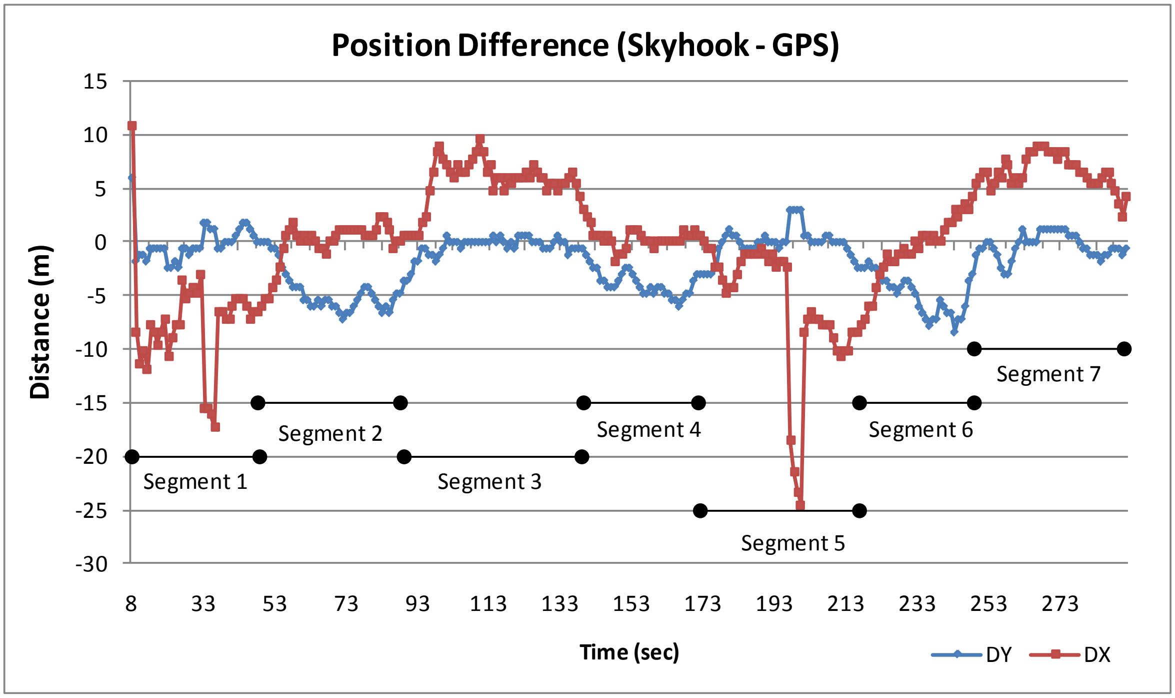

Figure 4-8 Position Comparison of GPS & Skyhook Data

4.2.3 Digital Compass

Three experiments were conducted to evaluate the performance of digital compass on the Android Smartphone. Results of experiment #1 were collected while walking sequentially along each segment (from segment 1 to 7) at the Northrop Mall as shown in Figure 4-7. In experiment #2, heading data were recorded from the Smartphone while walking around a rectangular block. In both experiment #1 and #2, the Smartphone was held in hand closely to the body while walking. Experiment #3 collected heading data by placing the phone at a stationary location pointing toward different direction in north, south, east and west, respectively.

Experiment #1

Heading measurement of each segment is plotted from Figure 4-9 to 4-15. Table 4-1 summarizes the mean and standard deviation of headings measured from the digital compass. Segment 2, 4, and 6 in north/south direction have smaller heading variances (5~10 degrees) as compared to the heading variances in the other segments in east/west direction (10~15 degrees).

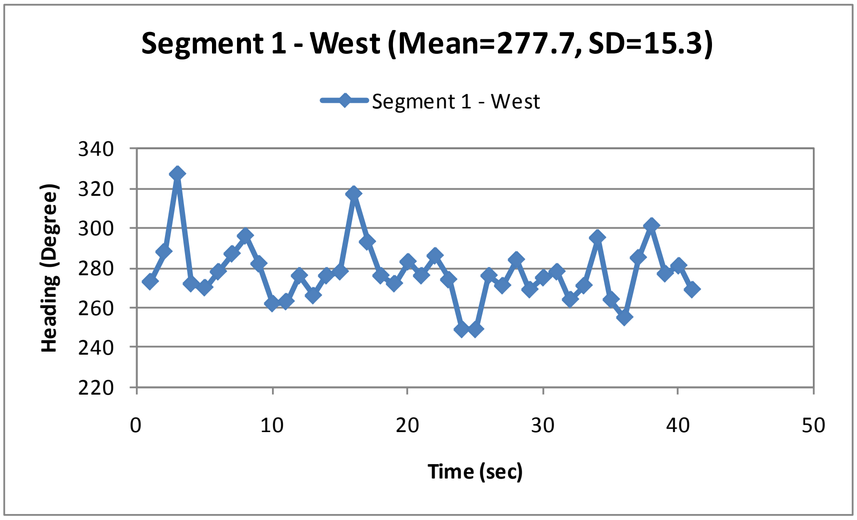

Figure 4-9 Heading Variation – Segment 1

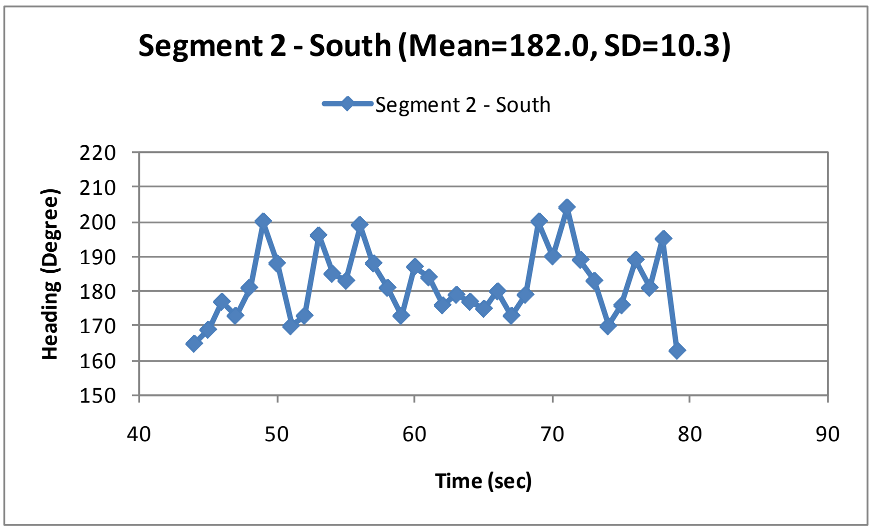

Figure 4-10 Heading Variation – Segment 2

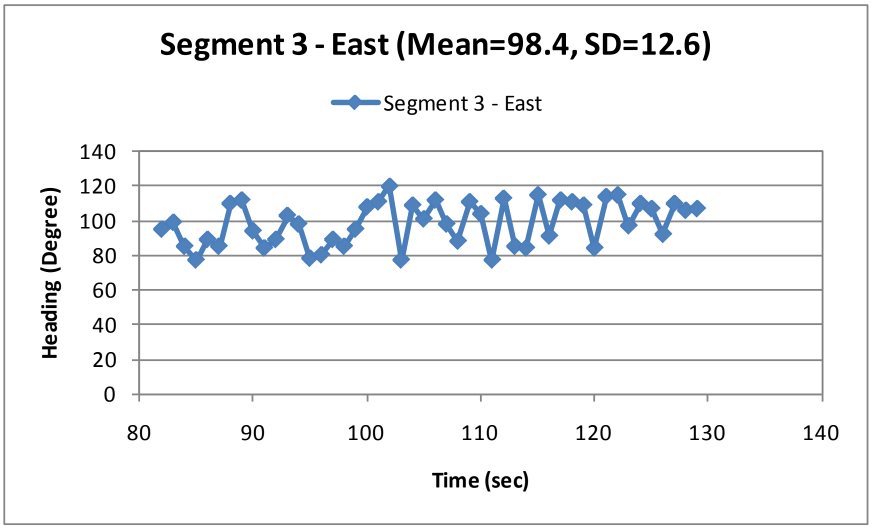

Figure 4-11 Heading Variation – Segment 3

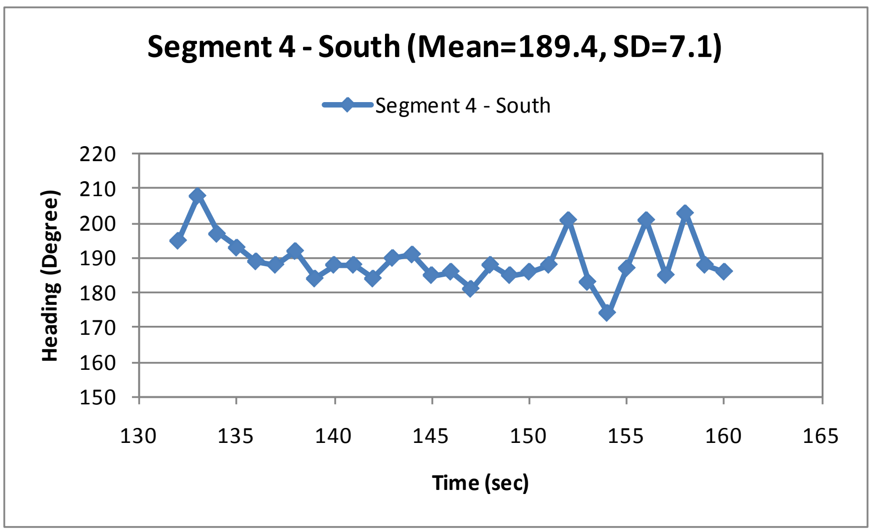

Figure 4-12 Heading Variation – Segment 4

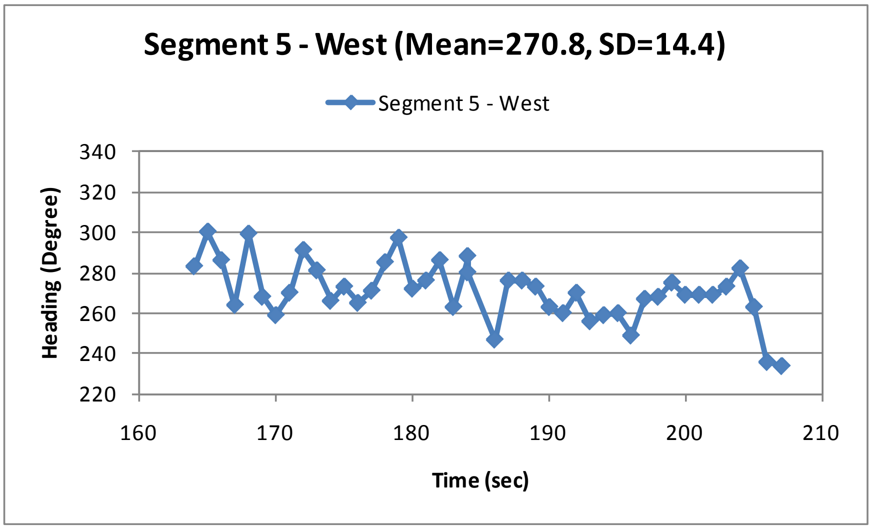

Figure 4-13 Heading Variation – Segment 5

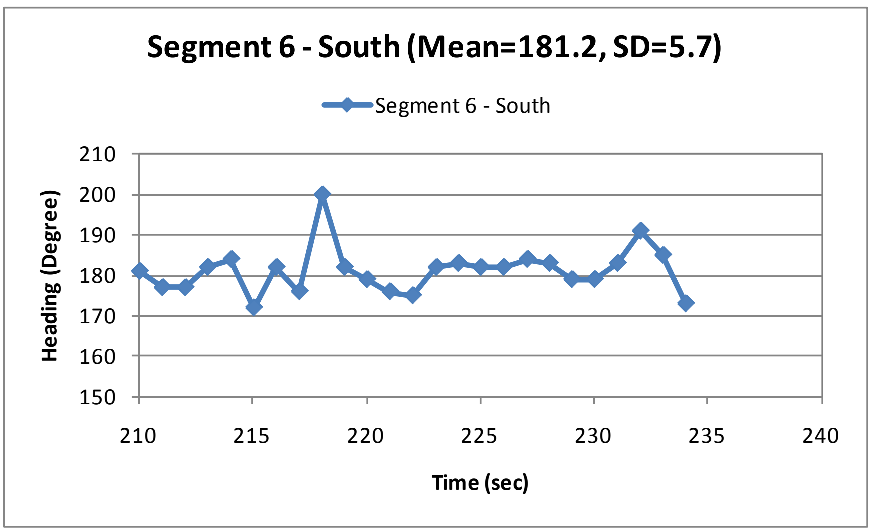

Figure 4-14 Heading Variation – Segment 6

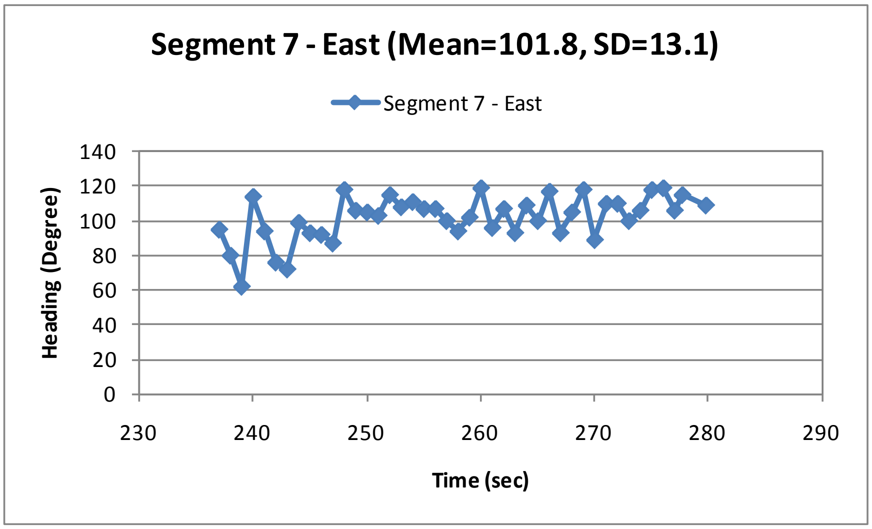

Figure 4-15 Digital Compass Heading Variation – Segment 7

Table 4-1 Heading Measurement by Segment

Heading (Degree)	Segment	1	2	3	4	5	6	7
	Mean	277.7	182	98.4	189.4	270.8	181.2	101.8
	SD	15.3	10.3	12.6	7.1	14.4	5.7	13.1

Experiment #2

Experiment #2 was conducted similar to #1 except data were collected at different location on campus while walking around a rectangular block. Results from experiment #2 are plotted from Figure 4-16 to 4-19. The standard deviation of the heading measurements are around 11~16 degrees except the southbound direction which has a much smaller deviation around 5 degrees. The magnetometer on the Smartphone is sensitive to magnetic flux at different location. The heading variances from experiment #1 and #2 consist of magnetic flux variations and actual heading variations when walking.

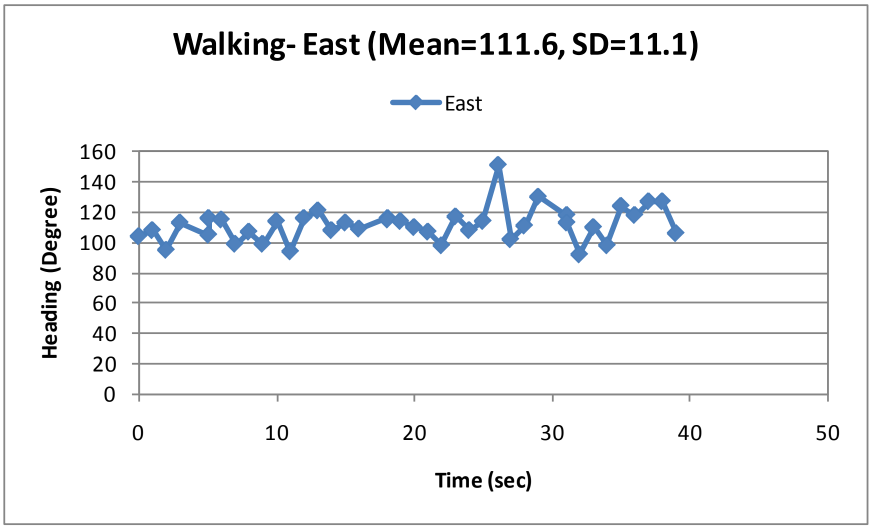

Figure 4-16 Heading Variation – Walking East

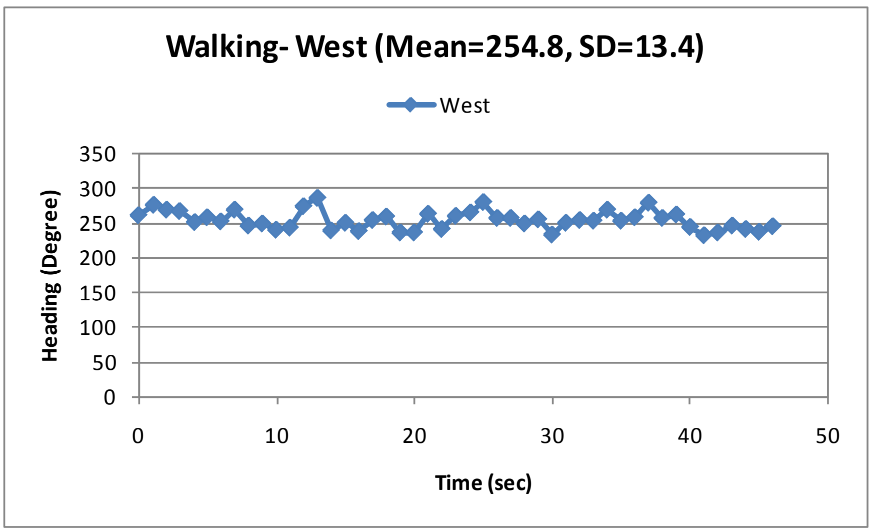

Figure 4-17 Heading Variation – Walking West

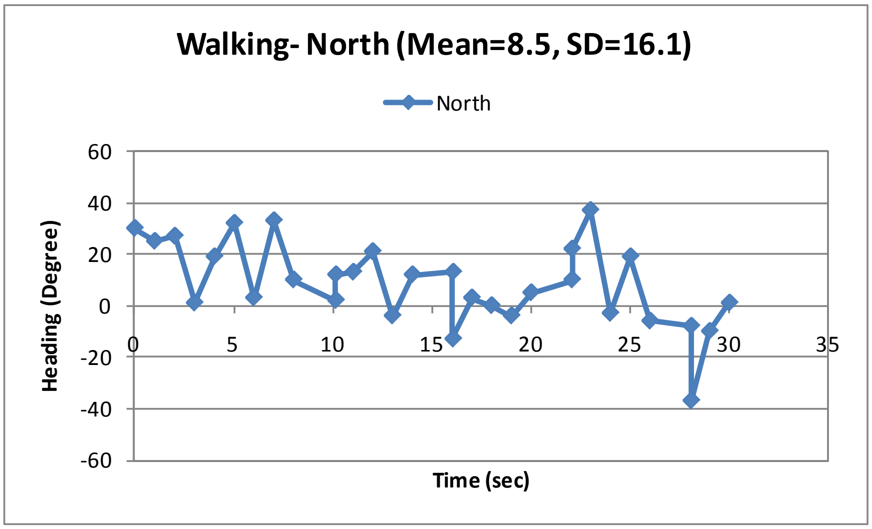

Figure 4-18 Heading Variation – Walking North

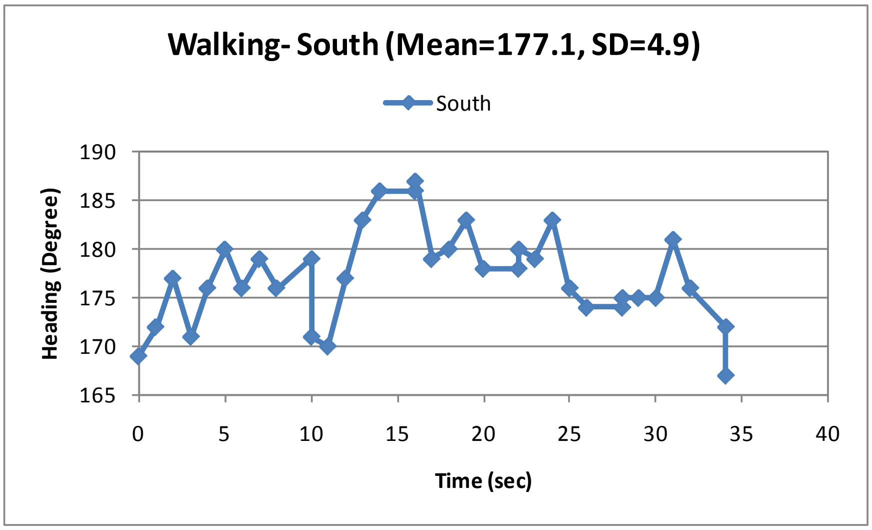

Figure 4-19 Heading Variation – Walking South

Experiment #3

In experiment #3, the Smartphone was placed at the same location where stationary GPS positioning accuracy was measured as displayed in Figure 4-4 at the Northrop mall area. Heading results are displayed from Figure 4-20 to 4-23 with standard deviation of headings vary from 2.8 to 5.3 degrees in all four directions.

Results from the three experiments are summarized in Table 4-2. Generally, there are 10 to 15 degrees of heading deviation while walking. This is primary caused by hand or body motion while walking and magnetic flux that varies by location. The heading deviation is much smaller (5 degrees) when the phone is held stationary. The Smartphone orientation sensor is acceptable when a user is standing at a location and pointing to different direction for environmental information. However, the 10-15 degree of heading accuracy while walking is not sufficient to providing directional navigation for a Pedestrian Dead-Reckoning (PDR) application. More accurate inertial sensors are required for PDR application.

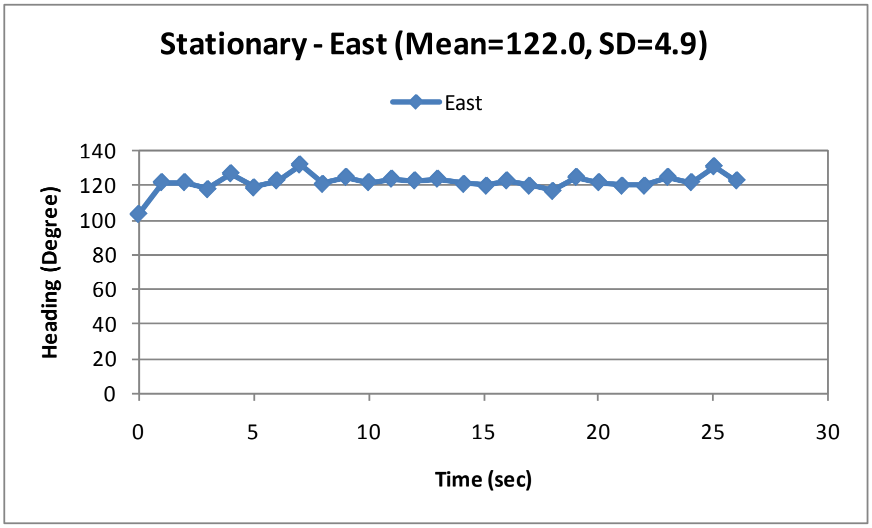

Figure 4-20 Heading Variation – Stationary East

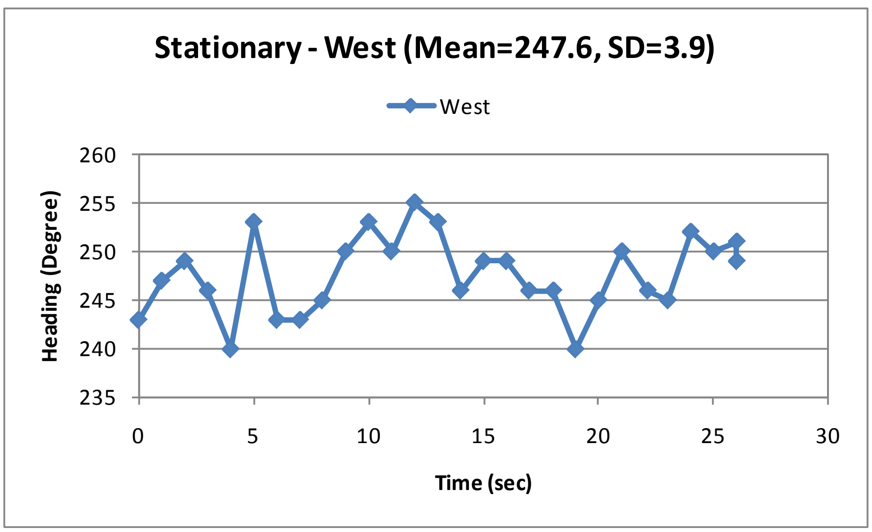

Figure 4-21 Heading Variation – Stationary West

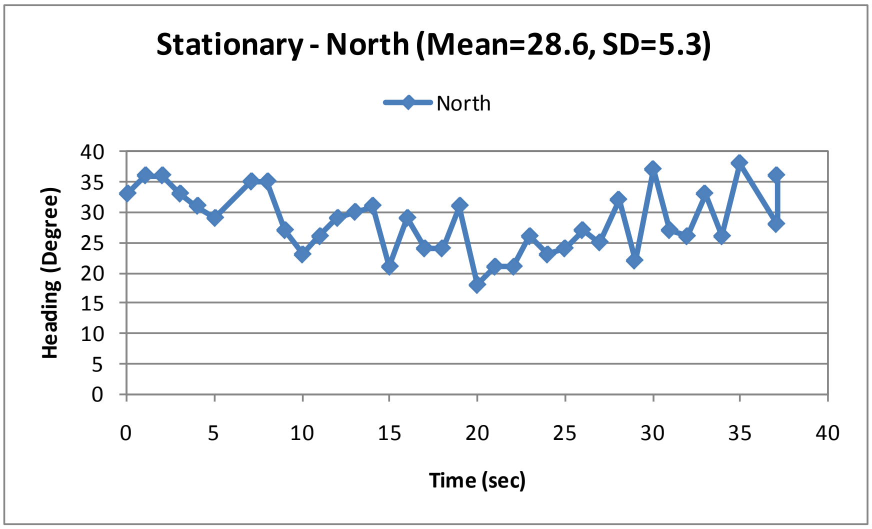

Figure 4-22 Heading Variation – Stationary North

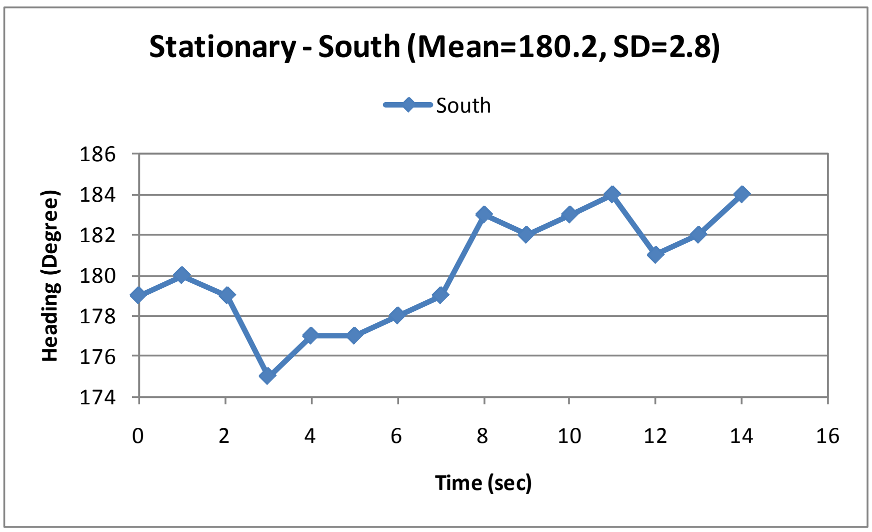

Figure 4-23 Heading Variation – Stationary South

Table 4-2 Summary of Heading Measurement Variation

Mode	SD (Degree)	Headings			
		East	West	North	South
Walking	Test #1	12.6	15.3	-	10.3
		13.1	14.4	-	7.1
		-	-	-	5.7
	Test #2	11.1	13.4	16.1	4.9
		-	-	-	-
Stationary	Test #3	4.9	3.9	5.3	2.8

4.2.4 Accelerometer

The HTC Magic phone contains a tri-axial MEM-based accelerometer (also called g-sensor) for detecting user environment. For example, mobile application can rotate screen display according to the phone orientation. Coordinates of the g-sensor are illustrated in Figure 4-24. Measurements of the acceleration while walking with phone placed in pocket or held in hand were investigated. Figure 4-25 shows the second by second acceleration measurements from each axis while walking with phone placed in coat pocket. The acceleration vector magnitude has an average value of 10.06 m/s/ and standard deviation of 1.6 m/s/s when phone is placed in the pocket. Initial acceleration output at 1 Hz sampling rate is not sufficient to estimate walking steps. Figure 4-26 illustrates the second by second acceleration measurements from each axis while walking with phone held in hand. The acceleration vector magnitude has an average value of 12.82 m/s/ and standard deviation of 1.33 m/s/s when phone is placed in the pocket. When the phone is held in hand, the swinging Acceleration output at 1 Hz sampling rate is not sufficient to estimate walking steps. Higher sampling rate can be configured in the program for walking steps estimation. Figure 4-27 displays the magnitude of acceleration vector collected at 300 ms sampling rate with an average value of 13.29 m/s/ and standard deviation of 1.33 m/s/s when phone is held in hand. Each peak represents a step and there are 120 steps in total in this testing. At higher sampling rate, number of steps can be derived from the acceleration data. Walking distance can also be computed if average step length of the user is known.

Figure 4-24 Coordinates of HTC Smartphone Accelerometers

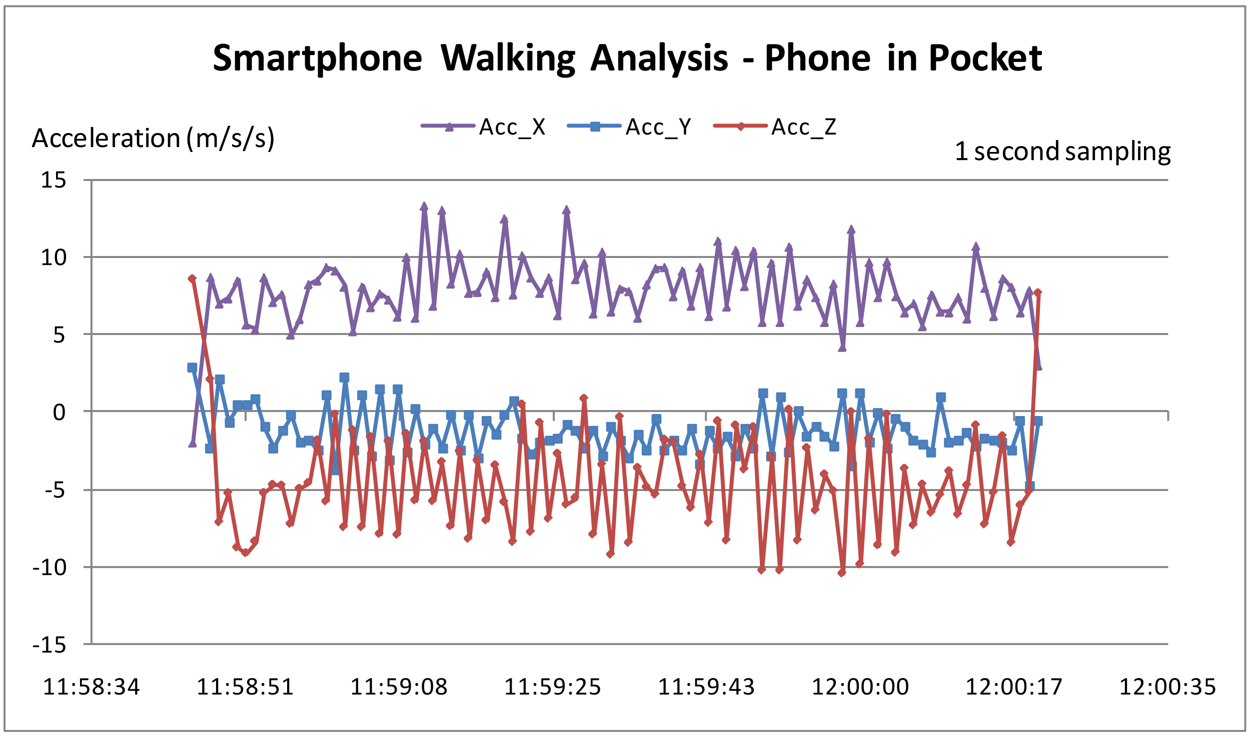

Figure 4-25 Acceleration Measurements of Smartphone in Pocket while Walking

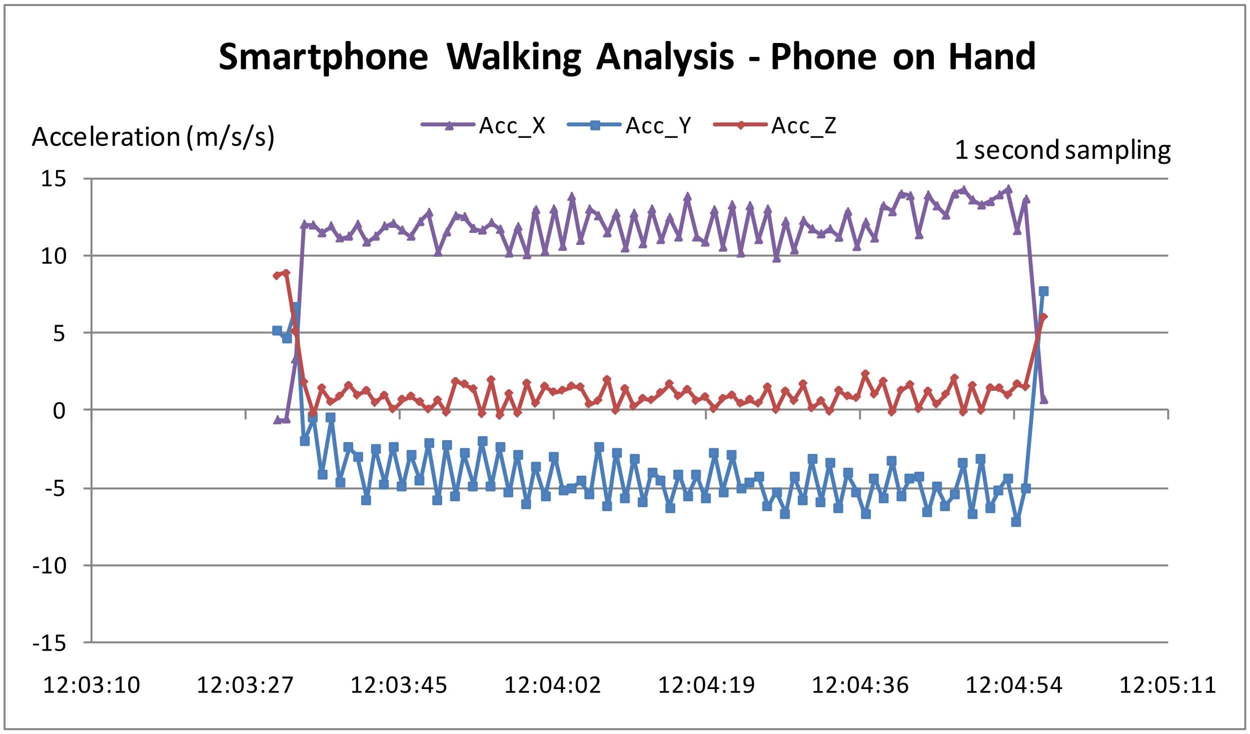

Figure 4-26 Acceleration Measurements of Smartphone in Hand while Walking

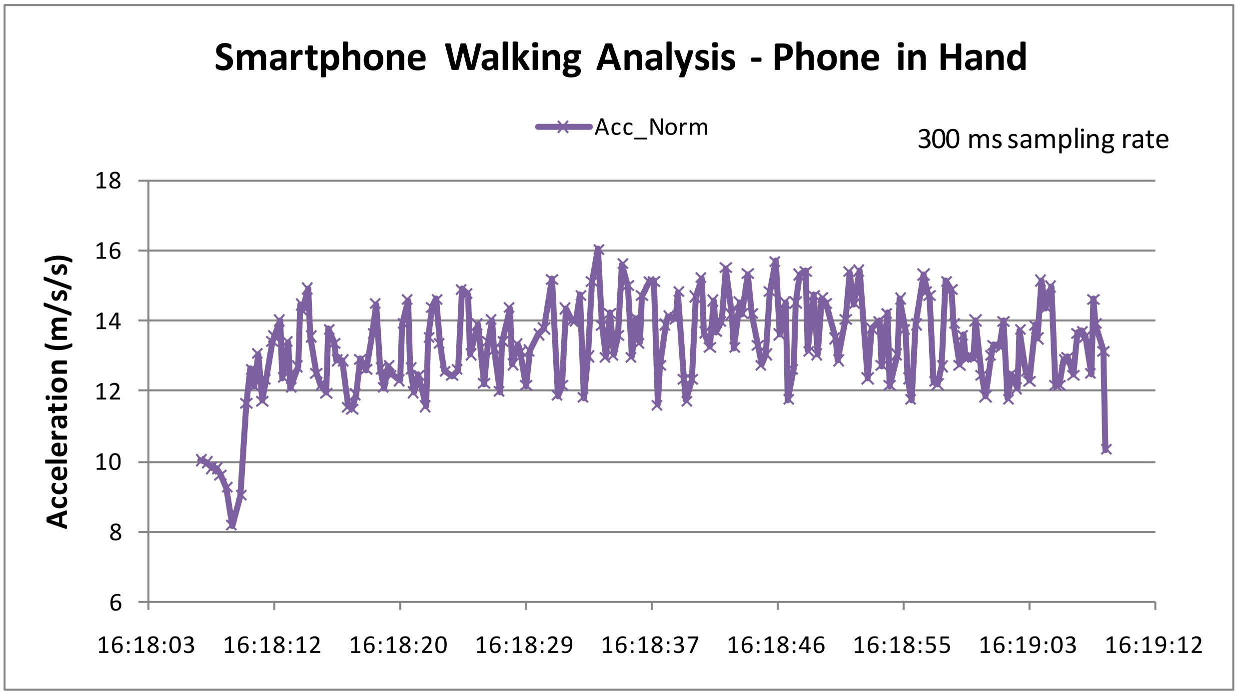

Figure 4-27 Acceleration Measurements at 300 ms Sampling Rate (120 steps)

4.2.5 *Programming Interface*

Functional flowchart of software design is illustrated in Figure 4-28. The Smartphone application will continuously monitor the location of the phone after initialization. Initial position and direction of travel will be used to search for the initial destination node in the geo-spatial database. When a user is within the range of a geo-ID tag, the application will transmit a Bluetooth scan to find the nearest tag in order to identify which corner the user locates with respect to the intersection geometry. While at the corner of an intersection, the user can use the phone to point at different direction followed by a single tap on the Smartphone screen to request for intersection geometry information, such as street name, number of lanes. After determining which direction to cross, the user can point to the desired direction and double tap on the screen to confirm the crossing direction. The Smartphone application will request for signal timing when the crossing direction is confirmed. Signal timing information will thereafter be broadcasted through the text-to-speech interface to announce time to cross and amount of available walk time. More detail about the programming interface design is included in Appendix E.

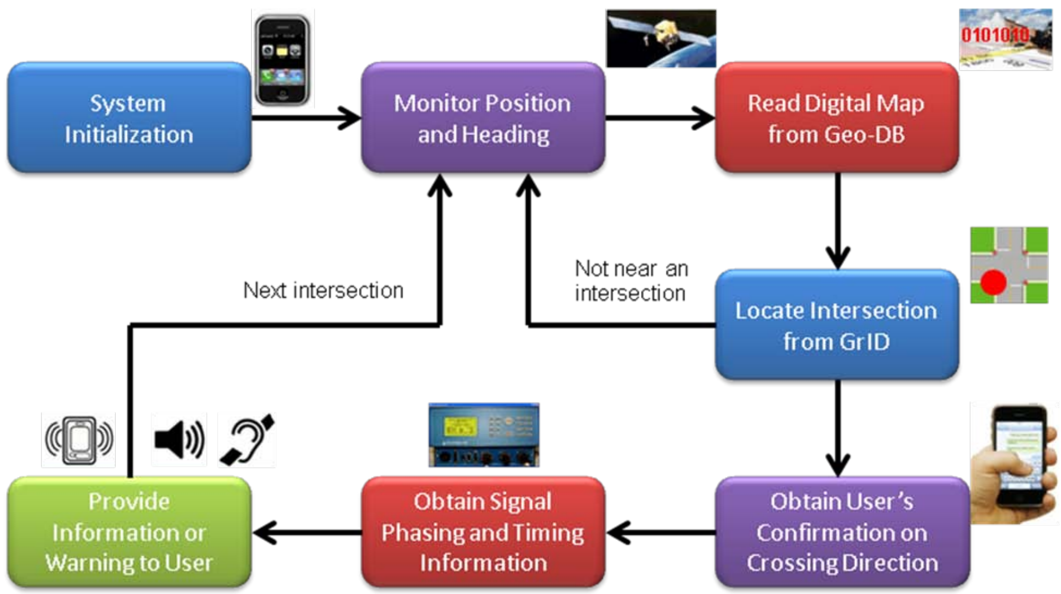

Figure 4-28 Mobile APS System Diagram

4.2.6 *Bluetooth Module*

A Bluetooth geo-ID, as shown in Figure 4-29, is developed using commercially available Bluetooth module from ConnectBlue (http://www.connectblue.com/). Each Bluetooth module has different Media Access Control (MAC) address. The MAC address of each module is used to identify the location of each corner of an intersection. The relationship of geo-ID and coordinate of intersection corners was recorded and stored in a database as part of the digital map of an intersection. The geo-ID is intended to be installed at intersections where GPS reception is weak, for example, in urban canyon environment. More detail about the Bluetooth module is included in Appendix F.

Figure 4-29 Bluetooth Geo-ID with 3 AA Batteries

4.2.7 User Interface Design

After considering the results from user survey related to user interface design, a simple user interface is designed to accommodate the need of blind pedestrians. The single tap command, as illustrated in Figure 4-30, will provide geometry information (street name, direction, and number of lanes) when user is at a corner of an intersection. After determining direction of crossing, the blind pedestrian can use the double-tap command to confirm crossing direction as shown in Figure 4-31. The Smartphone application will wirelessly request for signal timing and phasing information of the desired approach from the traffic signal controller. In both cases, brief speech feedback information to the blind pedestrian will be broadcasted through the text-to-speech interface.

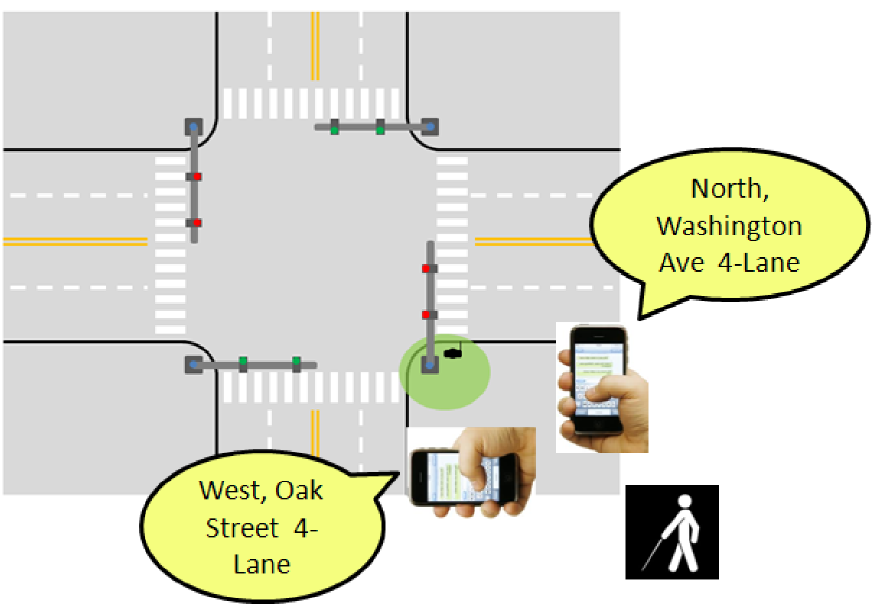

Figure 4-30 Single-Tap to Obtain Intersection Geometry Information

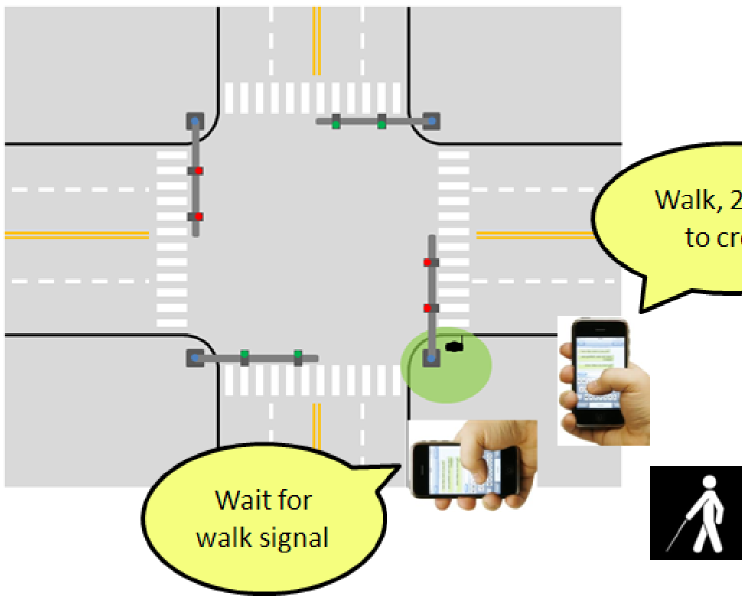

Figure 4-31 Double-Tap to Confirm Crossing and Obtain Signal Information

4.3 Failure Handling

4.3.1 Failure Due to GPS Inaccuracy

This section explains why GPS inaccuracy is so fatal for the application.

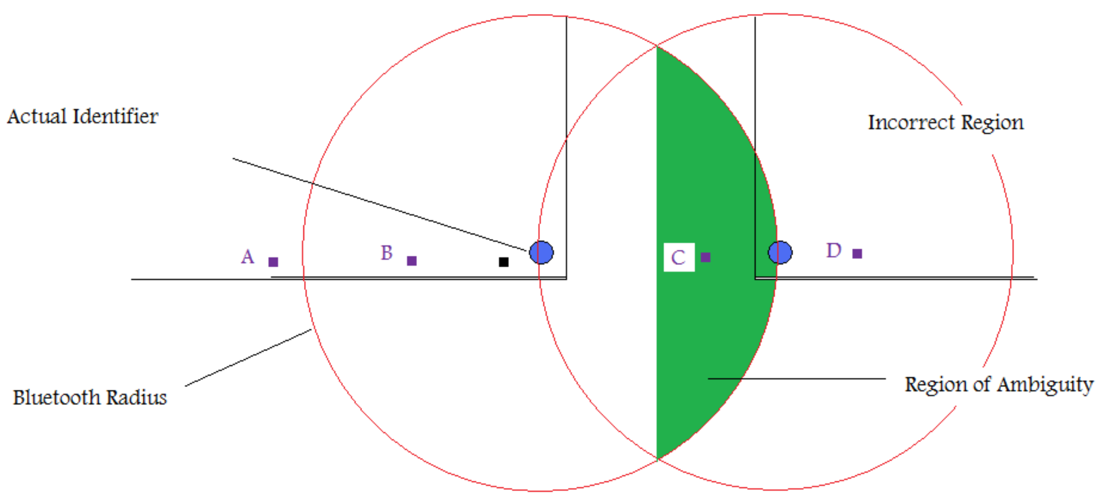

Figure 4-32 Region of GPS Ambiguity

A black square which represents user's actual position (near an intersection) is shown in Figure 4-32.

Locations identified by square dots (A, B, C and D) are possible positions as perceived by the Smartphone application because of potential GPS inaccuracy.

Scenario 1: If location B is chosen:

This implies that the accuracy of GPS is pretty good and the application will work fine in this case.

Scenario 2: If location A or D is chosen:

This implies that even though the user is at intersection, because of GPS inaccuracy, he still seems to be outside intersection region (The software will not perform properly, but can come back to normal behavior in some time). When the location is D, the next identifier is still not chosen because of the clause mentioned below for “C”.

Scenario 3: If location C is chosen:

At this time, the user appears closer to the other identifier, however the application will notice that to reach that identifier from the current identifier, crossing the road is necessary, because of this clause, even though the other identifier is close, the application will continue to work normally.

4.3.2 User Error

The protection we put for case “C” above introduces an error of another type, which occurs when a user crosses at an intersection without ***double tapping***. In this case the list is not modified since without confirmation, the list is not modified.

Handeling errors:

To handle these error cases the program is re-initialized if list is not modified within a period of 90 seconds. Errors may also occur when the user receives a phone call. After the call is completed, the application re-initializes the neighboring identifier list.

5. DISCUSSION

5.1 Intersection Geometry Design

Blind pedestrian usually use the sidewalk boundaries as natural alignment for determining the direction of crosswalk. Blind pedestrians have difficulties finding the way at intersections that are not rectangular. The modern roundabout intersection design presented more challenges for pedestrian with vision impairment in maintaining alignment, determining walking direction, and selecting gaps between vehicles (Long, 2007). A non-rectangular intersection is displayed in Figure 5-1. When a blind pedestrian is traveling westbound toward location B, he or she may extending the sidewalk alignment at corner B and perceives that there is crosswalk toward location D and end up crossing the intersection diagonally. Similarly, when a blind pedestrian is walking toward corner D, he or she may end up crossing directly from location D to C where there is actually no pedestrian crosswalk at all.

Obviously, the intersection geometry design can be improved to consider people with different needs. A national movement called complete street (http://www.completestreets.org) is gaining more attention to involve planners and traffic engineers to consistently build intersection and street safer, more accessible and livable by considering all users in different mode.

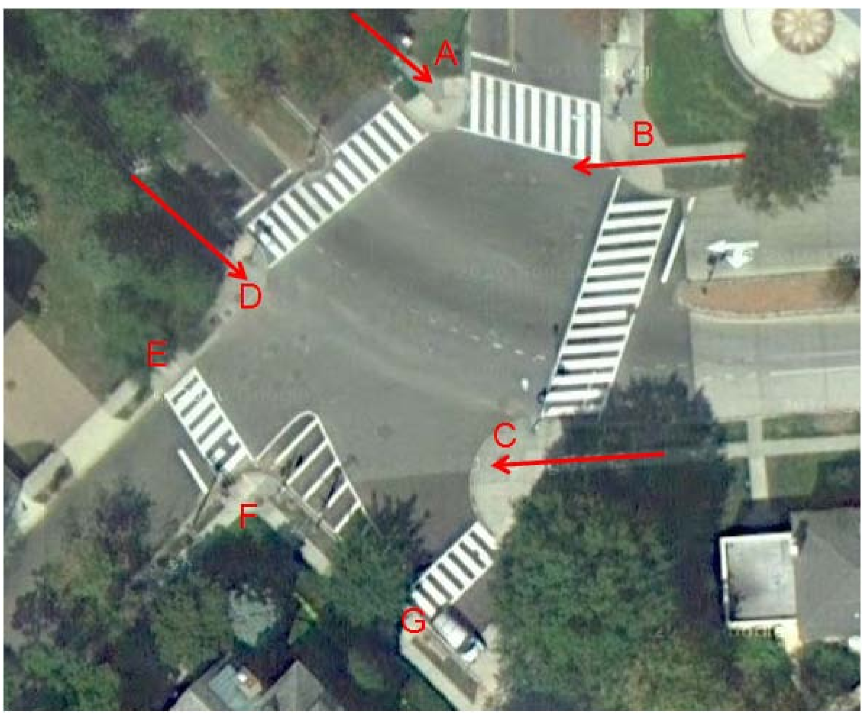

Figure 5-1 Alignment of Sidewalk at Non-Rectangular Intersection (Background image from Google, Map Data © 2011 Google)

5.2 Locating Crosswalk

Knowing a crosswalk exists and finding the beginning of a crosswalk are two additional challenging tasks for blind pedestrian wayfinding. The Bluetooth geo-ID can help inform and confirm blind pedestrians that they are at a corner of an intersection. However, they need to use the wayfinding skills they learned from O&M training to find the beginning of crosswalk. The ADA ramp and the tactile dome surface often provide useful cues for blind pedestrians to identify the beginning of a crosswalk.

5.3 Challenges with Smartphone Sensors

The MAPS system can address the non-rectangular intersection issue to some degree by providing intersection geometry information and direction of crosswalk. However, the effectiveness of this approach depends on the accuracy of sensors on the Smartphone. Current GPS accuracy on the Smartphone can reach up to 10 meters in open environment. The digital compass has accuracy of 10 degree depending on the magnetic noises in the environment. Pedestrian dead-reckoning solution using high performance sensors can provide better navigation solution assuming accurate initial position and orientation is available. Another solution might use image processing for identifying the zebra crossing as proposed by Coughlan & Shen (2006). The MAPS aims to provide decision support for blind pedestrians at signalized intersection crossing, but to replace their wayfinding skills already learned from O&M training.

5.4 Potential Benefit and Impact

There are concerns over the noise, the pushbutton location, and the installation and maintenance costs associated with current APS systems. In the long term, the MAPS system has the potential and capability to enhance, if not replace, existing APS system. Given the elimination of conduits carrying signals and power to the vibrotactile buttons located around the intersection, the MAPS system can be deployed on a larger scale and more cost-effective manner.

Intersections equipped with Dedicated Short Range Communications (DSRC) will advance the capabilities of MAPS to the next level of safety applications. In the near-term, the MAPS will take advantage of the low-latency capability of DSRC to coordinate and cooperatively communicate among the pedestrian (waiting at the crossing), the traffic signal controller and approaching vehicles in order to provide dynamic decision-making support to the travelers. Information such as the presence of a blind pedestrian waiting at the crossing can be made available via IntelliDrive in order to alert drivers attempting to make a turn. Or, the traffic controller can hold or extend the walk signal for blind pedestrians until they are completely cleared at the crosswalk. Furthermore, IntelliDrive-based wireless connectivity can promptly warn blind pedestrians not to cross when an approaching vehicle is not likely to stop at the crosswalk while the light is transitioning into red for automobiles.

Although the proposed MAPS system is primarily targeted towards the blind and the elderly, there are also potential benefits for people with low vision and sighted pedestrians that may be distracted (while for example talking or texting on their cell phone) while at the intersection crossing. Integrated DSRC and MAPS system can inform pedestrians prior to entering the crosswalk when there is a potential conflict between vehicles and pedestrians.

6. FUTURE WORK

Future research will focus on the following areas.

- Conduct usability test on the speech feedback to blind users
- Develop veering alert algorithm using pedestrian dead-reckoning and image processing techniques
- Investigate how blind and low-vision individuals gain their spatial knowledge at signalized intersection
- Field study and evaluation of the effectiveness of MAPS as compared to current APS system.

7. SUMMARY

People with vision impairment generally have difficulty crossing intersections due to the lack of information available to them about the traffic, signal and intersection geometry. Among the intersection crossing sub-tasks, locating the crosswalk, determining when to cross and maintaining alignment with the crosswalk while crossing are the most difficult tasks for the blind and visually impaired to execute. The current Accessible Pedestrian Signal (APS) system requires the blind to search for a pushbutton if one even exists. It often requires the pedestrian to move away from their path of travel, which is often used as an alignment cue for crossing. Due to the high cost of the APS installation, most agencies do not deploy them at all signalized intersections. In addition to the installation and maintenance costs that accrue to the local traffic agency, current APS systems contribute significant "noise" to the local neighborhood. Furthermore, the auditory guiding cues provided by the APS are often inaudible because of the ambient traffic noise associated with rush hour. There is room for improvement in terms of the design and accessibility of both APS and non-APS crosswalk signals for blind and low-vision pedestrians.

Among the intersection crossing sub-tasks, locating crosswalk, determining when to cross and maintaining alignment to crosswalk while crossing are the most difficult tasks for the blind and visually impaired. We have interviewed ten blind and low-vision people to understand what types of information they use at intersection crossings and identified information types that could assist them. Six high-level recommendations emerged for the design of MAPS:

1. Additional information needed about intersection
2. Output: short auditory phrases
3. Feedback should not interfere with pedestrians' ability to use their canes or listen to traffic cues
4. Tactile cues and short auditory message are recommended as warnings in a dangerous situation
5. Be able to repeat warnings / output
6. Automatic activation of walk signal or allow activation from the mobile interface

A prototype Mobile Accessible Pedestrian Signals (MAPS) system was developed to support decision making at signalized intersections. The MAPS system integrates sensors on a Smartphone, Wi-Fi, and Bluetooth technologies, and traffic signal controllers were developed to provide intersection geometry information and Signal Phasing and Timing (SPaT) to pedestrians who are blind at signalized intersections. A single-tap command on the Smartphone screen allows users to request for intersection geometry information, such as street name, direction and number of lanes at a corner of an intersection. A double-tap input while pointing toward desired direction of crossing will confirm the crossing direction, request for pedestrian phase, and the Smartphone application will then wirelessly request for signal timing and phasing information from traffic signal controller.

Blind pedestrians usually use the sidewalk boundaries as natural alignment for determining the direction of crosswalk. Blind pedestrians have difficulties finding the way at intersections that are not rectangular. The MAPS system can address the non-rectangular intersection issue to some degree by providing intersection geometry information and direction of crosswalk. However, the effectiveness of this approach depends on the accuracy of sensors on the Smartphone. Knowing a crosswalk exists and finding the beginning of a crosswalk are two additional challenging tasks for blind pedestrian wayfinding. The Bluetooth geo-ID can help inform and confirm blind pedestrians that they are at a corner of an intersection. However, blind pedestrians need to use the wayfinding skills they learned from orientation and mobility (O&M) training to find the beginning of crosswalk.

Future work will focus on usability tests of the system and evaluate the effectiveness of the MAPS prototype as compared to existing APS systems, and development of veering alert algorithm using pedestrian dead-reckoning and image processing techniques.

REFERENCES

The ASK-IT project (2009). http://www.ask-it.org/, accessed October 2009.

Aslan, I. & Krüger, A. (2004). "The Bum Bag Navigator (BBN): An advanced pedestrian navigation system." Proceedings of AIMS 2004, Nottingham, U.K. http://w5.cs.uni-sb.de/~baus/aims04/cameraready/P3.pdf, accessed January 2010.

Bae, M., Choi, K., Lim, J. & Shin, Y. (2009). "Evaluation Method of Location Tracking Technology Using Wireless LAN AP for a Pedestrian LBS." Proceedings of the 16th ITS World Congress, Stockholm, Sweden.

Barbeau, S.J., Georggi, N.L. & Winters, P.L. (2010). "Integration of GPS-Enabled Mobile Phones and AVL: Personalized Real-Time Transit Navigation Information on Your Phone." Proceedings of the National Academy of Sciences, Transportation Research Board 89th Annual Meeting, Washington, D.C. http://www.locationaware.usf.edu/wp-content/uploads/2010/04/TRB2010-Paper.pdf, accessed July, 2010.

Barlow, J.M., Bentzen, B.L. & Bond, T. (2005). "Blind Pedestrians and the Changing Technology and Geometry of Signalized Intersections: Safety, Orientation, and Independence." *Journal of Visual Impairment & Blindness, 99*(10): 587-598.

Bekiaris, E., Kalogirou, K. & Panou, M. (2007). "Personalised infomobility services within ASK-IT project." Proceedings of the 14th ITS World Congress, Beijing, China.

Bentzen, B.L., Barlow, J.M. & Franck, L. (2000). "Addressing barriers to blind pedestrians at signalized intersections." *Journal of Institute of Transportation Engineers (ITE), 70*(9): 32-35.

Bentzen, B.L. (2007). "Making the Environment Accessible to Pedestrains Who Are Visually Impaired: Policy Research." In J.J. Rieser, D.H. Ashmead, F. Ebner, & A.L. Corn (Eds.), *Blindness and Brain Plasticity in Navigation and Object Perception* (pp. 313-333). New York: Psychology Press.

Bentzen, B.L., Crandall, W.F. & Myers, L. (1999). "Wayfinding System for Transportation Services – Remote Infrared Audible Signage for Transit Stations, Surface Transit, and Intersection." *Journal of the Transportation Research Board*, *1671*: 19–26.

Blake, L. (2011). "Proving his point." *Star Tribune*. http://www.startribune.com/local/west/114846184.html? elr=KArksUUUoDEy3LGDiO7aiU, accessed February 2, 2011.

Coldefy, J. (2009). "The Mobiville Project: Large Scale Experimentation of Real-Time Public Transport Information Service Providing Satellite Based Pedestrian Guidance on Smart Phones." Proceedings of the 16th ITS World Congress, Stockholm, Sweden.

Coughlan, J.M. & Shen, H. (2006). "A fast algorithm for finding crosswalks using figure-ground segmentation." Proceedings of 2nd Workshop on Applications of Computer Vision, in conjunction with ECCV, Graz, Austria.

Crandall, W.F., Brabyn, J., Bentzen, B.L. & Myers, L. (1999). "Remoted Infrared Signage Evaluation for Transit Stations and Intersections." *Journal of Rehabilitation Research and Development, 36*(4): 341–355.

Davies, T.C., Burns, C.M. & Pinder, S.D. (2006). "Using ecological interface design to develop an auditory interface for visually impaired travelers." Proceedings of OZCHI 2006, pp. 309-312, Sydney, Australia.

Davies, T.C., Burns, C.M. & Pinder, S.D. (2007). "Testing a novel auditory interface display to enable visually impaired travelers to use sonar mobility device effectively." Proceedings of Human Factors and Ergonomics Society, 51st Annual Meeting, pp. 278-282, Baltimore, MD.

Davies, T.C. & Burns, C.M. (2008). "Advances in cognitive work analysis and the design of ecological visual and auditory displays." *Cognitive Technology, 13*(2): 17-23.

Dawidson, E. (2009). "Pedestrian Navigation in Stockholm, How Local Data Together with Advanced Positioning Techniques Can be Used for Detailed Routing." Proceedings of the 16th ITS World Congress, Stockholm, Sweden.

The e-Adept accessibility project (2009). http://www.eadept.se, accessed October 2009.

Edwards, S., Bryan, H. & Wagner, J. (2007). "Indoor Localisation for Disabled People: ASK-IT Project." Proceedings of the 14th ITS World Congress, Beijing, China.

Garaj, V. (2001). "The Brunel Navigation System for Blind: Determination of the Appropriate Position to Mount the External GPS Antenna on the User's Body". Proceedings of the U.S. Institute of Navigation - GPS 2001 Technical Meeting, Salt Lake City, UT.

Gaunet, F. & Briffault, X. (2005). "Exploring the Functional Specifications of a Localized Wayfinding Verbal Aid for Blind Pedestrians: Simple and Structured Urban Areas". *Human Computer Interaction, 20*(3): 267–314.

Gill, J. (1997). Mobility of Blind and Elderly People Interacting with Computers. *Digital Accessibility Team* (DAT). http://www.tiresias.org/research/reports/mobicf.htm, accessed October 2009.

Giudice, N.A., Bakdash, J.Z., Legge, G.E. & Roy, R. (2010). "Spatial learning and navigation using a virtual verbal display." *ACM Transactions on Applied Perception, 7*(1): 3:1-3:22 (Article 3).

Giudice, N.A., Bakdash, J.Z. & Legge, G.E. (2007). "Wayfinding with words: Spatial learning and navigation using dynamically-updated verbal descriptions." *Psychological Research, 71*(3): 347-358.

Giudice, N.A. & Legge, G.E. (2008). "Blind Navigation and the Role of Technology." In A. Helal, M. Mokhtari & B. Abdulrazak (Eds.), *The Engineering Handbook of Smart Technology for Aging, Disability, and Independence.* Hoboken, NJ: John Wiley & Sons, Inc.

Giudice, N.A. & Tietz, J. (2008). “Learning with virtual verbal displays: Effects of interface fidelity on cognitive map development”. In C. Freksa, N. Newcombe, P. Gärdenfors & S. Wölfl (Eds.), *Spatial Cognition VI: Lecture Notes in Artificial Intelligence* (Vol. 5248, pp. 121-137). Berlin: Springer.

Golledge, R.G., Loomis, J.M., Klatzky, R.L., Flury, A. & Yang, X.L. (1991). “Designing a personal guidance system to aid navigation without sight: Progress on the GIS component.” *International Journal of Geographical Information Systems, 5*(4): 373-395.

Golledge, R.G., Klatzky, R.L. & Loomis, J.M. (1996). “Cognitive mapping and wayfinding by adults without vision.” In J. Portugali (Ed.), *The Construction of Cognitive Maps* (pp. 215-246). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Golledge, R.G., Klatzky, R.L., Loomis, J.M., Speigle, J. & Tietz, J. (1998). “A geographical information system for a GPS based personal guidance system.” *International Journal of Geographical Information Science*, *12*: 727-749.

Golledge, R.G., Marston, J.R., Loomis, J.M. & Klatzky, R.L. (2004). “Stated preferences for components of a Personal Guidance System for non-visual navigation.” *Journal of Visual Impairment and Blindness*, *98*(3): 135-147.

Golledge, R.G. & Gärling, T. (2004). “Cogntive maps and urban travel.” In: D.A. Hensher, K.J. Button, K.E. Haynes & P.R. Stopher (Eds.), *Handbook of Transport Geography and Spatial Systems* (Ch. 28). Amsterdam: Elsevier.

Grierson, L., Zelek, J. & Carnahan, H. (2009). “The Application of a Tactile Way-finding Belt to Facilitate Navigation in Older Persons.” *Ageing International*, *34*(4): 203-215.

Guth, D. (2007). “Why Does Training Reduce Blind Pedestrians’ Veering?” In J.J. Rieser, D.H. Ashmead, F. Ebner & A.L. Corn (Eds.), *Blindness and Brain Plasticity in Navigation and Object Perception* (pp. 353-365). New York: Psychology Press.

Guth, D., Ashmead, D., Long, R., Wall, R. & Ponchillia, P. (2005). “Blind and sighted pedestrians’ judgments of gaps in traffic at roundabouts.” *Human Factors*, *47*(2): 314-331.

Guth, D. & LaDuke, R. (1995). “Veering by blind pedestrians: Individual differences and their implications for instruction.” *Journal of Visual Impairment & Blindness*, *89*: 28–37.

Helal, A., Moore, S. & Ramachandran, B. (2001). “Drishti: An Integrated Navigation System for Visually Impaired and Disabled.” Proceedings of the 5th International Symposium on Wearable Computer, Zurich, Switzerland. http://www.icta.ufl.edu/projects/publications/wearableConf.pdf, accessed June, 2010.

Helft, M. (2009). “For the Blind, Technology Does What a Guide Dog Can’t.” *The New York Times*, http://www.nytimes.com/2009/01/04/business/04blind.html, accessed February 2009.

Hess, T.M. (2005). “Memory and Aging in Context.” *Psychological Bulletin*, *131*(3): 383-406.

Johnni, P. (2009). “Stockholm – A City for Everyone How New Technology Can Make Every Day Life Easier for Elderly and People with Disabilities.” Proceedings of the 16th ITS World Congress, Stockholm, Sweden.

Jonsson, A., Sandberg, S. & Uppgård, T. (2007). “Urban guidance for the blind and visually impaired – pedestrian route planning and navigation using a mobile handset.” In P. Cunningham & M. Cunningham (Eds), *Expanding the Knowledge Economy: Issues, Applications. Case Studies*. Amsterdam: IOS Press.

Kim, C.-G. & Song, B.-S. (2007). “Design of a wearable walking-guide system for the blind.” Proceedings of the 1st international convention on rehabilitation engineering; assistive technology: in conjunction with 1st Tan Tock Seng Hospital Neurorehabilitation Meeting, Singapore.

Kim, W.-H., Kim, K.-S., Kim W.-K. & Lee, C.-H. (2010). “Development of High-tech Walking-aid System through Unions of 2D Barcode and Braille Block for the Blind and Visually Impaired.” Presented at 17th ITS World Congress Annual Conference, Oct. 25-29, Busan, Republic of Korea.

Kim, Y., Kim, C.-H. & Kim, B. (2000). “Design of an auditory guidance system for the blind with signal transformation from stereo ultrasonic to binaural audio.” *Artificial Life and Robotics*, *4*(4): 220-226.

Kirasic, K.C. (2002). “Age differences in adults' spatial abilities, learning environmental layout, and wayfinding behavior.” *Spatial Cognition and Computation*, *2*(2): 117-134.

Klatzky, R.L., Beall, A.C., Loomis, J.M., Golledge, R.G. & Philbeck, J.W. (1999). “Human navigation ability: Tests of the encoding-error model of path integration.” *Spatial Cognition and Computation, 1*: 31-65.

Klatzky, R.L., Loomis, J.M., Beall, A.C., Chance, S.S. & Golledge, R.G. (1998). “Spatial updating of self-position and orientation during real, imagined, and virtual locomotion.” *Psychological Science, 9*(4): 293-298.

Li, C. (2006). “User preferences, information transactions and location-based services: A study of urban pedestrian wayfinding.” *Computers, Environment & Urban Systems*, *30*(6): 726-740.

Liu, H. & Ma, W. (2009). “A Virtual Vehicle Probe Model for Time-dependent Travel Time Estimation on Signalized Arterials.” *Transportation Research Part C, 17*(1): 11-26.

Liu, H., Wu, X., Ma, W. & Hu, H. (2009). “Real-Time Queue Length Estimation for Congested Signalized Intersections.” *Transportation Research Part C, 17*(4): 412-427.

Long, R. (2007). “Crossing Streets without Vision: Access to Information, Strategies for Traveling, and the Impact of Technology, Training, and Environmental Design.” In J.J. Rieser, D.H. Ashmead, F. Ebner & A.L. Corn (Eds.), *Blindness and Brain Plasticity in Navigation and Object Perception* (pp. 335-351). New York: Psychology Press.

Loomis, J.M., Golledge, R.G. & Klatzky, R.L. (1998). "Navigation system for the blind: Auditory display modes and guidance." *Presence: Teleoperators and Virtual Environments, 7*(2): 193-203.

Loomis, J.M., Golledge, R.G., Klatzky, R.L. & Marston, J.R. (2007). "Assisting wayfinding in visually impaired travelers." In G.L. Allen (Ed.), *Applied spatial cognition: From research to cognitive technology*. (pp. 179-203). Mahwah, NJ: Lawrence Erlbaum Associates.

Loomis, J.M., Marston, J.R., Golledge, R.G. & Klatzky, R.L. (2005). "Personal guidance system for people with visual impairment: A comparison of spatial displays for route guidance." *Journal of Visual Impairment & Blindness, 99*(4): 219-232.

Loomis, J.M., Klatzky, R.L. & Golledge, R.G. (2001). "Navigating without vision: Basic and applied research." *Optometry and Vision Science, 78*(5): 282-289.

Marston, J.R., Loomis, J.M., Klatzky, R.L. & Golledge, R.G. (2007). "Nonvisual Route Following with Guidance from a Simple Haptic or Auditory Display." *Journal of Visual Impairment & Blindness, 101*(4): 203-211.

Markoff, J. & Fackler, M. (2006). "With a Cellphone as My Guide." *The New York Times*. http://www.nytimes.com/2006/06/28/technology/28locate.html, accessed June 2009.

The NOPPA project (2009). http://virtual.vtt.fi/virtual/noppa/noppaeng.htm, accessed October 2009.

Pai, M.C. (2006). "The neuropsychological studies of dementias in Taiwan: focus on way-finding problems in Alzheimer's patients." *Acta Neurol Taiwan, 15*(1): 58-60.

Ponchillia, P., MacKenzie, N., Long, R., Denton-Smith, P., Hicks, T. & Miley, P. (2007). "Finding a Target with an Accessible Global Positioning System." *Journal of Visual Impairment & Blindness, 101*(8): 479-488.

Ponchillia, P., Rak, E., Freeland, A. & LaGrow, S.J. (2007). "Accessible GPS: Reorientation and Target Location among Users with Visual Impairments." *Journal of Visual Impairment & Blindness, 101*(7): 389-401.

Rieser, J.J., Ashmead, D.H., Ebner, F. & Corn, A.L. (Eds). (2007). *Blindness and Brain Plasticity in Navigation and Object Perception*. New York: Psychology Press.

Rogers, W.A., Meyer, B., Walker, N. & Fisk, A.D. (1998). "Functional limitations to daily living tasks in the aged: a focus group analysis." *Human Factors, 40*(1): 111-115.

Rosenbaum, R.S., Gao, F., Richards, B., Black, S.E. & Moscovitch, M. (2005). "Where to? Remote Memory for Spatial Relations and Landmark Identity in Former Taxi Drivers with Alzheimer's Disease and Encephalitis." *Journal of Cognitive Neuroscience, 17*(3).

Sanderson, P., Anderson, J. & Watson, M. (2000). "Extending ecological interface design to auditory displays." Proceedings of OZCHI 2000, pp. 259-266, Sydney, Australia.

Tauchi, M., Sawai, H., Takato, J., Yoshiura, T. & Takeuchi, K. (1998). “Development and Evaluation of a Novel Type of Audible Traffic Signal for the Blind Pedestrians.” The 9th International Mobility Conference Proceedings, pp. 108–109, Rehabilitation Research and Development Center, Veterans Administration Medical Center, Decatur, GA.

Tjan, B.S., Beckmann, P.J., Roy, R., Giudice, N. & Legge, G.E. (2005). “Digital Sign System for Indoor Wayfinding for the Visually Impaired”, Computer Vision and Pattern Recognition.” 2005 IEEE Computer Society Conference on 20-26 June 2005, San Diego, CA.

Uc, E.Y., Rizzo, M., Anderson, S.W., Shi, Q. & Dawson, J.D. (2004). “Driver route-following and safety errors in early Alzheimer disease.” *Neurology*, *63*(5): 832-837.

Virtanen, A. & Koshinen, S. (2004). “NOPPA – Navigation and Guidance System for the Blind.” Proceedings of the 11th ITS World Congress, Nagoya, Japan.

WHO. (2009). Visual impairment and blindness. Fact Sheet #282. http://www.who.int/mediacentre/factsheets/fs282/en/, accessed November 2010.

Willis, S. & Helal, S. (2005). “RFID Information Grid for Blind Navigation and Wayfinding.” The 9th IEEE International Symposium on Wearable Computers (ISWC 2005), pp. 34-37, Galway, Ireland.

Wilson, J., Walker, B.N., Lindsay, J., Cambias, C. & Dellaert, F. (2007). “SWAN: System for Wearable Audio Navigation.” Proceedings of the 11th International Symposium on Wearable Computers (ISWC 2007), Boston, MA. http://sonify.psych.gatech.edu/publications/pdfs/2007ISWC-Wilson-et-al-submitted.pdf, accessed August 2009.

Zelek, J.S. & Holbein, M. (2008). “Wearable tactile navigation system.” US Patent Application number: 11/707,031, Publication number: US 2008/0120029 A1.

APPENDIX A: USER SURVEY CONSENT FORM

Consent Form

Accessible Traffic Signals for Blind and Visually Impaired Pedestrians

You are invited to participate in a research study to design usable traffic signals for pedestrians. You were selected because you are considered legally blind or to have low vision, you have completed orientation and mobility training, and are have experience orienting on your own. We ask that you listen to/read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by Michael Rakauskas and Chen-Fu Liao who are research staff at the University of Minnesota.

Background Information

The purpose of this study is to develop an accessible traffic signal for blind and visually impaired pedestrians that can be accessed by a mobile device or cell phone.

Procedures

If you agree to be in this study, we would ask you participate in an interview discussion. This discussion will focus on your past experiences while crossing intersections and using accessible pedestiran signals. The discussion will allow for follow-up questions and will cover the following topics:

1. **Your vision,**
2. **Your ability to orient by yourself,**
3. **Your experience crossing intersections,**
4. **Your usage and opinions of new technology,**
5. **Your opinions of a proposed pedestrian crossing system, and**
6. **Demographic information.**

This interview should last approximately one hour. The interview may be taped using audio or video equipment to record your responses, and if this occurs you will be notified by the interviewer.

Risks and Benefits of being in the Study

There are no direct risks or benefits associated with this interview.

Compensation

You will receive $50 for participating in this interview.

IRB Code # 1002S77624

Confidentiality

The records of this study will be kept private. In any report we might publish, we will not include any information that will make it possible to identify a subject. Research records will be stored securely and only researchers will have access to the records. Audio and video recordings will only be accessible to researchers on the project. Portions of these recordings may be used when presenting findings at internal project meetings or at scientific meetings. Your name and identifying information will never be linked to these recordings.

Voluntary Nature of the Study

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota or with Vision Loss Resources. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions

The researchers conducting this study are: Michael Rakauskas and Chen-Fu Liao. You may ask any questions you have now. If you have questions later, you are encouraged to contact Michael Rakauskas at 111 Church Street SE, Minneapolis, MN 55455, (612) 624-4614, or **mickr@me.umn.edu**.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), you are encouraged to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be given a copy of this information to keep for your records.

Statement of Consent

I have listened to/read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature:______________________

Date: _________________

Signature of Investigator:

____

Date: __________________

APPENDIX B: INTERVIEW QUESTIONS

B.1 Screening Protocol

A. Vision Background

With the best correction possible, what is your visual acuity? Please provide both measurements or indicate if N/A.

Without Glasses: 20 / ______________________

With Glasses: 20 / ______________________

Do any of these describe your state of vision? (can select more than one)

☐ Central blindness

☐ Peripheral blindness

☐ Left / Right eye blindness (circle one)

☐ Night blindness

How long have you been visually impaired?

☐ Since birth

☐ Since ....

Do you use any assistive equipment to improve your vision? (can select more than one)

☐ Magnifying glass Non-impaired, low-vision

☐ Readers (screen reader for your computer) *Blind candidate*

☐ Magnifiers (screen magnifier for your computer) *Low-vision candidate*

☐ Other ____

Circle examples of “Other” by candidate type:	
Blind	Low-Vision
Jaws, Windoweyes, Talking Clock, Braille Writer, [Trekker Breeze, StreetTalk VIP, Mobile Geo, BrailleNote GPS, Loadstone GS, Wayfinder Access]	Monacular, Closed Circuit TV, Glasses to Magnify, Larger Print

Aside from your vision, do you have any ailments or pathologies that affect your ability to walk cross an intersection safely? For example, balance (vestibular) issues, hearing impairment, etc.

☐ No

☐ Yes: Please describe ....

....
....

Definitions/Guidelines:

Legally Blind: Visual acuity (with best correction in the better eye) worse than or equal to 20/200 or a visual field extent of <20° in diameter, and use of equipment primarily in the “Blind” category (question 2, above).

Low vision: Having 20/70 or worse vision (with best correction in the better eye) or any limitation to the visual field, and use of equipment in either the “Blind” or “Low-vision” categories (question 2, above).

Non-Visually Impaired: Having 20/40 or better vision even with eyeglasses. They can wear eyeglasses, but have no real eye/vision problems. They most likely do not use equipment in either the “Blind” or “Low-vision” categories (question 2, above).

This definition is used in the U.S. to determine eligibility for certain disability benefits from the Federal Government and also restrictions. For example, people with vision worse than 20/40 even with eyeglasses can not obtain an unrestricted drivers license in most states (National Eye Institute 1992). This definition is also aligned with the FCC’s definition of “substantial impairment” (sect. 255 based on Americans with Disabilities Act of 1990). The meaning of "substantial" has been made precise by a Supreme Court Ruling ("Sutton vs. United Airlines") in this matter with the following results:

Disability must be determined with reference to corrective measures; if the individual's visual impairment is corrected, the impairment does not "substantially limit a major life activity."

B.2 Interview Protocol

Thank you for agreeing to help us with our research on technology that may assist the mobility of blind and low vision pedestrians. Today you will be asked a series of questions about how you navigate while walking to your destinations. We would like to design technology that helps meet your needs on a daily basis, and because of this your participation and input is important.

Your answers will be completely confidential. If you feel uncomfortable answering any question, you may pass (leave it blank). For multiple-choice options, please select one answer per question.

If at any time you would like a break or to stop, please let the interviewer know.

B. Navigation & mobility

How long have you been using the following methods of assistance (if at all)?

☐ Cane ____years

☐ Guide dog ____years

☐ Other ____years

What is your preferred method of assistance while navigating to a destination in an area you are familiar with?

☐ Cane

☐ Guide dog

☐ Asking other pedestrians I pass

☐ No outside assistance

☐ Other ____

What is your preferred method of assistance while navigating to a new destination in an area you are not familiar with?

☐ Cane

☐ Guide dog

☐ Asking other pedestrians I pass

☐ No outside assistance

☐ Other ____

Imagine that you are travelling from your residency to a physician's office in an unfamiliar part of town. Please describe the types of information you would need to make this trip successfully. (modified from Golledge et al. 2004)

....
....
....
....
....

Landmarks- landmarks, obstacles, auditory and sensory cues, surface and tactile cues	
Street- names & number of streets to cross, traffic & crossing information, side of street, & sidewalk info.	
Route- paths and routes, travel directions, cardinal directions, how far and long	
Destination- address, corner, and block info.	

Building- names and layout info on doors and entrances	
Transit- transit information and stops and route info.	

While walking this imagined route, what types of information will be easiest to locate/identify, from your past experience?

....
....
....

While walking this imagined route, what types of essential information will be most difficult to locate/identify, from your past experience?

....
....
....

What are your preferred methods to assist with pre-trip planning?

....
....
....

How proficient are you are at each of these travel skills (on the scale from…)

(Golledge et al. 2004)	**Well below average** **1**	**Below average** **2**	**Average** **3**	**Above Average** **4**	**Well above average** **5**
General sense of direction	☐	☐	☐	☐	☐
Independent travel	☐	☐	☐	☐	☐

Unsignalized (or stop sign) street crossings	☐	☐	☐	☐	☐
Signalized street crossings	☐	☐	☐	☐	☐
New environment	☐	☐	☐	☐	☐

C. Questions pertaining to intersection crossing

Please imagine that you are half a block from a signalized intersection that you must cross. Please describe step-by-step your process of making it safety across this intersection.

....
....
....
....
....

How important is it to identify the following information while crossing this signalized intersection (on a scale from...)

(Golledge et al. 2004)	Very un-important 1	Unimportant 2	Neutral 3	Important 4	Very important 5
Knowing which type of intersection you are waiting at	☐	☐	☐	☐	☐
Knowing when it is safe to cross a signalized intersection	☐	☐	☐	☐	☐
Finding the location of the crossing signal button	☐	☐	☐	☐	☐
Knowing your alignment relative to the crosswalk	☐	☐	☐	☐	☐
Knowing your alignment relative to traffic	☐	☐	☐	☐	☐
Remembering your alignment relative to your walking approach to the intersection after searching for the apron/entrance to the crosswalk	☐	☐	☐	☐	☐
Remembering your alignment relative to your walking approach to the intersection after searching for the crossing signal button	☐	☐	☐	☐	☐
Knowing which direction to walk while crossing an intersection	☐	☐	☐	☐	☐

Knowing that you are approaching the curb on the opposite side of the road you are crossing	☐	☐	☐	☐	☐
Other from above description	☐	☐	☐	☐	☐
Other from above description	☐	☐	☐	☐	☐

From this list, what are the most important pieces of information you use while crossing a signalized intersection?

....
....
....

Have you ever crossed a roundabout intersection?

☐ No

☐ Yes: where was it? ....

Please describe step-by-step your process of making it safety across this intersection.
....
....
....
....
....

How important was it to identify the following information while crossing this roundabout intersection (on a scale from...)

(Golledge et al. 2004)	**Very un-important** **1**	**Unimportant** **2**	**Neutral** **3**	**Important** **4**	**Very important** **5**
Knowing when it is safe to cross the roundabout intersection	☐	☐	☐	☐	☐
Knowing your alignment relative to the crosswalk	☐	☐	☐	☐	☐
Knowing your alignment relative to traffic	☐	☐	☐	☐	☐
Remembering your alignment relative to your walking approach to the intersection after searching for the apron/entrance to the crosswalk	☐	☐	☐	☐	☐
Remembering your alignment relative to your walking approach to the intersection after searching	☐	☐	☐	☐	☐

for the crossing signal button					
Knowing which direction to walk while crossing the roundabout intersection	☐	☐	☐	☐	☐
Knowing that you are approaching the curb on the opposite side of the road you are crossing	☐	☐	☐	☐	☐
Other from above description	☐	☐	☐	☐	☐
Other from above description	☐	☐	☐	☐	☐

From this list, what are the most important pieces of information you use while crossing a signalized intersection?

....
....
....

D. Self-ratings: Technology

Do you currently own a mobile phone?

☐ No

☐ Yes: what is the make/model: ....

Aside from calls, what other phone applications do you use regularly?
....
....
....

What do you like about using your phone to make calls or use applications?
....
....
....

What do you dislike about using your phone to make calls or use applications?
....
....
....

Do you currently own or use a mobile navigation assistant / GPS?

☐ No

☐ Yes: what is the make/model: ....

What features on this device do you use most often?
....
....
....

What do you like about using this device?
....
....
....

What do you dislike about using this device?
....
....
....

Have you experienced an Advanced Pedestrian Signal before? These signals give you audio or tactile information about the state of the light at the intersection or the location of the crosswalks in addition to a light signal.

☐ No

☐ Yes

Please describe how the signal(s) worked:
....
....
....
....
....
....

If you used more than one device, did you prefer one over the other? Why?
....
....
....

What did you like about using this device?
....
....
....

What did you dislike about using this (or either) device?
....
....
....

If you could design a device that provided you with assistance approaching and crossing a signalized intersection how would it work? Please describe in terms of the information and warnings it provides you, the pedestrian (e.g., audio, tactile):
....
....
....
....
....
....

E. System Description and Opinions

The accessible traffic signal system we are developing can be accessed via a mobile phone. This system will detect the pedestrian's location and intended direction of travel at the intersection. It will also wirelessly access the intersection traffic controller to provide accurate and immediate feedback on the signal state of the intersection.

This system may also assist pedestrians with locating the sidewalk, the crosswalk pushbutton, and keeping the pedestrian within the crosswalk while crossing the intersection.

The pedestrian will receive alerts by whatever means are possible from their mobile phone. This may include verbal warnings from a headphone or from a speaker, or the cell phone vibration can be used to warn the pedestrian.

You may not be familiar with this type of device, but please try to respond by telling us how you *think* this product would meet your needs on a daily basis.

If included in a system similar to the one described, how acceptable would the following types of warnings be to you (on a scale from...)

(Golledge et al. 2004)	**Very unac-ceptable 1**	**Unac-ceptable 2**	**Indifferent 3**	**Acceptable 4**	**Very acceptable 5**
Sensing vibrations from a mobile phone in your pocket	☐	☐	☐	☐	☐
Sensing vibrations from a mobile phone held in your hand	☐	☐	☐	☐	☐
Sensing vibrations from a mobile phone held outward and aimed at the intersection to determine the correct direction of travel	☐	☐	☐	☐	☐
Listening to audio from	☐	☐	☐	☐	☐

your cell phone speakers					
A small clip-on shoulder or collar mounted speaker	☐	☐	☐	☐	☐
Headphones worn near the ears (bone phone)	☐	☐	☐	☐	☐
Single headphone worn over one ear	☐	☐	☐	☐	☐
Stereo headphones worn over both ears	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

Imagine you are walking West on Franklin and would like to cross Lyndale at the intersection. You are using a similar system to the one described. This system provides alerts through a headphone in one of your ears. Describe what words would you expect it to use to notify you about these situations:

You are approaching the intersection of Franklin/Lyndale.	
You have arrived at a location where it is safe to wait, but it is not safe to begin crossing.	
It is now safe to begin crossing Lyndale.	
You begin crossing at a time when it is not safe to be in the crosswalk.	
As you cross, the system determines you are walking outside of the crosswalk and it wants to direct you.	
You are approaching the opposite side of the street.	

For the same situation as was just described, imagine you are now using a system that provides alerts by vibrating your mobile phone. Describe the types of vibrations you would expect it to use to notify you about these situations, (e.g., one short/long vibration, a continuous series of vibrations):

You are approaching the intersection of Franklin/Lyndale.	
You have arrived at a location where it is safe to wait, but it is not safe to begin crossing.	
It is now safe to begin crossing Lyndale.	
You begin crossing at a time when it is not safe to be in the crosswalk.	
As you cross, the system determines you are walking outside of the crosswalk and it wants to direct you.	
You are approaching the opposite side of the street.	

F. Demographic information.

Your date of birth: MM: ________ / DD: ________ / YYYY ________

Your sex:
1☐ Female
2☐ Male

What is the highest level of education you have completed?

1☐ Some high school – no diploma

2☐ High school graduate or equivalent

3☐ Some college or Associate degree

4☐ Bachelor's degree

5☐ Advanced degree (MBA, PhD, etc.)

6☐ Other, please specify ____

What is your current marital status?

1☐ Single

2☐ Married (including common-law & unmarried partner)

3☐ Separated

4☐ Divorced

5☐ Widowed

6☐ Other, please specify ____

What is your total annual household income?

1☐ Less than $25,000

2☐ $25,000 to $49,999

3☐ $50,000 to $74,999

4☐ $75, 000 to $99,999

5☐ More than $100,000

APPENDIX C: SYSTEMS AND PROJECTS RELATING TO GPS FOR VISUALLY IMPAIRED

See also: http://en.wikipedia.org/wiki/GPS_for_the_visually_impaired

Current Applications that provide step-by-step directions using GPS to reference loaded maps.

Name	Manufacturer	System Description	Interface
Trekker Breeze (formerly VisuAide)	Humanware http://www.humanware.com/en-usa/products/blindness/talking_gps/trekker_breeze/_details/id_101/trekker_breeze.html	Output: Audio TTS Features: Real-time information detection (Intersections and Point of Interest) Real-time/offline map browsing (Route Preview) Route planning and recording (Guiding Rules) Flexible level of vocal information Vocal Point of Interest creation Access to GPS status information	Maestro handheld accessible computer – Pocket PC Weight: 600 g (1.3 lbs) Size (W'H'D): 87mm (3.4") x 134mm (5.26") x 27mm (1") GPS receiver Speaker Wireless keyboard (Bluetooth) (optional)
Trekker Breeze	Humanware http://www.humanware.com/en-usa/products/blindness/talking_gps/trekker_breeze/_details/id_101/trekker_breeze.html	Output: Audio TTS Features: Real-time information detection (Intersections and Point of Interest) Route planning and recording (Guiding Rules) Vocal Point of Interest creation Access to GPS status information	Hand-held unit with built-in GPS Weight: 7 ounces Size: 5x2x1 inches
StreetTalk VIP (GPS Solution for the PAC Mate Omni)	Freedom Scientific http://www.freedomscientific.com/products/fs/streettalk-gps-product-page.asp	Output: Audio TTS Braile Features:	GPS PAC Mate Omni system

		Real-time information detection (Intersections and Point of Interest) Real-time/offline map browsing (Route Preview) Route planning and recording (Guiding Rules) Vocal Point of Interest creation Ability to share routes with others	
BrailleNote GPS / Sendero GPS	Sendero Group http://senderogroup.com/shopgps.htm	Output: Audio TTS Braile Features: Real-time turn-by-turn directions Real-time/offline map browsing (Route Preview) Route planning and recording (Guiding Rules) Street names, intersections and nearby points of interest in vicinity. User defined points of interest in vicinity Braille output of street and business names GPS signal quality	Bluetooth GPS BrailleNote
Mobile Geo	Sendero Group http://www.senderogroup.com/shopmgeo.htm	Output: Audio TTS Braile support Features:	Windows Mobile-based Smartphone, Pocket PC, or PDA

		Real-time turn-by-turn directions Information provided for both pedestrian and vehicular navigation. Street names, intersections and nearby points of interest in vicinity. User defined points of interest in vicinity GPS signal quality	
Loadstone GPS (software)	Open source software by Shawn Kirkpatrick http://www.loadstone-gps.com/	Output: Audio TTS Braile support Features: Real-time turn-by-turn directions	Bluetooth GPS Symbian/Series 60 mobile device (Nokia)
Wayfinder Access (software)	Wayfinder Systems AB http://www.wayfinder.com/?id=3996&lang=nl-BE	Output: Audio TTS Braile support Features: Real-time turn-by-turn directions Information provided for both pedestrian and vehicular navigation. Street names, intersections and nearby points of interest in vicinity. Feedback on points of Interest (POI), crossings or favorites that can be restricted, prioritized, and presented according to their distance from your location.	Bluetooth GPS A mobile phone using the s60v2 and s60v3 platform Talks and Mobile Speak applications Data subscription (GPRS, EDGE or 3G/UMTS) from your mobile operator/ wireless carrier. Map (pay per continent)

APPENDIX D: JAVA CLASS DESCRIPTION

D-1 GpsService.java:

This class gets location updates from the GPS module on the phone and updates the latitude and longitude variables in *gpsData* class.

MEMBER FUNCTIONS:

onBind(Intent intent):

Default onBind function called, necessary for initiating any service. Implementation of this function is necessary only when other applications can use this service.

onCreate()

Initiates Location update service. Called when the service is first initiated.

Public Class: LocationManager

http://developer.android.com/reference/android/location/LocationManager.html

Public Method:

requestLocationUpdates(String provider, long minTime, float minDistance, PendingIntent intent)

Registers the current activity to be notified periodically by the named provider.

onDestroy()

Stops listening for updates from GPS.

onLocationChanged()

Determines action to be taken when location updates are received.

MEMBER VARIABLES:

String provider;

Indicates which provider to use. Hardcoded to “gps”.

LocationManager lm;

The location manager refers to the location service.

boolean gps_status;

Tells whether gps is activated or not

LocationListener ll

Listener to manage location updates.

D-2 gpsData.java:

This class contains two static variables, which are updated by *GpsService* class. These variables correspond to the current latitude and longitude respectively.

MEMBER VARIABLES

Double Latitude, longitude;

These refer to the current locations received from “GPSservice.java”.

D-3 DBOpener.java:

This class contains a handle to the local SQLiteDatabase, it creates a new database if one doesn’t exist already.

MEMBER FUNCTIONS

DBOpener(Context context, String name, CursorFactory factory, int version)

This function is used to retrieve handle for the database on the phone from the superclass which is sqllitehelper class.

onCreate()

If the database does not already exist this function is called. It inserts some values into the database.

NOTE: Values can be externally added as well, once we get the database handle. Sync service hasn’t been done yet.

Initialize()

Initializes the database. Only once instance of this database exists at a given time. Constructor called here.

getInstance()

Returns the instance of the database.

getDatabase()

Returns a writable database of the current instance.

Close()

Nullify the instance when no longer needed by user.

MEMBER VARIABLES

private static SQLiteDatabase *sqliteDb***;**

A writable instance of the database

private static DBOpener *instance*;

Instance of the database, only one exists at a time

public static String *MY_DATABASE_TABLE;*

Name of the table in the database to be handled

public static final String *SQL_CREATE_TABLE;*

String which stores the SQL query to create the table. Used in the onCreate function

public static String *DATABASE_NAME;*

Name of the database to be handled

public static int *DATABASE_VERSION;*

Database version to be used

D-4 Bluetoothvalidator.java:

This class contains a function to handle intents which are created when a Bluetooth device is found during scanning.

MEMBER FUNCTIONS

Bluetoothvalidator()

Initializes the device address list (nothing in the list at initialization) and sets bv.found to false

onReceive()

If a Bluetooth device has been found, this function is called to check if the device address is present in the current list of possible devices.

MEMBER VARIABLES

BroadcastReceiver mReceiver;

This register the onReceive function for the Action that a Bluetooth device has been found during scanning

Boolean found;

Set to true if address is present in the device list

protected List<String> dev_address_list;

Contains the list of Bluetooth identifiers found during the current scan.

D-5 WifiClient.Java:

This class helps connect to the server and helps the main function to retrieve phase and timing information

MEMBER FUNCTIONS

WifiClient(String URl)

It takes in the URL, and gets the response from the web-server. It then calls the getresponse() function which parses the response received

getResponse()

This function parses the response and sets phase, time and status variables.

getPhase(), getStatus() and getTime()

These functions retrieve Phase, Status and Time respectively.

GetText(HttpResponse response) and GetText(InputStream in)

These functions convert response from webserver into text format after removing header information.

MEMBER VARIABLES

String Phase;

Stores the phase information

Int timeleft;

Stores the time left in the current signal phase

String status;

Stores whether the user is permitted to walk or not walk in this phase

String response;

Stores the response received from the webserver

D-6 callBlocker.java:

This class is used to toggle from airplane mode to normal mode or vice versa when necessary.

MEMBER FUNCTIONS

callBlocker()

Initializes the intent filter for service state (Airplane mode / Non-Airplane mode) and also initializes other variables.

checkStatus()

Tells whether Airplane mode is turned on or not

toggle()

Toogles from airplane mode to normal mode or vice versa

Unregister()

Unregisters a receiver which looks for status changes

MEMBER VARIABLES

Context context;

The context of the main activity of the application

Boolean isEnabled;

Stores whether Airplane mode is enabled or not

IntentFilter atfilter;

Stores the intent corresponding to the state of the systems (in airplane mode or not). This is reflected in isEnabled.

D-7 Variables.java:

This class stores some important constants used in the application

MEMBER VARIABLES

Int wait_time;

Time to wait after list modification, at whch list is re-initialized.

Double delta;

Distance in terms of longitude and latitude in which neighboring identifiers are searched for during the initialization procedure. It defines a square grid of 2*delta X 2*delta, where current co-ordinates are at the centre of the grid.

Double threshold;

Distance in terms of latitude and longitude, within which it can be said that the user is near an intersection.

D-8 dbValues.java:

This stores information regarding the neighbors of the current identifier.

MEMBER VARIABLES

String s[];

Stores neighboring id's of the current identifier

Int d[];

Stores directions in which the neighboring ID's are with respect to current identifier.

Int Xing[];

Stores whether or not a crossing is involved to go from the current identifier to the corresponding identifier.

NOTE: All this information is retrieved directly from the database entry corresponding to the current identifier.

D-9 CompassService.java:

This retrieves data from the compass sensor and updates values in "compassData.java".

MEMBER FUNCTIONS

Register()

Registers 'mSensorManager' for updates from the sensor

Unregister()

Unregister any further updates from the orientation type sensor

onSensorChnaged()

Set value of Compassdata.angle to the updated value received from the sensor.

D-10 CompassData.java:

This stores the values regarding the inclination of the phone.

MEMBER VARIABLES

Int angle;

Corresponds to the angle in which the user is pointing.

D-11 Dbsgps2.java:

This class is the main class which includes several important functions. This class contains the main function and handles events occurring when the application is running. This controls the main screen of the application.

MEMBER FUNCTIONS:

TimerFunction()

Initially it checks if list of neighboring nodes was created. If the function was called but no results retrieved it would do nothing.

If a list of ids was retrieved, the timer function checks if any point in this list is close to the current co-ordinates (found through GPS). If any node is found, then Bluetooth validation is done (To see if corresponding identifier can be found by Bluetooth verification).

If Bluetooth verification is successful, then we'll update the current list to a new list including the current identifier and the neighboring nodes.

The function first checks if an identifier is found (i.e. Bluetooth verification for a node done).

If the identifier is found, then the function retrieves data from the database that gets information for the current identifier (identified by GPS & Bluetooth validation) and all its neighboring nodes.

NOTE: The basic functionality of this function is that it updates the list of nodes that can be potential next identifiers and checks if current location is close to one of these.

The function is called every one second, after an initial delay of 2 seconds.

ModifyList()

This function is called when the user enters a Bluetooth identified region. After he enters the region, the current list is modified by first erasing the entire list and then creating a new list, which includes the identified **id** (current identifier, confirmed using Bluetooth).

The remaining entries in the list are neighboring nodes of this node. All entries except **-1** are added to the list.

CreateInitialList()

This function creates the initial set of identifiers when the application is started. It scans a radius of 400 m. When no identifiers are found within the radius of 400 m, then the application waits for 20 seconds before calling this function again.

onCreate()

This function is called when the application is just started. It initializes all the services and all variables before initiating the timer function.

onPause()

This function is called when the application exits, it releases all the services. It stops the GPS updates, Bluetooth etc.

NOTE: Some other functions were also put up in this class for debugging, these functions will be removed later. The functions included are additional button handler and printlist().

onTouchListener()

This function detects touches made on the screen of the android. On the first touch no action is taken, however if the next touch is detected within a timeframe of 2 seconds, a "***double tap***" is detected.

After detecting a double tap, a new timer is checked if the user is near an intersection. If the user is not near an intersection, he is given a TTS message saying that ***"not near intersection"***. If the user is near an intersection, the function checks the direction. If there is an identifier in that direction, the following happens:

If there is no crossing in that direction the user is told that he can proceed without waiting
If there is a crossing in that direction the user is told that he needs to wait until some data is received through the wifi connection.
If the wifi connection is not present, the user is told about that
Else the user is told to wait until the signal corresponding to that phase is received.

To get the phase information a timer is initiated which checks at an interval specified whether the corresponding phase has been found or not.

onKeyDown()

The function acts the same way as the previous function, except the fact that it speaks out the information regarding the identifier towards which the user is pointing.

It can also be used to give information regarding the position of the user.

WC_TimerMethod()

This function checks wifi response from the web-server corresponding to the current intersection.

NOTE: Currently the server is not setup in a way that it can respond to any intersection. The URL being used needs to be modified according to intersection id.

MEMBER VARIABLES:

boolean in_list_creation_process

This variable indicates that the list of possible neighboring identifiers is being modified, when this is true the 'timerfuction' does not do ay processing.

boolean initial_list_formed;

This variable indicates that the initial list formed after the start of the application has been populated.

protected static List<String> *str_list*;

This refers to the list of possible next identifiers, initially the list is empty.

protected static List<Double> *dblList1*, *dblList2*;

This refers to the respective latitudes and longitudes of the identifiers in list of possible next identifiers, initially the list is empty.

protected static List<Integer> btp_list, xing_list;

btp_list at position "**i**" refers to whether Bluetooth identifiers are present at that corner specified by **i'th** in the the str_list array. xing_list tells whether a xing is present from current identifier towards the identifier the user is pointing towards.

private SQLiteDatabase sqliteDatabase;

SQLiteDatabase is a class defined by me, the variable sqliteDatabase gives a handle to the main program to retrieve data from the database by executing SQL queries.

private DBOpener opener;

opener is used to create a database if not created yet, if created, it just gets the instance of the databse from the DBOpener class. This database is used by sqliteDatabase variable.

private Cursor c;

When SQL queries are executed, this variable stores the index of the current result from the DB.

private Date initial_time, curr_time;

Durin initialization of the program, it could happen that no identifiers are found in the list, the difference of these two times is used to trigger another search at intervals of 20 seconds.

private Intent i;

This intent corresponds to the GPS service, and is used to start the GPS module.

private IntentFilter filter;

This IntentFilter is used to take action when Bluetooth scanning finds a device.

private Timer init_timer;

This timer function is used to update the list of neighboring identifiers on a regular basis (1 second interval) by calling the ‘timerfunction()’ at regular intervals.

private Timer wc_timer;

This timer function is used to find when the user can cross the street identifiers on a regular basis by calling the ‘WC_timerfunction()’ at regular intervals. Timer is initiated when Double Tap is received.

private double curr_latitude, curr_longitude;

These refer to the latitude and longitude information as received from the GPS module, initially set to -1.

public static String *EXTRA_DEVICE_ADDRESS* = "device_address";

Used for compatibility with ‘backport.android’ Bluetooth module.

private BluetoothAdapter mBluetoothAdapter;

This variable is used to control the Bluetooth adapter on the phone.

private IntentFilter filter;

This intent filter checks for updates from Bluetooth module indicating that a new Bluetooth device has been found.

private BluetoothValidator bv;

When the above intent is found, the ‘mReceiver’ function is called to handle the intent.

Private Boolean act_found;

When the node is close to intersection, this variable is set to true, otherwise it is set to false.

Private int Xing;

Tells whether the direction in which the user is currently pointing contains a crossing or not (0 for no crossing, 1 for 2,6 phase and 2 for 4,8 phase.

Private callblocker cb**;**

This will be used to toggle the phone from airplane mode t normal mode and back.

Private int choice;

This is used to indicate whether the min_distance_id needs Bluetooth verification or not.

protected WakeLock mWakeLock; **PowerManager** pm;

These are used to acqire wakelocks, so that the application always stays on top.

TextToSpeech tts; Boolean ttsActive;

tts handles text to speech conversion. ttsActive indicates whether the tts module is working or not.

APPENDIX E: ANDROID APPLICATION FLOWCHARTS

E.1 Cross Functinoal Flowchart

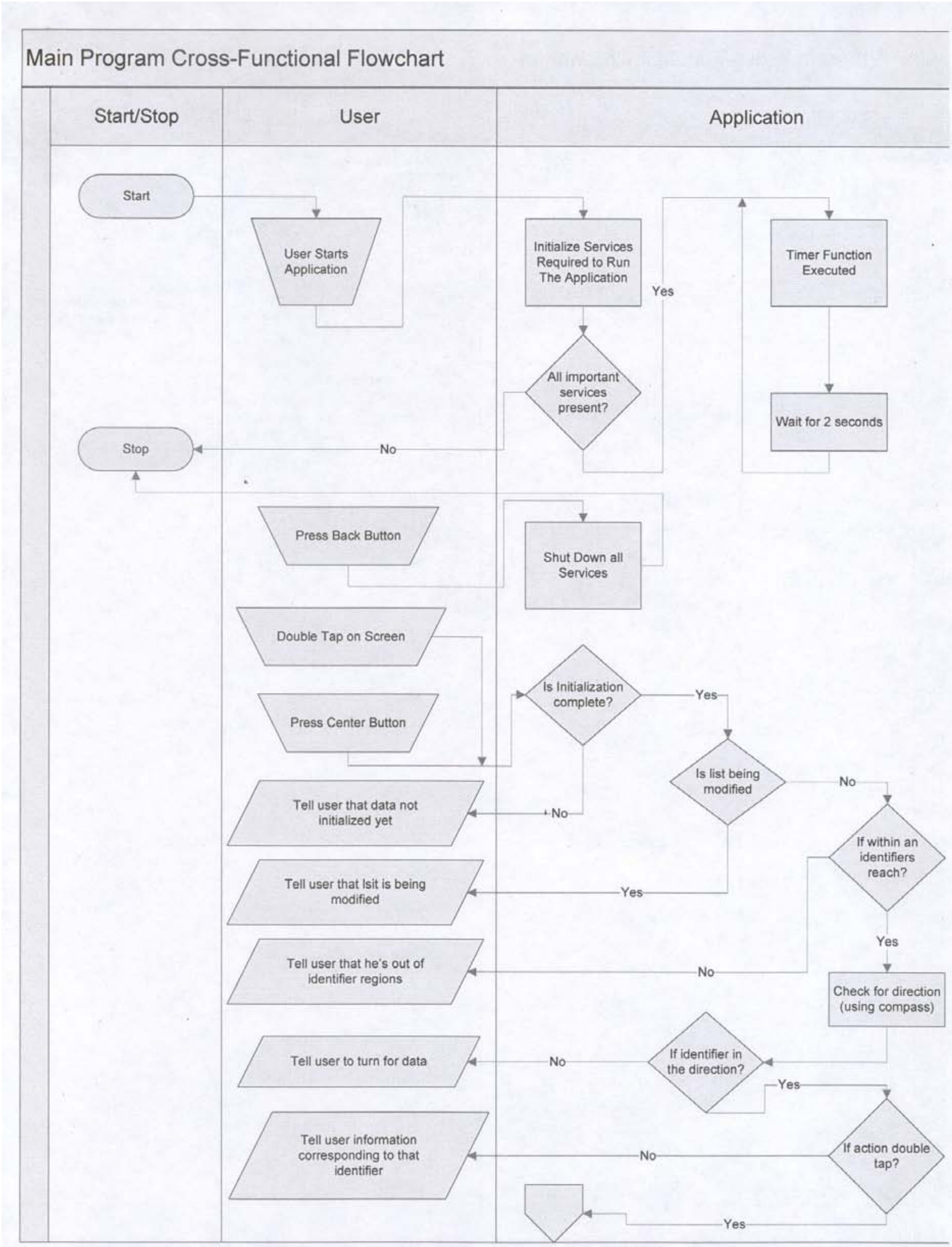

Figure E-1 Main Program Cross Functional Flowchart - Part 1

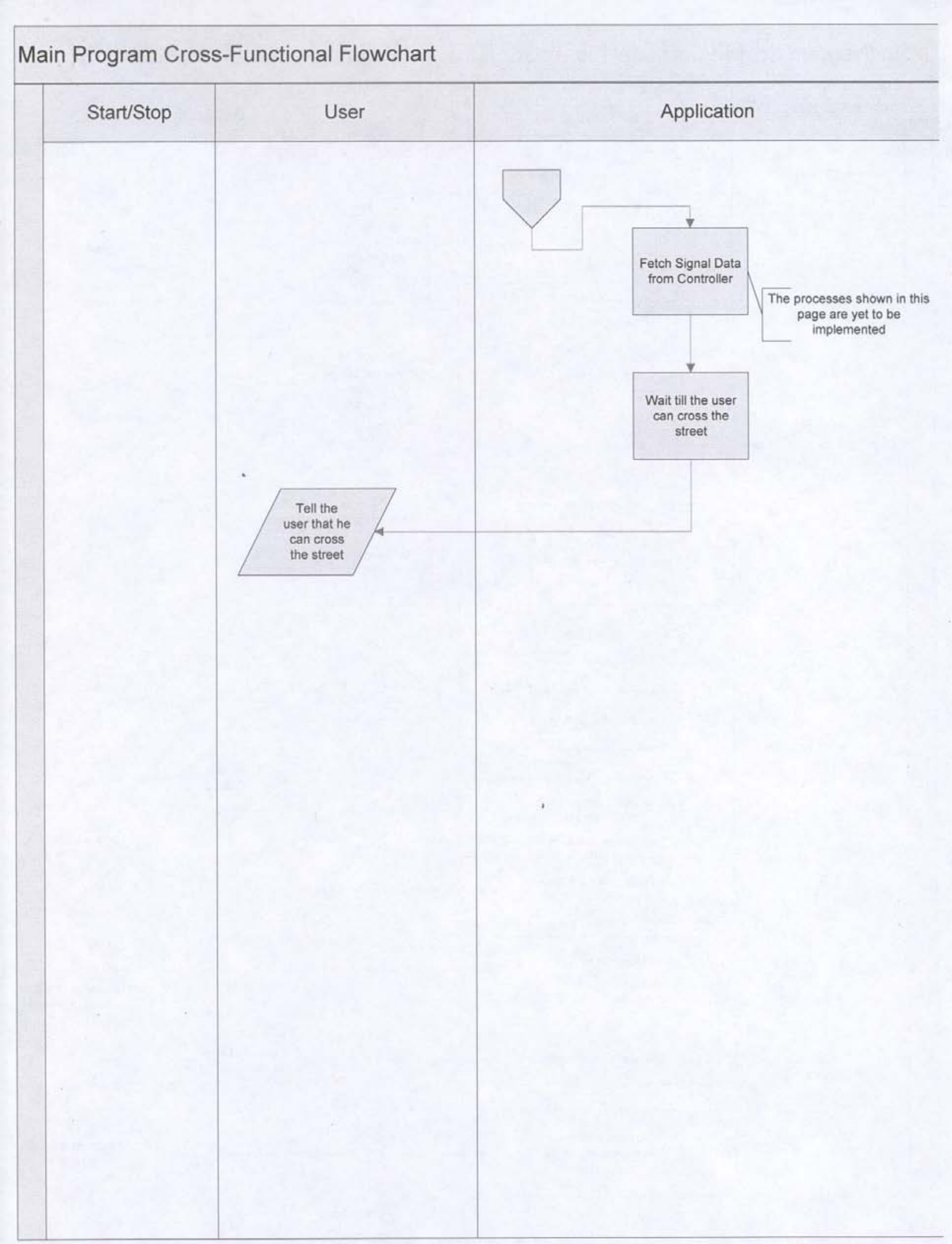

Figure E-2 Program Cross Functional Flowchart - Part 2

E.2 Individual Function

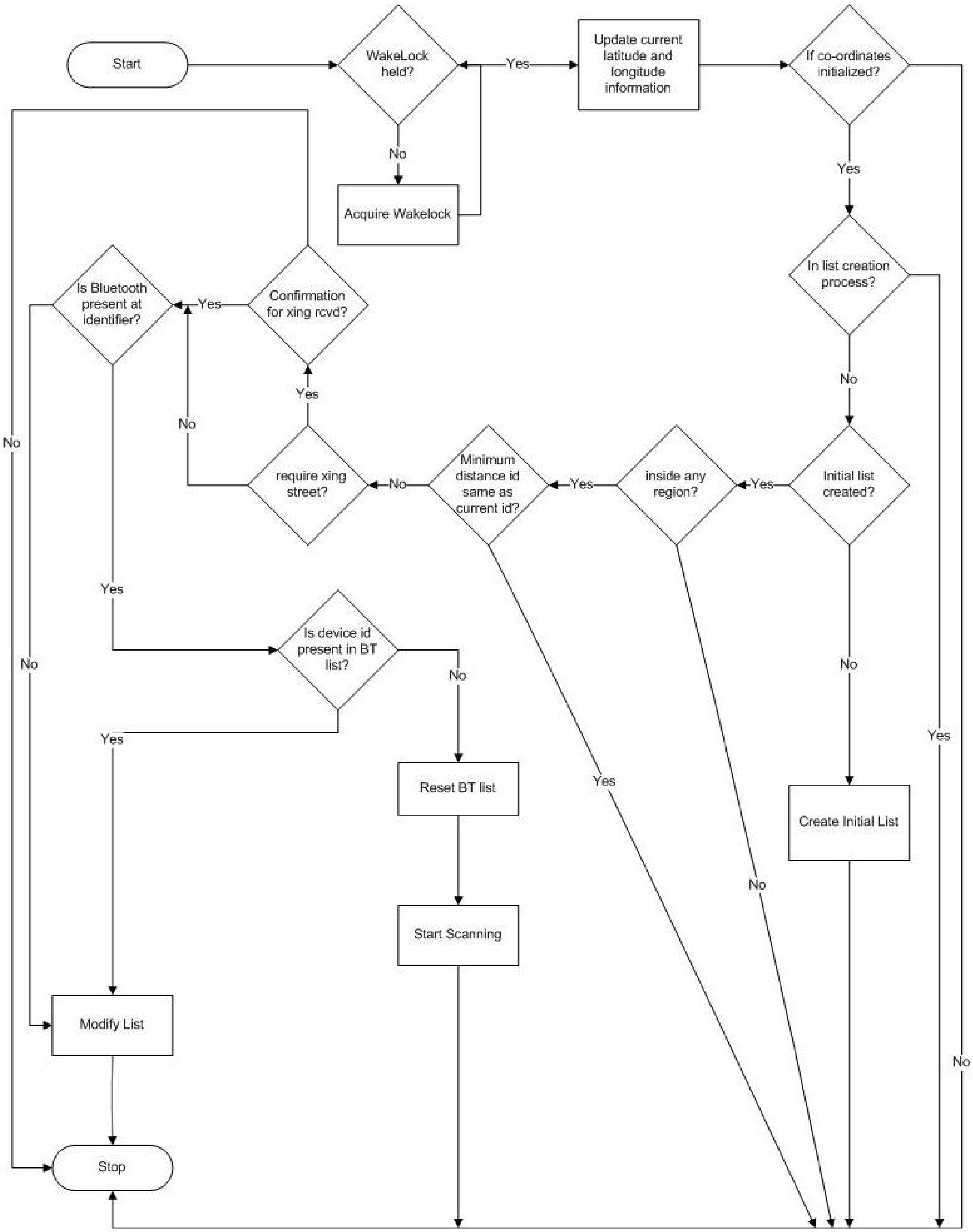

Figure E-3 Flowchart of the Timer Function

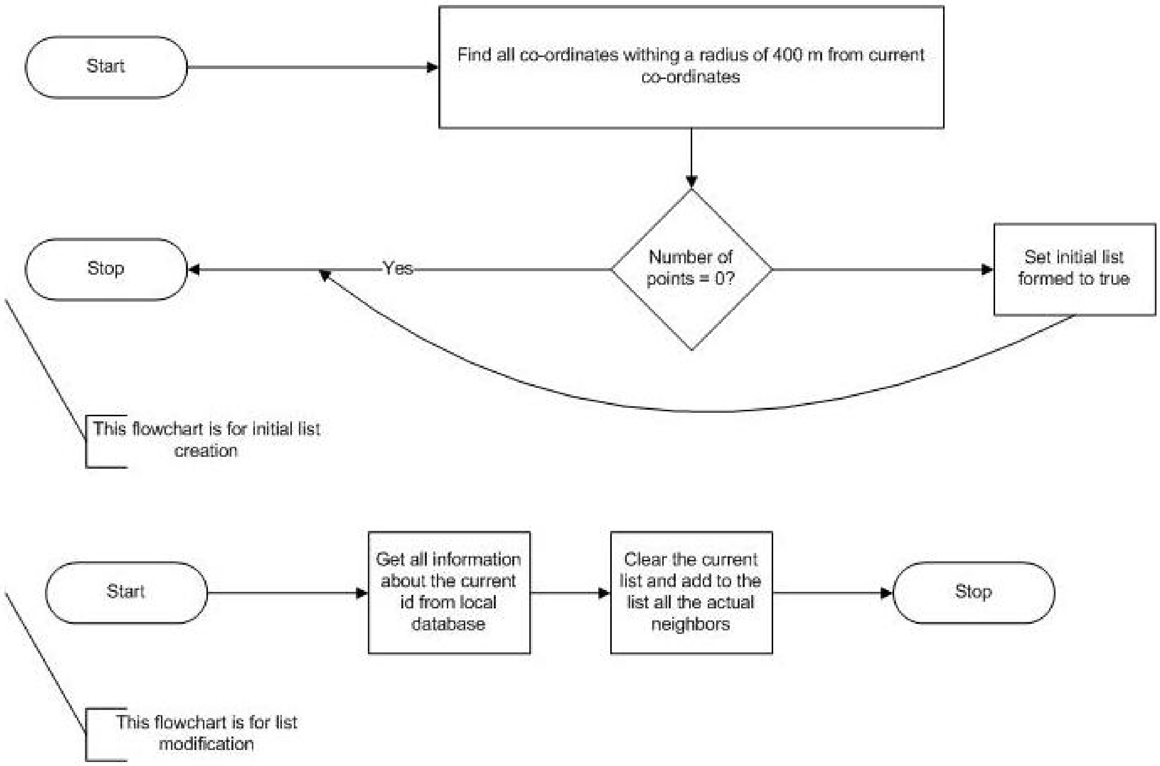

Figure E-4 Create Initial List & Modify List

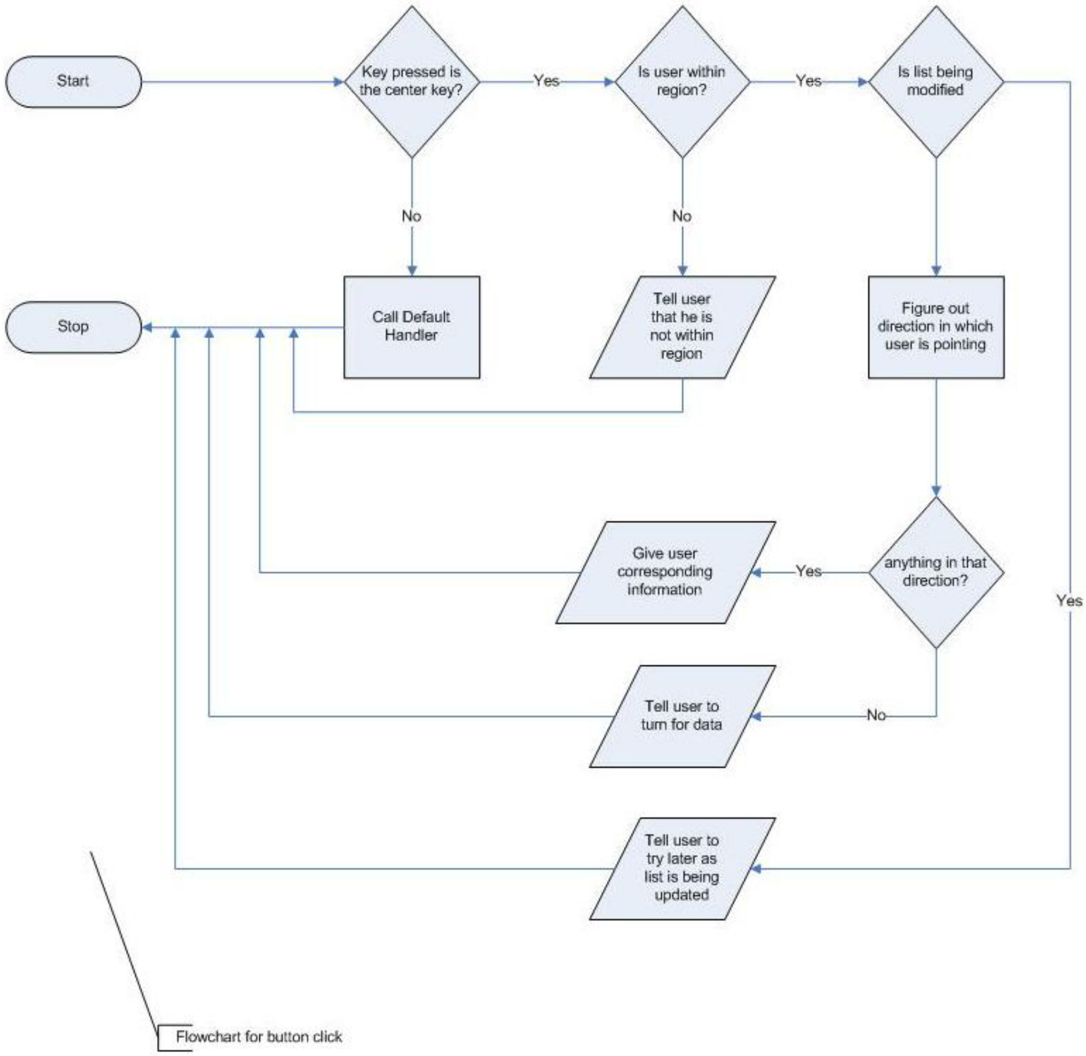

Figure E-5 Button Click

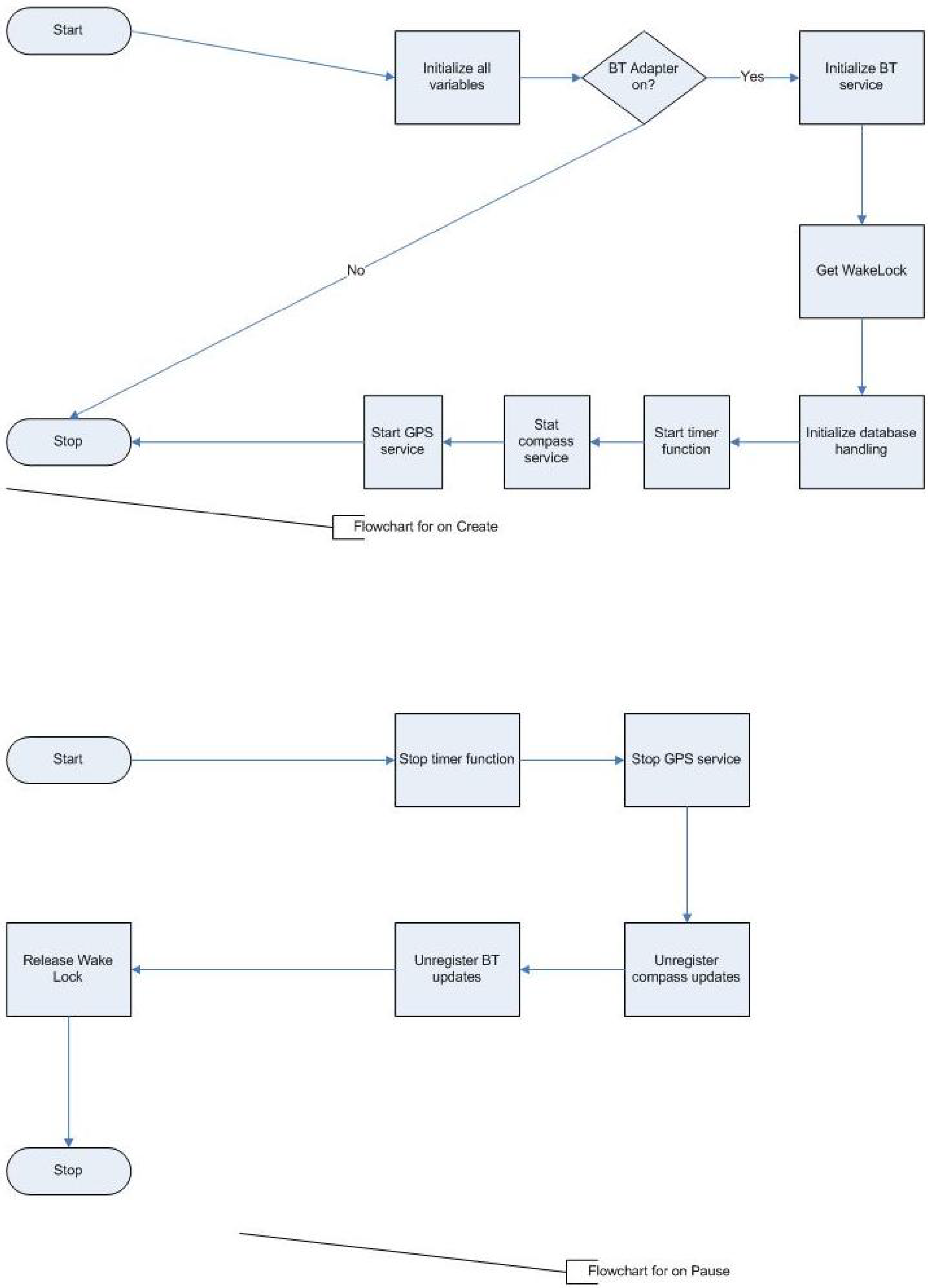

Figure E-6 Create & Stop Calls

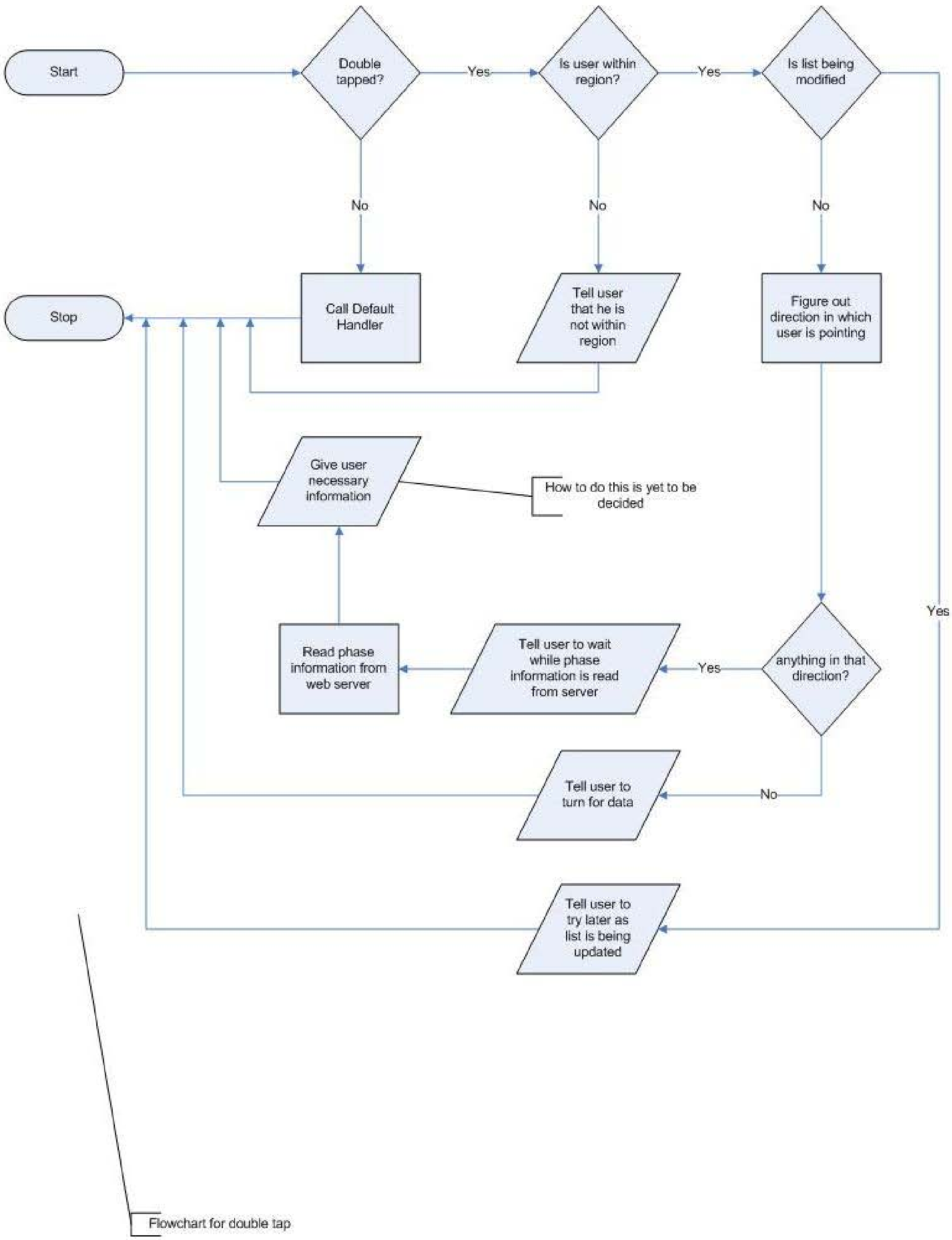

Figure E-7 Double Tap

APPENDIX F: CONNECTBLUE™ BLUETOOTH DEVICE

A USB programming interface board of the ConnectBlue™ module is illustrated in Figure F-1.

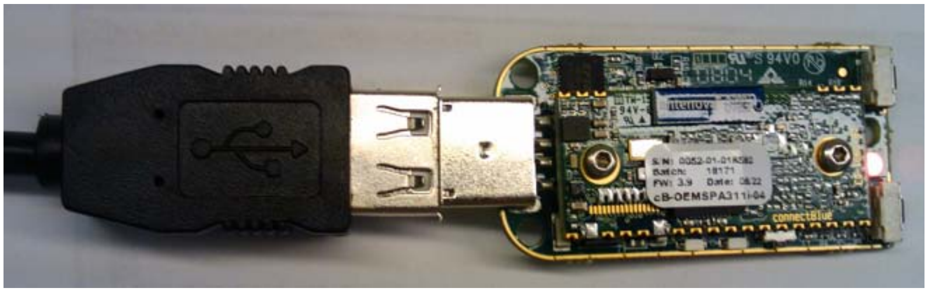

Figure F-1 Connectblue USB Programming Interface

ConnectBlue™ Bluetooth programming software interface is displayed in Figure F-2 to F-4 as follows.

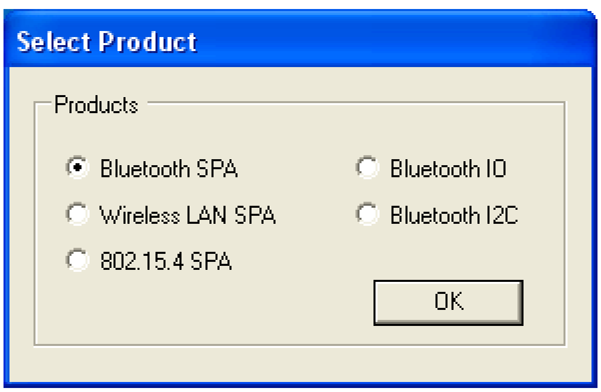

Figure F-2 ConnectBlue™ Graphical User Interface – Select Product

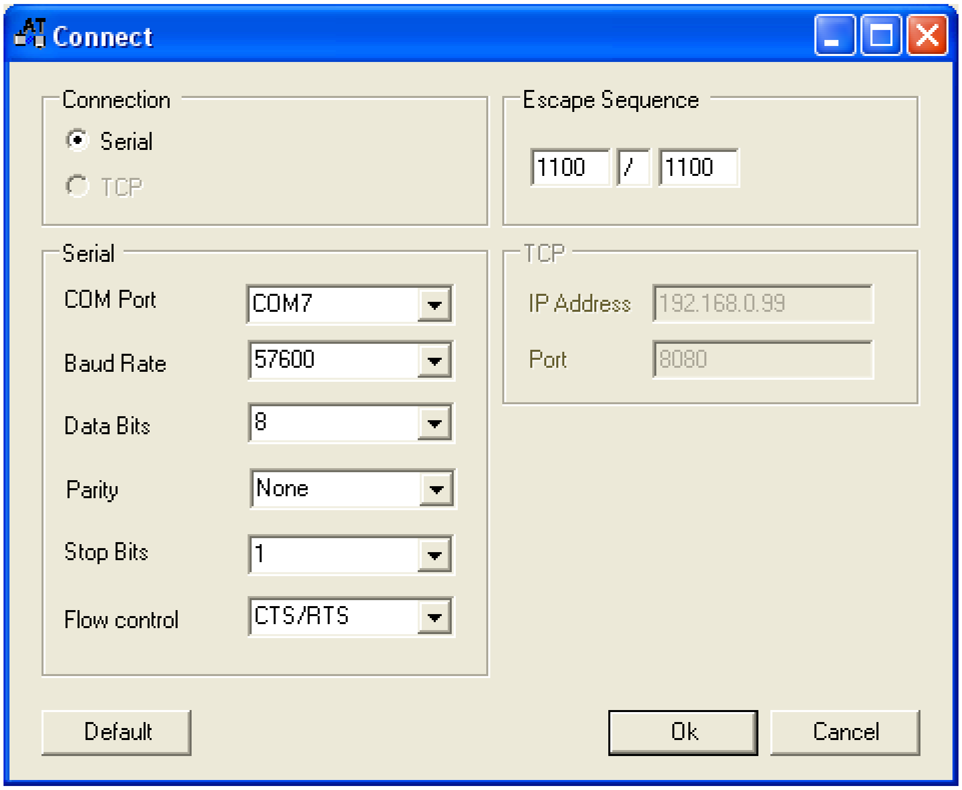

Figure F-3 ConnectBlue™ Graphical User Interface – Connection

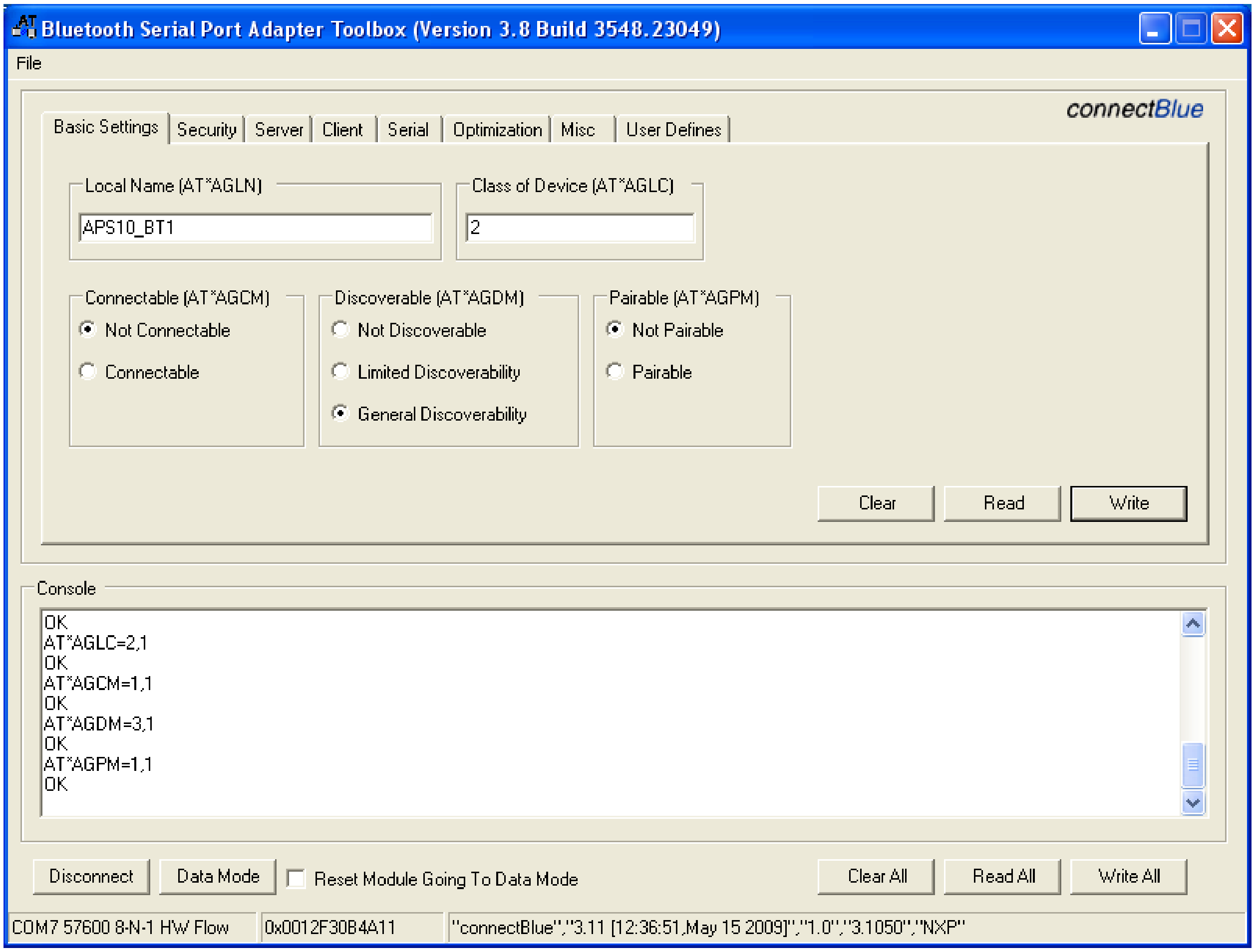

Figure F-4 ConnectBlue™ Graphical User Interface – Programming

APPENDIX G: SAMPLE JAVA SOURCE CODE

G.1 GPS Service.java

```
package dbs.gps5;

import android.app.Service;
import android.content.Intent;
import android.location.Location;
import android.location.LocationListener;
import android.location.LocationManager;
import android.os.Bundle;
import android.os.IBinder;

public class GpsService extends Service {

	// GPS stuff

	String provider; //which provider to use
	LocationManager lm; //the location manager which mages location updates
	boolean gps_status = false; //tells whether gps is activated or not

	/* Compulsory to implement this function for Services, doesn't do anything */
	@Override
  public IBinder onBind(Intent intent) {
    return null;
  }

	/* Initiates the GPS service, by starting receiving GPS updates */
	public void onCreate(){
		/* initializing GPS related objects */
		lm = (LocationManager) this.getSystemService(LOCATION_SERVICE);
		provider = "gps";
		lm.requestLocationUpdates(provider, 1000, 0, ll);
	}

	/* Stops receiving updates from GPS */
	public void onDestroy() {
		super.onDestroy();
		if ((lm != null) && (ll != null)) {
			this.lm.removeUpdates(ll);
		}
	}

	/* start listening for GPS updates */

	final LocationListener ll = new LocationListener() {
```

```
		/* Updates the latitude and longitude information */
		public void onLocationChanged(Location location) {

			gpsdata.latitude = location.getLatitude();
			gpsdata.longitude = location.getLongitude();
		}

		/* Sets gps status to false */
		public void onProviderDisabled(String provider) {
			gps_status = false;
		}

		/* Sets gps status to true */
		public void onProviderEnabled(String provider) {
			gps_status = true;
		}

		/* No Action */
		public void onStatusChanged(String provider, int status, Bundle extras) {
		}
	};

}
```

G.2 WiFiClient.java

```
package dbs.gps5;

import java.io.BufferedReader;
import java.io.IOException;
import java.io.InputStream;
import java.io.InputStreamReader;
import org.apache.http.HttpResponse;
import org.apache.http.client.ClientProtocolException;
import org.apache.http.client.HttpClient;
import org.apache.http.client.methods.HttpGet;
import org.apache.http.impl.client.DefaultHttpClient;
import android.util.Log;

public class WifiClient {

	/* Stores the response received from the web-server */
	private String response;

	/* Stores the phase of the traffic signal at the current intersection */
	private String phase;
```

```
/* Indicates whether the user can cross or not */
private char status;

/* time left in the current phase */
private int timeleft;

/* indicates whether response from web-server has been received or not */
protected boolean rcvd;

/* Get the response received from the web-server in text format */
public static String GetText(InputStream in) {
	String text = "";
	BufferedReader reader = new BufferedReader(new InputStreamReader(in));
	StringBuilder sb = new StringBuilder();
	String line = null;
	try {
		while ((line = reader.readLine()) != null) {
			sb.append(line + "\n");
		}
		text = sb.toString();
	} catch (Exception ex) {

	} finally {
		try {

			in.close();
		} catch (Exception ex) {
		}
	}
	return text;
}

public static String GetText(HttpResponse response) {
	String text = "";
	try {
		text = GetText(response.getEntity().getContent());
		Log.e("foundd",text);
	} catch (Exception ex) {
	}
	return text;
}

/* Initializing the Wificlient for a particular website, it gets all the fields
 * required by calling the parser*/
public WifiClient(String url) {
```

```
		rcvd = false;
		response = "";
		HttpClient client = new DefaultHttpClient();
		HttpGet method = new HttpGet(url);

		try {
			HttpResponse resp = client.execute(method);
			Log.e("foundd","c");
			response = GetText(resp);
			getResponse();
		} catch (ClientProtocolException e) {
			response = "no";
			Log.e("foundd","a");
			e.printStackTrace();
		} catch (IOException e) {
			response = "no";
			Log.e("foundd","b");
			e.printStackTrace();
		}
		rcvd = true;
	}

	/* This function does all the parsing */
	public void getResponse() {
		int start = response.lastIndexOf("Ph")+6;
		int end = response.lastIndexOf("Wa");
		int other = response.lastIndexOf("se");

		if ((start == -1)||(end == -1)){
			status = 'N';
			phase = "N";
			return;
		}

		phase = response.substring(start, start+3);

		if (response.charAt(end - 2) == 't') {
			status = 'D';
		}
		else {
			timeleft = Integer.parseInt(response.substring(end + 5, other - 1));
			if (timeleft < 3) {
				status = 'D';
			}
			else {
```

```
                    status = 'W';
                }
            }
        }

        //These function return respective fields to the main program
        public int getPhase(){
            if (phase.equals("4,8")){
                return 1;
            }
            if (phase.equals("2,6")){
                return 2;
            }
            return -1;
        }

        public char getStatus(){
            return status;
        }

        public int getTime(){
            return timeleft;
        }
}
```

G.3 myAPS_servlet.java

```
/*
 * myAPS_servlet.java
 *
 * Description:
 *     Send signal timing data
 * Note:
 * Created on 2/1/2010
 */

/**
 *
 * @author  Chen-Fu Liao
 * Sr. Systems Engineer
 * Minnesota Traffic Observatory
 * University of Minnesota
 * 200 Transportation and Safety Building
 * 511 Washington Ave. SE
 * Minneapolis, MN 55455
```

```
 *
 * @version 1.02
 * Include JNDI DataSource with MySQL DBCP
 */

import java.io.*;
import java.net.*;
import java.util.* ;
import javax.servlet.*;
import javax.servlet.http.*;
import javax.naming.InitialContext;


public class myAPS_servlet extends HttpServlet {
    // Data declaration
    String score_filename = "/home/cliao/sysAPS_Log" ;
    String logData="" ;

    /** Initializes the servlet.
     */
    public void init(ServletConfig config) throws ServletException {
        super.init(config);

    }

    /** Destroys the servlet.
     */
    public void destroy() {
        try {
        }
        catch (java.lang.Exception e) {
            System.out.println("Error (myAPS_servlet:destroy).") ;
        } ;
    }

    /** Handles the HTTP <code>GET</code> method.
     * @param request servlet request
     * @param response servlet response
     */
    protected void doGet(HttpServletRequest request, HttpServletResponse response)
    throws ServletException, IOException {

    response.setContentType("text/html");
    PrintWriter out = response.getWriter();
    out.println("<!DOCTYPE HTML PUBLIC \"-//W3C//DTD HTML 4.0 " +
                                "Transitional//EN\">\n" +
```

```
        "<HTML>\n" +
        "<HEAD><TITLE>Hello WWW</TITLE></HEAD>\n" +
        "<BODY>\n" +
        "<H1>Hello WWW</H1>\n" +
        "</BODY></HTML>");


}

/** Handles the HTTP <code>POST</code> method.
 * @param request servlet request
 * @param response servlet response
 */
protected void doPost(HttpServletRequest request, HttpServletResponse response)
throws ServletException, IOException {
  //processRequest(request, response);
  ObjectInputStream inputFromApplet = null ;
  PrintWriter out = null ;
    String header = "<html><body><p>Phae 1, red, time left 6 sec<br>" ;
    String tail = "</p></body></html>" ;

  try {
    // get an inputStream from Applet
    inputFromApplet = new ObjectInputStream(request.getInputStream()) ;
    logData = (String) inputFromApplet.readObject() ;
    //System.out.println( "Received request command: " + logData ) ;
    inputFromApplet.close() ;

    BufferedWriter outf = new BufferedWriter(new FileWriter(score_filename, true));
    outf.write(header+logData+tail);
    outf.flush();
    outf.close();

    // send back confirmation to applet
    out = new PrintWriter(response.getOutputStream()) ;
    response.setContentType("text/plain") ;
    //out.println("Signal Timing - Request Received.") ;
      out.println(header+logData+tail) ;
    out.flush() ;
    out.close() ;

  }
  catch (Exception e)
  {
    System.out.println( "Error I/O (doPost).") ;
    System.out.println(e) ;
```

```
        }
    }

    /** Returns a short description of the servlet.
     */
    public String getServletInfo() {
        String msg = "myAPS Servlet";
        return msg ;
    }

}
```

APPENDIX H: LIST OF APS EQUIPPED INTERSECTIONS IN THE CITY OF MINNEAPOLIS

H.1 Existing APS Intersections

Franklin Avenue SE & East River Parkway
Cedar Avenue & 5th Street S
Washington Avenue S/Cedar Avenue & 15th Avenue S
Hennepin Avenue S & 29th Avenue S
University Avenue & Central Avenue
2nd Avenue S & 12th Street S
Washington Avenue S & 19th Avenue S
Olson Memorial Highway & Penn Avenue
Hennepin Avenue & Central Avenue
Lake Street & 28th Avenue S
Lake Street & 33rd Avenue S
Lyndale Avenue S & Franklin Avenue
Lyndale Avenue S & 54th Street
7th St N & Van White Memorial Bl

H.2 Additional APS Intersections (will be installed in spring 2011)

Hiawatha Ave & 26th St
Hiawatha Ave & 28th St
Hiawatha Ave & Lake St
Hiawatha Ave & 32nd St
Hiawatha Ave & 35th St
Hiawatha Ave & 38th St
Hiawatha Ave & 42th St
Hiawatha Ave & 46th St
Hiawatha Ave & 50th St
Lake St & Excelsior Blvd
Hennepin Ave/Lyndale Ave & Vineland Pl
University Ave & Oak St
Convention Center Mid-Block Crossing on Grant St
Convention Center Mid-Block Crossing on 2nd Ave S.