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Using a Smartphone App to Assist the Visually Impaired at Signalized Intersections

Final Report

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16. Abstract (Limit: 250 words)

The blind and Visually Impaired (VI) rely heavily on walking and public transit for their transportation needs. A major challenge for this population is safe crossing of intersections. As a result of the American with Disabilities Act (ADA), Accessible Pedestrian Signal (APS) systems at signalized intersections have improved significantly since 2000. However, these systems still have shortcomings for both users and municipalities, and new approaches are needed to adequately serve pedestrians with low vision. As part of our ongoing effort to develop a prototype Mobile Accessible Pedestrian Signal (MAPS) application for the blind and VI, we interviewed ten blind and low-vision people to better understand what types of information they use at intersection crossings and to identify information types that could assist them. With these survey results, a MAPS prototype was developed that provides signal and intersection geometry information to Smartphone users at signalized intersections. User interaction is via simple tactile input (single or double-tap) and Text-To-Speech (TTS) technology. A MAPS prototype was developed and tested to evaluate the functionalities of providing signal and orientation information to the visually impaired travelers at signalized intersections. This proposal will build upon the developed MAPS and investigate how blind and low-vision individuals gain their spatial knowledge surrounding an intersection and how the MAPS can be used to support their decision-making strategy at intersection crossings.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AADT	Annual Average Daily Traffic
ACB	American Council of the Blind
ADA	American Disability Act
App	Application Software for Mobile Device
APS	Accessible Pedestrian Signal
ATC	Advanced Traffic Controller
BIU	Bus Interface Unit
CID	Controller Interface Device
COMS	Certified Orientation and Mobility Specialist
CTS	Center for Transportation Studies
CWA	Cognitive Work Analysis
DB	Database
DCU	Data Collection Unit
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
IMEI	International Mobile Equipment Identity
I/O	Input / Output
IRB	Institutional Review Board
ITS	Intelligent Transportation Systems
O&M	Orientation and Mobility
LBS	Location Based Service
MAPS	Mobile Accessible Pedestrian Signal
MnDOT	Minnesota Department of Transportation

MTO	Minnesota Traffic Observatory
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NEMA	National Electrical Manufacturers Association
NFB	National Federation of the Blind
PB	Pushbutton
RFID	Radio Frequency Identification
RITA	Research & Innovative Technology Administration
SD	Standard Deviation
SDLC	Synchronous Data Link Control (SDLC)
SPaT	Signal Phasing and Timing
SQL	Structured Query Language
TAD	Travel Assistance Device
TTS	Text To Speech
UI	User Interface
UMN	University of Minnesota
USB	Universal Serial Bus
VA	Veteran Affairs
VIST	Visual Impairment Services Team
VLR	Vision Loss Resources
VPN	Virtual Private Network
WDA	Work Domain Analysis
WHO	World Health Organization

EXECUTIVE SUMMARY

According to the fact sheet published by the World Health Organization (WHO) in 2011, there are about 284 million people who are visually impaired worldwide, and 39 million of them are blind. Among individuals aged 15 years and older, approximately 7.8 million people (3.4 percent) have difficulty seeing words or letters in ordinary newspaper print, and 1.8 million of these reported being completely unable to see (U.S. Census, 2008).

People with vision impairment have different perception and spatial cognition as compared to 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 blind people in their attempts to find their way and further limit their transportation accessibility and mobility.

After receiving orientation and mobility (O&M) training from O&M specialists, people with vision impairment usually can travel independently to known places along familiar routes by relying on a white cane or a guide dog. However, neither a white cane nor a guide dog provides spatial awareness (such as signalized intersection information/street names, bus stops/stations) along a path or guidance information to a destination. Travelers with vision impairment may have difficulty planning or feel anxious about unfamiliar routes, often obtaining and closely following detailed turn-by-turn instructions to reach new destinations. Physical and psychological barriers discourage people who are blind or those with vision impairment from traveling in unfamiliar environments.

In addition to a cane and guide dog, many aids based on various types of technologies have been developed in the past, and several of these are commercially available to support both indoor and outdoor wayfinding and navigation for people who are blind and visually impaired. Most have significant limitations; to our knowledge, there is currently no single technology that can offer a complete solution for both indoor and outdoor navigation and guidance for people who are blind or for individuals with vision impairment. The visually impaired pedestrians 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 blind pedestrians make safe crossing decisions, ten blind and low-vision individuals were interviewed in a previous project. 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 his or her 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 Mobile Accessible Pedestrian Signals (MAPS) system was, thereafter, developed (Liao et al., 2011) by integrating sensors on a smartphone and incorporating user's need to provide appropriate decision support at intersection crossing. Wireless technologies (Bluetooth, cellular or Wi-Fi), controller interface device (CID) that provides Signal Phasing and Timing (SPaT) information, and a smartphone app were integrated to provide environmental information and personalized signal information to blind pedestrians.

Two simple user input interfaces were developed for blind users, as described as follows.

1. A single-tap command on the smartphone screen while pointing to a desired direction will request intersection geometry information, such as street name, direction, and number of lanes, at a corner of an intersection. For example, it will announce "*You are pointing to east, Harvard street, 2-lane*', while pointing the phone to the east with a single tap. The MAPS application will also provide direction information if there is no crossing information in the direction users pointed to. For example, it will announce, for example, "*No information in northeast. Please turn for data*", while pointing the phone to the middle of an intersection with a single tap.

2. While pointing the phone toward a desired direction of crossing, the double-tap input will confirm the crossing direction and submit a request for pedestrian walk signal. The smartphone application will then wirelessly request signal timing and phasing information from the traffic signal controller. Speech feedback to the blind pedestrians is then announced through the Text-To-Speech (TTS) interface already available on smartphones. For example, the smartphone will announce '*Please wait for walk signal*' every 5 seconds after a double-tap. As soon as the walk sign is on, the smartphone will vibrate for 1 second to alert the user and then announce, '*walk sign is on, xx seconds left*'. When it's about 5 seconds before the ending of a walk phase, the smartphone will vibrate again then announce '*5 seconds left*' to alert the user finishing the crossing soon.

The primary goal of the current work is to validate the use and functioning of the MAPS system in real-world application. The purpose is to identify if the smartphone app could effectively provide geometry and signal timing information and thus provide decision support for the visually impaired pedestrians. This was accomplished by recruiting a representative sample of pedestrians (18 visually impaired participants, 11 male and 7 female) from metro areas in the Twin Cities across a range of ages (average age is 44.2 with standard deviation, SD = 15.2).

Participants were given a brief tutorial (10-15 min) on how to operate a smartphone device including pointing to different directions for geometry and signal timing information. Participants were then asked to perform one crossing task at the first intersection already equipped with APS system and two crossing tasks at second intersection with and without the use of the MAPS system. Objective measures, such as walk speed at sidewalk and crosswalk, in-position time, and time to step into crosswalk, were analyzed to evaluate users' performance while using different types of systems. The in-position time is defined as the time duration from the participant arriving at an intersection to the beginning of waiting to cross. The time to step into crosswalk is defined as the time duration between when the walk sign is turned on and the participant actually steps onto the crosswalk.

In addition, the current work sought to evaluate the usability of the MAPS system to better understand users' perceptions of workload, satisfaction, usefulness, and willingness to use the information presented by the smartphone application.

Key findings from the field experiments are summarized as follows:

- 50% of the participants own and use a smartphone device.
- Cane and guide dog are the preferred methods of navigation assistance.
- 95% of the participants considered their travel skills as average, above average or well above average (Self-assessed travel skills include sense of direction, independent travel, and signalized intersection crossing).
- Pushbutton locating tone at APS intersection is helpful.
- 65% of the participants preferred using MAPS system over regular pushbutton.
- 82% of the participants reported MAPS system provides helpful geometry information.
- 59% of the participants reported MAPS system provides helpful signal information.
- Crosswalk speed is significantly faster than the sidewalk speed at intersection #1 (equipped with APS system), but no significant difference between the sidewalk and crosswalk speed at second intersection was found.
- Average pushbutton searching time is 7.8 and 26.6 seconds for the APS and regular pushbutton, respectively. (Note: MAPS system does not require finding a pushbutton).
- Average in-position time using MAPS system (9.8 sec) is lower than the in-position time using APS (14.5 sec) and regular pushbutton (34.8 sec).
- On average, the participants wait about 3.1 sec to step into crosswalk at APS intersection after walk sign is on. The average time to step into crosswalk at non-APS intersection is 7.1 sec without using MAPS device and 5.5 sec while using the MAPS assistance.
- No significant difference in number of veering at both intersections (Note: couple guide users veered when the dog was distracted by people nearby).
- The participants reported the MAPS system is moderately useful (0.95 using bipolar scales between -2 and 2).
- Participants reported the MAPS system is moderately satisfying (1.04 using bipolar scales between -2 and 2).
- 79% of the participants understand the purpose of the system.

- 71% of the participants understand the process of the system.
- 65% of the participants are confident with the performance of the system.
- Overall, 57% of the participants trust the MAPS system.

The single and double-tap user inputs seem relatively easy for the visually impaired participants to maneuver. However, the 15-minute tutorial on how to properly use the device is not sufficient. There is still a learning curve for users to understand how the system works. For example, a common issue found from the field experiment is that the participants usually point the phone to a desired direction and immediately bring the phone to their ears in order to clearly hear the auditory message at a busy intersection. The MAPS system often was confused by the desired direction of information when users bringing the phone immediately to their ears before the orientation measurements from the digital compass are stabilized.

In addition to the direction issue, the system was tested at an experiment site several times without GPS signal reception issue. However, a few participants experienced incorrect geometry information due to the fact that the GPS receiver on the phone was not able to identify which side of the street a user was locating. To ensure the reliability of identifying user location, a Bluetooth geo-ID, as we previously suggested for urban areas, is needed to determine users' location at a signalized intersection. Additional enhancements, such as reducing the latency of signal data communication and automatically learning the walk phase duration, have been made to the existing system. This will allow the MAPS to provide walk time countdown information to visually impaired pedestrians if they select to hear the countdown announcement from user configuration settings in the future.

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 in a more cost-effective manner. Although the MAPS system is primarily targeted toward the blind and the elderly, there are also potential benefits for people with low vision and sighted pedestrians who may be distracted (while, for example, talking or texting on their cell phone) at the intersection crossing.

In the future, we would like to explore alternatives to make the system hands-free and include user configurable settings for selectable vibration pattern, message frequency, and speech rate as suggested by the participants. We also would like to use this smartphone-based approach to investigate solutions for navigating visually impaired pedestrians at work zones or bus stops by incorporating Bluetooth Geo-ID or other positioning technologies.

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 evaluate and validate a smartphone-based decision support system while providing geometry and signal information to the blind and visually impaired pedestrians at signalized intersections. Both objective and subjective measures were developed to evaluate system usefulness, trust and user's satisfaction.

1.2 Brief History of Accessible Pedestrian Signals (APS)

The audible pedestrian signals first appeared in 1920's 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 and 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).

Apostolopoulos et al. (2012) developed a system to guide people with vision impairment through buildings using sensors on smartphones. The system takes advantage of feedback from a visually impaired user, who confirms the presence of landmarks. The system then calculates the user's location in real time and uses it to provide audio instructions on how to reach the desired destination. Estimation of users' step length is a critical parameter in the navigation model.

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.

To overcome the lack of accessibility of touch-screen-based mobile platforms, Apple Inc. has (http://www.apple.com/) included assistive technology as standard features for people with disabilities. For example, the VoiceOver screen reader feature on iPhones allows the device to speak the names of the onscreen menu to users. It also allows people with vision impairments to interact with the device via gesture combinations. The VoiceOver feature allows a user to touch the screen of an iPhone to hear a description of the item under the finger. The uses can then gesture with a double-tap, drag or flick to navigate the phone (http://www.apple.com/accessibility/iphone/vision.html). The Android community (http://www.android.com/) is also developing similar feature for voice browsing.

1.3.5 Verbal Guidance and Usability

Gaunet and Briffault (2005) developed a set of verbal guidance rules for assisting visually impaired pedestrians in navigating through urban areas. Gaunet (2006) conducted navigational experiments in simple structured, and complex unstructured urban areas. The findings offer interesting perspectives for guidance rules originating from verbal instructions given to visually impaired pedestrians. Gaunet suggested that these instructions could also be used by sighted users with a few specific modifications.

Roentgen et al. (2011) evaluated four electronic navigational devices for the visually impaired. Five-point scale of D-Quest (Wessels & de Witte, 2003) based questionnaire in seven aspects (dimension, weight, adjustment, safety, simplicity, comfort, and effectiveness) was used in combination with open questions to access 18 participants' subjective experiences. They concluded that participants' preferences regarding device usability and functionality linked closely with individual's O&M and computer skills, and their knowledge and expectations of the devices' functional ability (Roentgen et al., 2011).

Havik et al. (2011) evaluated the effectiveness of different types of verbal information provided by electronic travel aids in assisting wayfinding performance among 24 visually impaired users. The results suggested that a combination and route and environmental information are preferred by the participants, even though the combined information did not always result in an optimal wayfinding performance. They recommended including distance information to next information point and more landmarks or information points in the environment.

1.4 Report Organization

The rest of this report is organized as follows. The mobile Accessible Pedestrian Signal (MAPS) system architecture and software design are discussed in Section 2. Experiment design, procedures and performance measures are included in Section 3. Experiment results are presented in Section 4. Lesson learned and future works are discussed in Section 5. Finally, conclusion is presented in Section 6.

2 MOBILE ACCESSIBLE PEDESTRIAN SIGNAL (MAPS)

2.1 Background

After receiving orientation and mobility (O&M) training from O&M specialists, people with vision impairment usually can travel independently to known places along familiar routes by relying on a white cane or guide dog. However, neither the white cane nor the guide dog provides spatial awareness along a path or traffic signal information at an intersection. Travelers with vision impairment may have difficulty planning or feel anxious about unfamiliar routes, often obtaining and closely following detailed turn-by-turn instructions to reach new destinations.

In addition to a cane and guide dog, many aids based on various types of technologies have been developed in the past. Several of these are commercially available to support both indoor and outdoor wayfinding and navigation for people who are blind. Several of these technologies aim to address the indoor and outdoor wayfinding problem separately. These solutions generally do not provide intersection geometry and traffic signal information for pedestrians who are blind or visually impaired.

The newer generation of Accessible Pedestrian Signal (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. Currently, each APS system costs over $6,000 per intersection plus labor. There is limited number of intersections equipped with the APS system due to limited amount of resources available to the public agency. In US, there is no standard pushbutton location and it often requires additional stub for installing pushbutton station poles.

Modern smartphone devices containing GPS, a digital compass, motion sensors, and Bluetooth interfaces have become ideal candidates for the necessary portable computing portion of the system. Recent advancements in positioning technologies, wireless infrastructures, smartphones, and mapping services have already enabled large-scale pedestrian navigation services such as NAVITIME (http://www.navitime.com/) for the sighted.

As part of our previous effort to develop a prototype Mobile Accessible Pedestrian Signal (MAPS) application for providing signal timing and intersection geometry information to people with vision impairment, we previously conducted a survey to better understand the challenges experienced by the visually impaired pedestrians and the types of information they use at intersection crossings (Liao et al., 2011). Various information modalities that can assist them were also identified. Ten pedestrians who are blind or have low-vision were interviewed with several questions regarding their vision, navigation, and orientation experience, and their use of assistive technologies in wayfinding.

Key recommendations for a mobile decision support system from the user survey are listed as follows.

1. Need additional information about the intersection and signal timing
2. Auditory message should be brief and clear
3. Use tactile feedback for warning
4. Activate pushbutton automatically or from the mobile device
5. Decision support system should not interfere with user's wayfinding ability (e.g., using cane, listening to traffic)

A MAPS prototype system was developed for people who are blind and visually impaired as an alternative to the existing APS design based on input from the Minnesota Department of Transportation (MnDOT) and the City of Minneapolis who felt that the cost of maintaining the APS after their installation was "out of control". The goal of the MAPS system is to integrate information from sensors that are commonly available on a smartphone in determining user location and orientation. The mobile system can wirelessly communicate with the traffic signal controller to obtain real time signal phasing and timing (SPaT) information, which together can then inform the pedestrian with vision impairment as to when to cross and how to remain aligned with the crosswalk.

2.2 System Objectives

The first objective is to provide intersection geometry, traffic signal information and automatic pedestrian phase request through a smartphone device. A smartphone application prototype will integrate available sensors on the phone to determine a user location and orientation with respect to an intersection. The smartphone app then wirelessly communicates with a traffic controller and receives near real-time signal timing and phasing updates. Corresponding signal phasing information is 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, # sec left*' will be broadcasted through Text-to-Speech (TTS) interface to support decision making at crossing. Automatic pedestrian pushbutton request 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 second objective is to evaluate the usability of the system and users' trust while using this system at a signalized intersection. Both subjective and objective measures are developed to evaluate the performances such as speed on crosswalk versus sidewalk, in-position time and time to step into crosswalk. The in-position time is defined as the time duration from the participant arriving at an intersection to the beginning of waiting to cross. The time to step into crosswalk is defined as the time duration between the walk sign is turned on and the participant actually steps onto crosswalk.

2.3 System Architecture

A smartphone app was initially developed using an Android developer phone OS 1.6. It was also tested on HTC (http://www.htc.com/us/) and Samsung (http://www.samsung.com/us/) Google phones running Android OS 2.x. The MAPS application integrates digital compass, GPS, Wi-Fi, and Text to Speech (TTS) interface to identify user location and obtain signal information.

The system diagram of MAPS data communication is illustrated in Figure 2-1. For field experiment, a Smart-Signal unit, or traffic Data Collection Unit (DCU), was installed in a TS2 traffic signal controller cabinet to obtain signal timing and phasing information through the Synchronous Data Link Control (SDLC) interface, i.e., Bus Interface Unit (BIU). Real-time traffic phasing and timing information is wirelessly transmitted to a signal database server located in Minnesota Traffic Observatory (MTO) in the Civil Engineering Department at University of Minnesota. When users perform a single-tap on the smartphone screen while pointing to a desired direction, the smartphone app will interact with the signal data server to obtain geometry information. After determining which direction to cross, the visually impaired pedestrians can simply perform a double-tap on the smartphone screen to submit pedestrian crossing request. The double-tap action then sends the request to traffic controller cabinet through the signal database server. The pedestrian call interface, residing in a Virtual Private Network (VPN), handles the request from the smartphone to active the pushbutton inputs in the controller cabinet. The VPN is to ensure system security that no unauthorized users or systems can trigger the pushbutton request remotely. Ideally, the wireless router/modem will not be necessary when the signal data can be accessed through the MnDOT's firewall in the future.

A digital map, containing intersection geometry, street name, number of lanes, and direction information is stored in a spatial database on the smartphone as a 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 can be included to help determining pedestrian location with respect to an intersection.

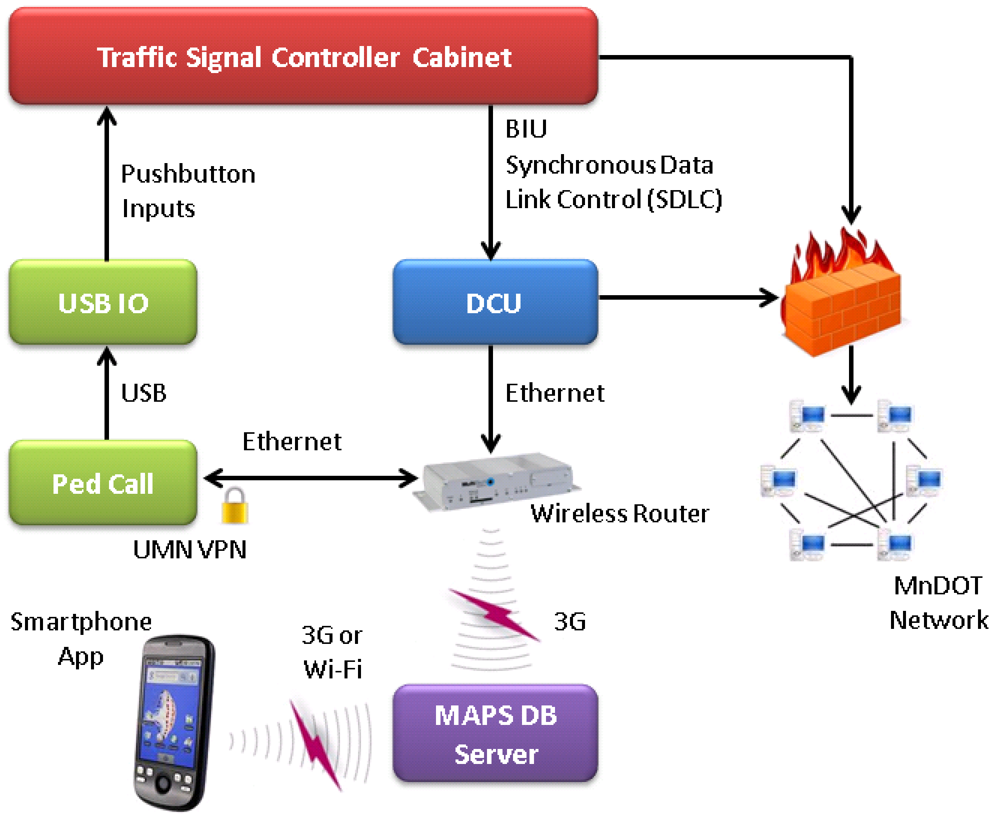

Figure 2.1 MAPS System Diagram

2.3.1 Smart-Signal Data Collection Unit (DCU)

The Smart-Signal DCU was developed by Professor Henry Liu and his research team 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 data triggered by inductive loop detector, pedestrian calls and phasing changes. The DCU was chosen to leverage previous research effort sponsored by the MnDOT and ITS Institute. The DCU may be eliminated when future Advanced Traffic Controller (ATC) has the capability of broadcasting signal timing and phasing information wirelessly.

In order to provide real-time signal and timing data, the DCU continuously monitors the states of signal phases, pedestrian walk sign, and loop detectors. When there is a signal phase or a detector state change, the DCU will transmit a text string to a server residing in MTO lab.

For example, a detector state change will generate the following output string.

```
$D0104081223000314781140000328!
```

Where,

$: Leading character
Intersection ID: 0104
Date: 08-12-23 (yy-mm-dd)
Time: 00:03:14.781
Detector ID: 14
Detector occupied duration: 328 ms
!: End of data string

Upon the data sent, the detector status changes from on to off, and no detector off duration time will be sent.

As another example, a signal state change will generate the following string output string.

```
$S0101120302141540700004G00015000!
```

Where,

$: Leading character
Intersection ID: 0101
Date: 12-03-02 (yy-mm-dd)
Time: 14:15:40.700
Phase : 04
Status: G
Duration: 15000 ms
!: End of data string

Upon the data was sent, the status changes from green to red/yellow. The signal string sent is the information about the previous signal state and not the current one. For example, the above string indicates that G was the previous signal state that lasted for 15000 milliseconds. The phase values will be 1-8 for the normal phases and 9-12 for the pedestrian phases.

The various signal statuses sent by the DCU are

- R => Previous signal was R and current signal is G
- G => Previous signal was G and current signal is Y
- Y => Previous signal was Y and current signal is R
- F => Previous signal was a flashing state.

2.3.2 Database Server

A database server contains the following tables that store intersection spatial information, signal timing and pushbutton requests. The database server allows data communications between the smartphone client application and a traffic signal controller.

- 'intx_geo' table stores the intersection geometry information such as street name and number lanes. It contains the 'Intx_ID', 'Walk_Phase', 'Walk_Time', 'Cross_Street', and 'Num_Lane' data fields.
- 'intx_xing_phase' table defines the crosswalk direction and its associated signal phase. It contains the 'Intx_ID', 'Bluetooth_ID', 'Dir', and 'Phase' data fields.
- 'pushbutton_request' table stores the pushbutton request from smartphone client when double-tap is performed. It contains the 'Intx_ID', 'Phase', and 'PB_State' data fields.
- 'signal_state' table stores the real-time signal data from DCU. It contains the 'data_ID', 'Date', 'TimeStamp', 'Signal_State', 'Time_Left', and 'Intx_ID' data fields.

2.3.3 Relay Output and Wireless Communication

A USB IO module, as illustrated in Figure 2-1, is a relay digital output device manufactured by ACCES I/O Products, Inc. (http://www.accesio.com/). When a double-tap is performed on the smartphone and detected by the 'Ped Call' program, the relay output will be closed from a '*normally open'* state to request walk signal from the controller cabinet. This interface replaces the pushbutton functionality as actually pressing down a mechanical pushbutton.

For additional system security, data communication between the smartphone, app and signal database uses cellular or Wi-Fi network. User authentication can be implemented using smartphone International Mobile Equipment Identity (IMEI) number with password protection. For system security purposes, communication between the signal database and the controller cabinet resides inside a private network (e.g., UMN VPN). Additional authentication layer is added to prevent unauthorized access remotely.

Additional information about other system hardware devices is presented in Appendix F.

2.4 Software Design

2.4.1 MAPS Server

The MAPS server includes a SQL-based traffic signal database (as described in section 2.3.2), a network socket listener program that processes signal data from DCU, and a servlet program that handles communications with smartphone clients. As illustrated in Figure 2-2, the socket listener, including socket server, client worker, database connection and signal data classes, is a multi-thread application designed to handle traffic signal data and pedestrian walk phases from multiple intersections. Intersection ID, direction, and pushbutton request are submitted to the Java servlet program when a double-tap is performed on the smartphone. The servlet updates pushbutton request flag in the database and then returns the corresponding signal phase and state according to the direction and location inputs from smartphone app.

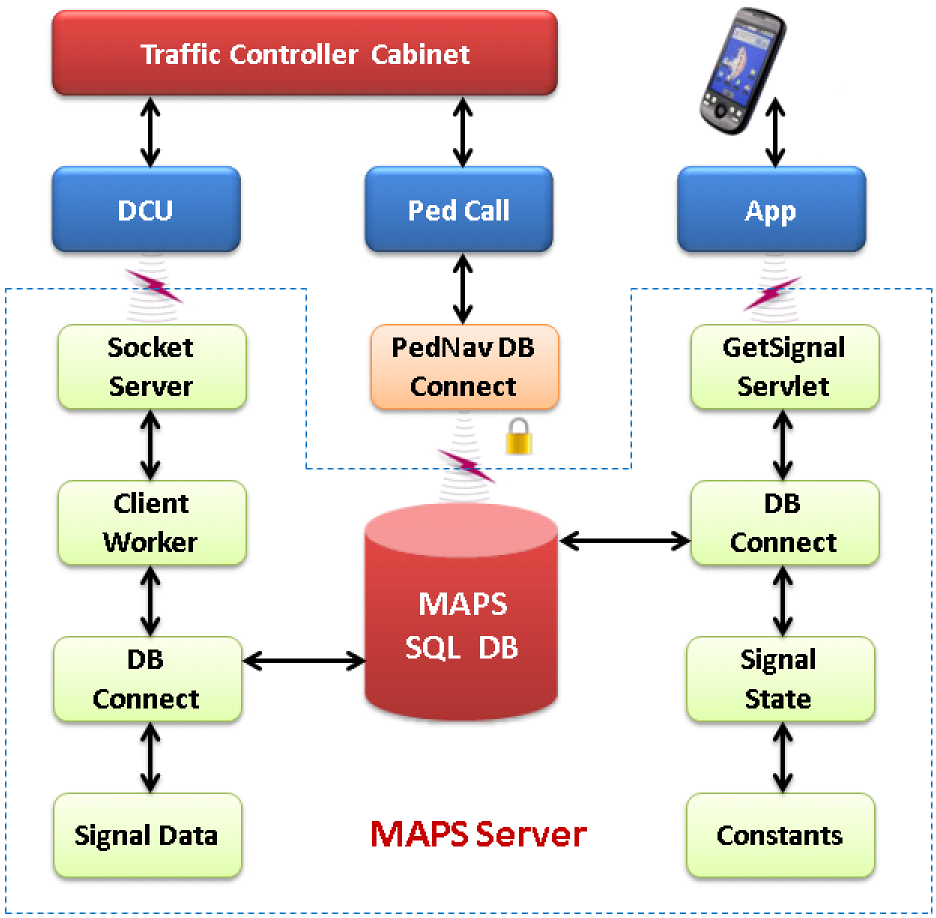

Figure 2.2 Software Architecture of MAPS

2.4.2 Smartphone App

The smartphone application consists of GPS service, compass service, digital map database, Bluetooth communication interface, wireless client, and pedestrian navigation classes. The GPS and compass services provide location and orientation updates of a smartphone user. Intersection geometry and available crosswalk and sidewalk directional information are loaded locally to a SQLite database on the smartphone. The Bluetooth interface allows the smartphone app to scan nearby vicinity if a Bluetooth ID tag exists. Communication between the smartphone and the MAPS server is handled through the wireless client interface as illustrated in Figure 2-2.

Two simple user inputs were developed for the visually impaired users. 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, as shown in Figure 2-3. For example, it will announce "*You are pointing to east, Harvard street 2-lane*', while pointing the phone in east direction with a single tap. The MAPS application will also provide direction information if there is no crossing information in the direction users pointed to. For example, it will announce, for example, "*No information in north-east. Please turn for data*", while pointing the phone to the middle of an intersection with a single tap.

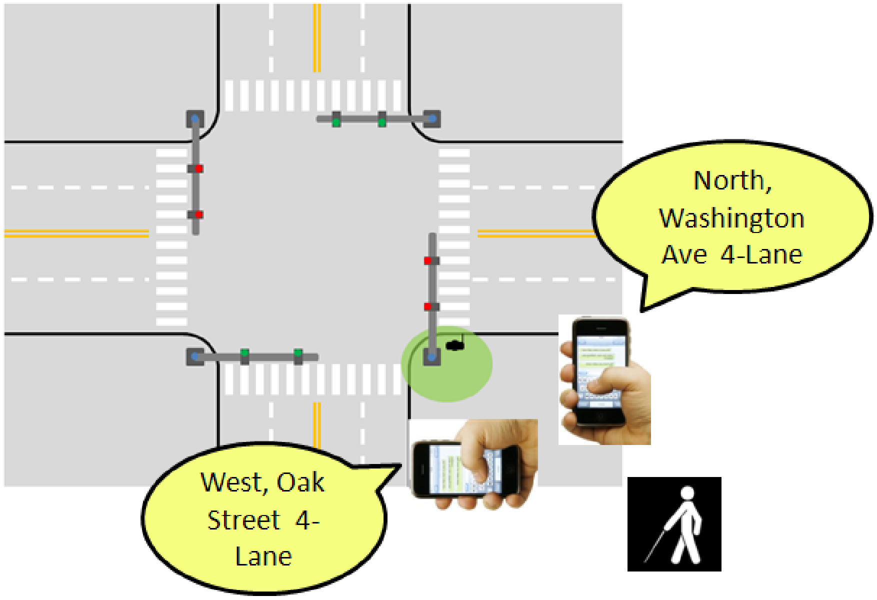

Figure 2.3 Single-Tap to Obtain Intersection Geometry Information

While pointing the phone toward a desired direction of crossing, the double-tap input will confirm the crossing direction and submit a request for pedestrian walk signal. The smartphone application will then wirelessly request signal timing and phasing information from traffic signal controller. Speech feedback to the blind pedestrians is then announced through the Text-To-Speech (TTS) interface already available on smartphones as illustrated in Figure 2-4. For example, the smartphone will announce '*Please wait for walk signal*' every 5 seconds. As soon as the walk sign is on, the smartphone will vibrate for 1 second to alert the user and then announce, '*walk sign is on, xx seconds left*'. When it's about 5 seconds before the ending of a walk phase, the smartphone will vibrate again then announce '*5 seconds left*' to alert the user finishing the crossing soon. The user's interface for single and double tap inputs are illustrated in Figure 2-3 and 2-4, respectively.

Detail description regarding the smartphone app is available in the final report of "Development of Mobile Accessible Pedestrian Signals (MAPS) for Blind Pedestrians at Signalized Intersections" project (Liao et al., 2011). Further information regarding the software design of the MAPS system is included in Appendix E.

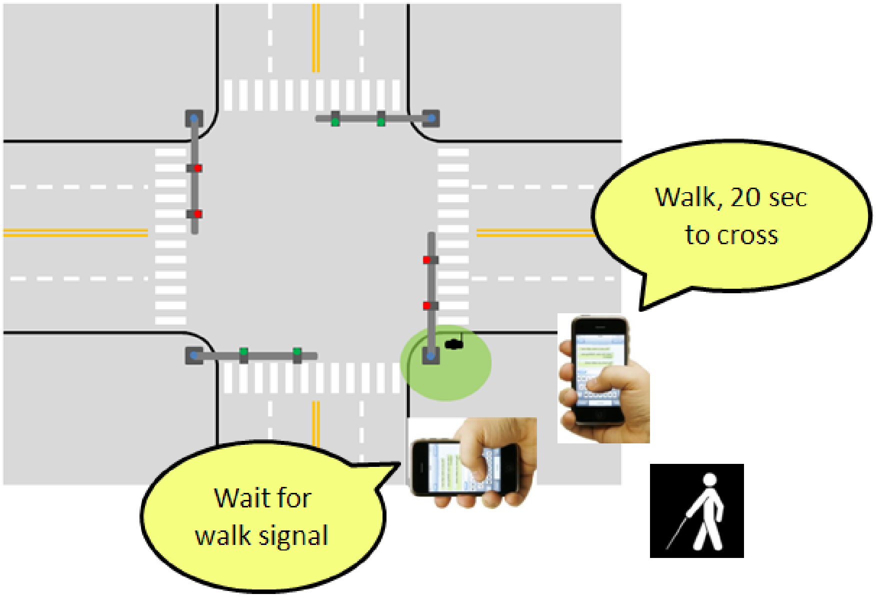

Figure 2.4 Double-Tap to Confirm Crossing and Obtain Signal Information

3 EXPERIMENT DESIGN

Documentation of proposed field experiment was submitted to and approved by University of Minnesota Institutional Review Board (IRB Code # 1112S07962).

3.1 Locations

Two intersections in Golden Valley west of City of Minneapolis were identified and recommended by Orientation and Mobility (O&M) specialist for field experiment. Intersection #1 is located at Winnetka Avenue and Golden Valley Road. The Winnetka Avenue, five lanes, goes in north-south direction and the Golden Valley Road, four lanes, is in the east-west direction. This intersection is installed with APS system manufactured by Polara Engineering, Inc. (http://www.polara.com/). Intersection #2, couple blocks away from the first intersection is located at Rhode Island Avenue and Highway 55 (Olson Memorial Highway). The Rhode Island Avenue, four lanes, goes in north-south direction and Highway 55, seven lanes, is in the east-west direction. This intersection does not have APS system installed. Pedestrians are required to use existing pushbutton to cross the intersection. Crossing experiments at intersection #1 and #2 were conducted on separate Friday on April 13 & 20, 2012, respectively.

3.2 Participants

Upon the approval of the IRB review, recruiting ads were posted and announced at Vision Loss Resources (VLR) in Minneapolis and through word of mouth to the visually impaired communities. Participants are required to meet the following criteria.

- Be 18 to 64 years of age,
- Have completed orientation and mobility training,
- Be proficient in using a cane or a guide dog,
- Be willing to have audio and/or video recorded during the interview and intersection crossing tasks.

During one month of recruitment, thirty individuals who are visually impaired contacted the research team and expressed their interests in participating in this research study. Twenty people were selected randomly but finally eighteen individuals responded and agreed to participate. Consent agreement (included in Appendix A) was read loudly to each individual by one of the research team members while a witness in presence. Braille version of the consent form was also available to the participants. All participants provided their written consent for participating.

Eleven male and seven female individuals participated in the experiment, with mean age 44.2 years, standard deviation 15.2 years. Two participants are veterans. Ten participants have total peripheral blindness and the others have low vision. Thirteen of the participants use a long cane and five use a dog. All participants have completed orientation and mobility training during their lives. Regarding intersection crossing frequency, nine of the participants cross more than four intersections a day, five of them cross one to two intersections a day, two of them cross one to four intersections a week, and the other two participants cross less than one intersection a week. Nine of the participants own and use a smartphone, eight of them have regular cell phone, and one individual does not have a mobile phone.

3.3 Materials

The experiment at intersection #1 took place nearby a commercial area on a light raining day from 7:40 AM to 5:30PM. The experiment at intersection #2, two blocks away from the first intersection, took place on a bright sunny day from 7:40 AM to 5:30PM. Sidewalk areas were clear with no obstacles at both locations. However, the sidewalk surface, at couple spots, was a bit uneven at intersection #2. A traffic data collection unit (DCU) and a relay IO module were installed in the controller cabinet at intersection #2 to provide signal information to smartphone users. Survey questionnaire regarding usability, acceptance, and trust of the smartphone-based traffic signal system was read to each individual and their responses were recorded on the questionnaire. See Appendix B for questionnaire details.

3.4 Procedures

At each location, participants were asked to perform crossing tasks and then interviewed by a research team member before and after each crossing task. The crossing tasks and interviews focus on participants' experiences while crossing signalized intersections, using audible pedestrian signals, or a smartphone-based accessible pedestrian signal device provided by the research team.

For each crossing task, a certified O&M specialist brought each participant to a starting point which was located about 100 to 200 feet (north) away from the north-east corner of the intersection, as illustrated in Figure 3-1. Visually impaired participants were asked to travel along the sidewalk using their own navigational skills to reach the corner of the intersection. While at the intersection, the visually impaired participants need to find and use the pushbutton to request a pedestrian walk signal or use the smartphone-based pedestrian signal device to determine when it is possible to cross. Participants then cross the street that is perpendicular to the sidewalk they just travelled and arrive at the other side of street.

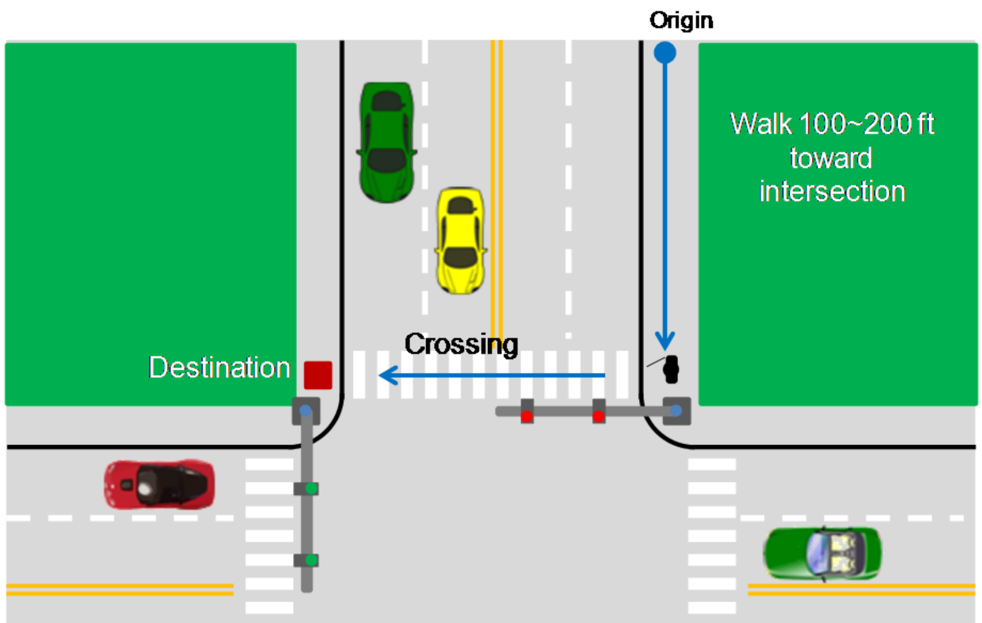

Figure 3.1 Crossing Path

The pre and post-experiment questionnaires covered the following topics:

- Vision,
- Ability to orient by themselves,
- Experience crossing intersections,
- Usage and opinions of the new technology,
- Opinions of the smartphone-based pedestrian crossing system,
- Usability and acceptance of the smartphone-based pedestrian signal system,
- Trust of the smartphone-based traffic information system, and
- Other demographic information.

Each experiment session lasted approximately 30 minutes for each participant. The field experiment and interviews were recorded using video and audio equipments to effectively capture participants' responses and intersection crossing performance, for example, walking speed, in-position time and time to step into crosswalk when walk sign is on.

3.4.1 Instructions given to Participants at Intersection #1

Instruction given to each participant at the beginning of the task

The O&M specialist walked with each participant across Winnetka Ave. from the NW to the NE corner and turned north then walked about 100 feet to the starting point. The O&M instructor had each individual turn 180 degrees around and said to the participants the following.

"This is the starting point and you are facing South, Winnetka is your parallel street. Please walk straight about 100 feet to the intersection, locate the pushbutton, turn right and cross Winnetka Ave., a 5-lane street. It is a print letter L shaped route. The APS will say, 'The walk sign is now

on to cross Winnetka Ave.' Any questions? Let me know when you're ready and I will give a signal to the camera man. OK. Go when you are ready."

Instruction given when participant veers

If participants were veering and in danger, the O&M instructor spoke to them "*walk to your right, do you hear your traffic?*" For some clients, the instructor tapped their right shoulder and said, "*Walk this way*". In a situation where 2 cars blocked the crosswalk, the O&M instructor said, "*there is a car in the crosswalk either go around in the front of the car or the back, another car in the cross walk*", when the participant encountered the second car in the crosswalk.

No messages were communicated to participants when participants press the wrong pushbutton.

<u>3.4.2 Instructions given to Participants at Intersection #2</u>

Instruction given to each participant at the beginning of crossing task #1

The O&M specialist walked with the volunteer approx. 1/8 mile to starting point 238 feet north of the NE corner of Rhode Island Ave. and Highway 55. Then the following instruction was given to the participants.

"*This is the starting point and you are facing south, Rhode Island Ave. is your parallel street. Please walk straight about 200 feet to the intersection, locate the pushbutton, turn right and cross Rhode Island Ave., which is a 4-lane street. It is like a print letter L shaped route. Pushing the button will give you enough time to cross, it will not talk. Any questions? Let me know when you're ready. I will give a signal to the camera man. OK. Go when you are ready.*"

For most of participants, the O&M specialist told them the pushbutton is located behind the wheel chair ramp and to their left.

Instruction given when participant veers

The O&M specialist only had to cue a few participants when they were veering out of the crosswalk. The O&M specialist tapped the shoulder of participants on the left side to signal walk to the left or on the right shoulder to walk towards the right.

Instruction given to each participant at the beginning of crossing task #2

The O&M specialist walked approximately 1/8 mile to starting point 238 feet north of the NE corner of Rhode Island Ave. and Highway 55. The O&M specialist said to the participants the following.

"*This is the same starting point and you are facing south, Rhode Island Ave. is your parallel street. Please walk straight about 200 feet to the intersection and line up to cross turning right, use the smartphone tap once to locate the direction west, adjust the phone direction if you do not hear the correct geometry information such as 'facing west, Rhode Island Ave. 4 lanes.' Next, double tap the smartphone and listen for the phone to speak, 'walk sign is now on to cross Rhode Island Ave.' Use your hearing, useable vision and O&M techniques to cross safely. Use the* *phone as secondary information. Any questions? Let me know when you're ready. I will give a signal to the camera man. OK. Go when you are ready.*"

3.5 Performance Measures

3.5.1 Subjective Measures

Subjective measures include: sufficient information needed to cross intersection, sufficient time to cross, feel safe during crossing, usefulness and satisfaction of the MAPS system and trust of using the smartphoe based system. Questionnaires for both intersections are listed in section A & B as follows. Questionnaire in section C surveys participants' opinions about the MAPS system they used at intersection #2. Questinnaire in section D evaluates participants' level of agreement with the statement in relating to the system they used. Complete users survey protocol and questionnaire are included in Appendic B.

A. APS intersection crossing (Intersection #1)

1. Do you prefer using a pushbutton for requesting walk phase at signalized intersection?

☐ No ☐ Yes ☐ Don't know

2. Do you have difficulty locating the pushbutton?

☐ No ☐ Yes ☐ Don't know

3. Does the APS system provide sufficient information to assist your intersection crossing?

☐ No ☐ Yes ☐ Don't know

4. Do you feel you have sufficient time to cross this intersection?

☐ No ☐ Yes ☐ Don't know

5. Do you feel you stay alignment with the crosswalk?

☐ No ☐ Yes ☐ Don't know

B. Non-APS intersection crossing (Intersection #2)

6. Do you prefer using a pushbutton or the mobile assistive device for requesting walk phase at signalized intersection?

☐ No ☐ Yes ☐ Don't know

7. Do you have difficulty locating the pushbutton?

☐ No ☐ Yes ☐ Don't know

8. Do you feel you have sufficient time to cross this intersection?

☐ No ☐ Yes ☐ Don't know

9. Do you feel you stay alignment with the crosswalk?

☐ No ☐ Yes ☐ Don't know

10. Does the mobile assistive device provide sufficient information to assist your intersection crossing?

☐ No ☐ Yes ☐ Don't know

11. Do you feel the mobile device provide helpful information about the intersection geometry to support your wayfinding?

☐ No ☐ Yes ☐ Don't know

12. Do you feel the mobile device provide helpful information about the intersection signal timing to support your intersection crossing?

☐ No ☐ Yes ☐ Don't know

C. Acceptance and Usability (Van der Laan et al., 1997)

	2	1	0	-1	-2	
1. Useful	☐	☐	☐	☐	☐	Useless
	2	1	0	-1	-2	
2. Pleasant	☐	☐	☐	☐	☐	Unpleasant
	-2	-1	0	1	2	
3. Bad	☐	☐	☐	☐	☐	Good
	2	1	0	-1	-2	
4. Nice	☐	☐	☐	☐	☐	Annoying
	2	1	0	-1	-2	
5. Effective	☐	☐	☐	☐	☐	Superfluous
	-2	-1	0	1	2	
6. Irritating	☐	☐	☐	☐	☐	Likeable

	2 1 0 -1 -2		
7. Assisting	☐ ☐ ☐ ☐ ☐	Worthless	
	-2 -1 0 1 2		
8. Undesirable	☐ ☐ ☐ ☐ ☐	Desirable	
	2 1 0 -1 -2		
9. Raising Alertness	☐ ☐ ☐ ☐ ☐	Sleep-Inducing	

D. System Trust and Confidence (Lee & Moray, 1992)

1. The performance of the system enhanced my safety at signalized intersection crossings.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

2. I am familiar with the operation of the system.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

3. I trust the system.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

4. The system is reliable.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

5. The system is dependable.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

6. I have confidence in this system.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

7. The system has integrity.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

8. I am comfortable with the intent of the system.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

9. I am confident in my ability to cross a signalized intersection without the system.

Strongly Disagree 0	25	50	75	Strongly Agree 100
☐	☐	☐	☐	☐

3.5.2 Objective Measures

Objective measures, including walk speed, initial alignment to the crosswalk at beginning of crossing, time to step into crosswalk when walk phase is on, number of veering, number of assistance needed from O&M specialist, will be derived from recorded video data.

4 RESULTS

Results from survey questionnaires and performance measures derived from recorded video data of 18 visually impaired participants are compiled, analyzed and discussed in this section.

4.1 Self Assessment

Self-reported travel skills and navigation assistance preference from the participants were reported in the self-assessment questionnaires (multiple choices) prior to the field experiment. The results displayed in Figure 4-1 indicated that white cane was selected as the most preferred method of assistance (44%) followed by asking other people (26%) and using guide dog (22%).

With regard to the travel skills of the visually impaired participants, 5 participants (28%) responded that their general sense of orientation is about average, while 12 people (66%) responded that their general sense of orientation is above (4 participants, 22%) or well above average (8 participants, 44%) as shown in Figure 4-2. For travel independence, 4 participants (22%) responded as average independent travelor, and 14 participants (78%) considered their independent travel skill is above (5 participants, 28%) or well above average (9 participants, 50%) as illustrated in Figure 4-3. Figure 4-4 shows that 4 participants (22%) considered their skills in crossing signalized intersection as average, and 14 individuals (78%) considered their street crossing skills above (7 participants, 39%) or well above average (7 participants, 39%).

To summarize the self-assessment, almost all participants consider themselves have good sense of direction. They are independent travelers, and generally have no problem in crossing signalized intersections.

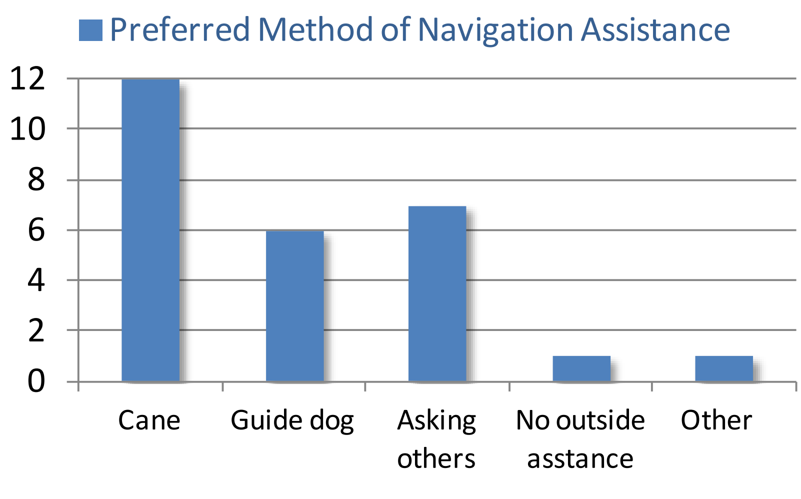

Figure 4.1 Preferred Method of Navigation Assistance

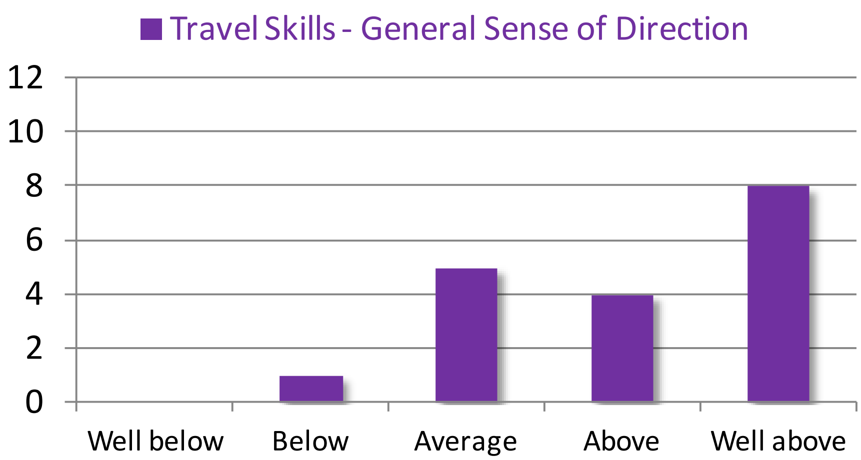

Figure 4.2 General Sense of Direction

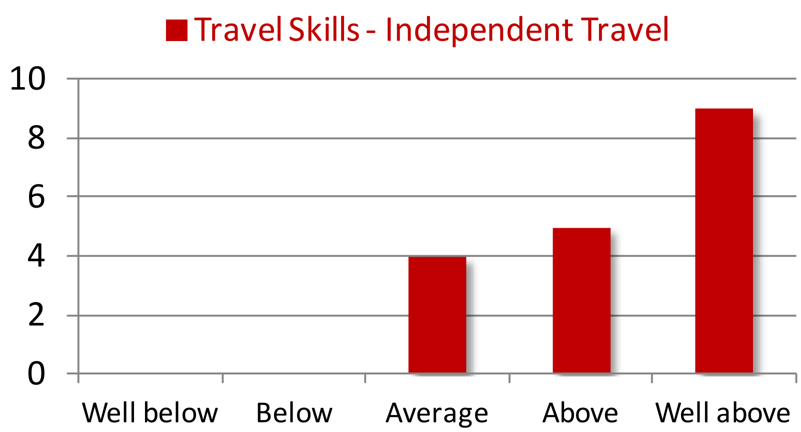

Figure 4.3 Independent Travel

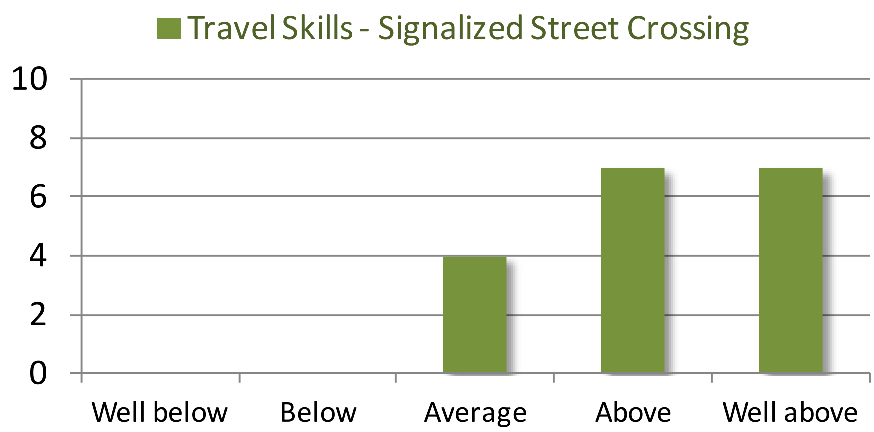

Figure 4.4 Signalized Street Crossing

4.2 Objective Measures

Video data collected at both intersections were analyzed to compare participants' travel speed on sidewalk versus crosswalk, and the time to step into crosswalk. As listed in Table 4-1, the crosswalk length at intersection #1 (APS equipped) and #2 are 28.7 meter (94 ft) and 33.8 meter (111 ft), respectively. APS pushbutton is required at intersection #1, operated under actuated signal control plan, to call for walk signal. At intersection #2, participants were asked to use existing pushbutton to request for crossing in the first task and then to use our device for crossing request and assistance for the second crossing. Participants' travel speed at sidewalk (2.5 mph) is slower (statistically significant) than the speed at crosswalk (2.9 mph) using paired t-test (p-value = 0.01). However, the travel speed difference on sidewalk and crosswalk at intersection #2 is not significant using paired t-test (p-value = 0.06 and 0.77, respectively).

In average, the visually impaired participants spent 7.8 seconds (SD 6.1 sec) in searching for APS pushbutton at intersection #1. At intersection #2, where no pushbutton-locating tone is available to visually impaired pedestrians, the participants spent 26.6 seconds (SD 56.5 sec), in average, to locate the regular pushbutton. The pushbutton stub pole at intersection #2 is located behind the ADA ramp; it took several participants more than 2 minutes in locating the pushbutton. Four participants veered outside crosswalk path at both intersections. The research team also observed that guide dog may easily be distracted by people close by and thus guided the visually impaired participant toward a person nearby. For example, couple guide dogs led the participant toward the camera man at the last quarter of crosswalk instead of staying on the crosswalk path.

Table 4.1 Comparison of Objective Measures

Intersection ID	1	2	
Intersection Type	**APS**	**Non APS**	
Crosswalk Length, meter (ft)	28.7 (94)	33.8 (111)	
Crossing Task #	1	2	3
Sample Size (N)	18	17	17
Ped Call	APS PB	Regular PB	MAPS
Crosswalk Speed, Average (mph)	**2.91**	**3.36**	**3.33**
Crosswalk Speed, SD (mph)	0.44	0.82	0.60
Sidewalk Speed, Average (mph)	**2.54**	**3.11**	**3.30**
Sidewalk Speed, SD (mph)	0.37	0.54	0.64
Sidewalk vs. Crosswalk Speed Comparisons (p-value)	0.01	0.06	0.77
Pushbutton Search Time, Average (sec)	**7.8**	**26.6**	NA
Pushbutton Search Time, SD (sec)	6.1	56.5	NA
In-Position Time, Average (sec)	**14.5**	**34.8**	**9.8**
In-Position Time, SD (sec)	7.5	57.2	6.7
Time to Step Into Crosswalk, Average (sec)	**3.1**	**7.1**	**5.5**
Time to Step Into Crosswalk, SD (sec)	1.5	4.7	3.2
Number of Veers Outside Crosswalk	4	2	4

The in-position time is defined as the time duration from the participant passing the pushbutton pole to a waiting location at the beginning of crosswalk. The average in-position time at intersection #1 is 14.5 sec (SD 7.5sec). At intersection #2, the average in-position using MAPS system is 9.8 sec (SD 6.7 sec) as compared to average in-position time of 34.8 sec (SD 57.2) while using regular pushbutton. The MAPS allows the visually impaired users to be more efficient in ready position at the beginning of a crosswalk when there is no need to find the pushbutton.

At intersection #1, the average time to step into crosswalk is about 3.1 seconds (SD 1.5 sec). At intersection #2 without the APS device, participants wait about 7.1 seconds (SD 4.7 sec) to step into crosswalk. Without audio notification of when the walk sign is on, the visually impaired pedestrians usually have to listen to the sound from parallel traffic surges. In the experiment, the participants were asked to cross in parallel with Highway 55, which is a busy state highway with Annual Average Daily Traffic (AADT) of 33,500 vehicles (See intersection layouts and signal controller timing plan in Appendix C). The average time for the visually impaired participants to step into crosswalk at non-APS equipped intersection will vary depending on parallel traffic because the visually impaired travelers were taught to judge possible time to cross by listening to the traffic.

When using MAPS system, the participants averagely waited about 5.5 seconds (SD 3.2 sec) to step into the crosswalk. This is about 2.5 seconds longer than the time observed at APS intersection (#1). The extra two seconds is probably incurred by, (a) the data communication between the smartphone app and the signal controller (1 sec), and (b) the announcement duration of '*walk sign is ON, xx seconds left*' from the smartphoen app when users were trying to listen and understand what the message meant before stepping into the crosswalk. In addition, the visually impaired pedestrians are more familiar with existing APS system and messages. The APS system has simple message type (e.g., '*wait'* or '*walk'*) that may contribute to the shorter step-into-crosswalk responding time. We expect the average step-into-crosswalk time will drop when users are more familiar with the MAPS system. Detail objective measures derived video data are included in Appendix D.

4.3 Subjective Measures

4.3.1 Intersection #1

Survey results from intersection #1 were analyzed and listed in Table 4-2. Most of the participants (89% or 16 out of 18) do not use any GPS device for navigation. 16 participants experienced intersection crossing using APS device previously. At the APS equipped intersection, participants (94% or 17 out of 18) preferred pushbutton to activate walk signal request. 14 participants did not have difficulty in locating the pushbutton. However, 3 participants had difficulty locating the button during busy traffic. Most of the participants (11) felt that the APS system provide sufficient information to support their street crossing task. Couple participants commented that the audible message was announced in all directions when walk sign is on and the APS system does not provide street width (e.g., number of lanes) information. 11 participants (61%) felt the length of walk phase is sufficient, but the other 7 participants (39%) would need more time for walk signal. 14 participants felt they were aligned at the beginning of their crossing. Four individuals veered outside crosswalk path during the crossing task (See Table 4-1 & 4-2).

Table 4.2 Intersection #1 Survey Responses

Intersection #1 Responses	No	Yes	Don't Know
Use GPS Navigation Previously	16	2	0
Have Prior APS Experience	2	16	0
Prefer Pushbutton (PB) over No PB	1	17	0
Have Difficulty in Locating PB	14	3	1
APS Provides Sufficient Info	2	16	0
Have Sufficient Time to Cross	7	11	0
Feel Aligned to Crosswalk	2	14	2

4.3.2 Intersection #2

Survey responses from second intersection were analyzed and listed in Table 4-3. Most of the participants (11 or 65%) preferred not to locate the pushbutton as compared to using the smartphone to activate walk signal request automatically. 8 participants (47%) had difficulty in locating the pushbutton because of the non-standardized pushbutton location. Most participants (15 or 88%) reported that the existing crossing time is sufficient. 15 participants aligned themselves well at beginning of crosswalk; however, 4 people wavered off the crosswalk (see Table 4-1 & 4-3 for details).

During the second crossing task while using MAPS device, a few participants experienced unreliable GPS signal that led to the result of MAPS being confused and considered the participant being already at the other side (NW corner) of the intersection. The inconsistent GPS positioning solution caused the MAPS to provide incorrect information. Subjective measures in the following discussion included users' comments while using the MAPS with GPS positioning issue.

As compared to the two crossing tasks at intersection #2, eleven participants felt (65%) the MAPS system provide sufficient information, 14 (82%) people responded that MAPS provides helpful geometry information, but only 10 participants (59%) felt the MAPS provides helpful signal information.

Table 4.3 Intersection #2 Survey Responses

Intersection #2 Responses	No	Yes	Don't Know
Prefer PB over MAPS	11	4	1 - Both 1 - Neither
Have Difficulty in Locating PB	9	8	0
Have Sufficient Time to Cross	2	15	0
Feel Aligned to Crosswalk	2	15	0
MAPS Provides Sufficient Info	6	11	0
MAPS Provides Helpful Geometry Info	3	14	0
MAPS Provides Helpful Signal Timing Info	6	10	1

(Note: One participant did not show up at second intersection.)

4.4 MAPS System Evaluation

4.4.1 Usability and Acceptance

Cronbach's Alpha (α), a coefficient of reliability, is commonly used as a measure of internal consistency and reliability of a psychometric test score for a sample of subjects (Cronbach, 1951). It describes how closely related a set of items are as a group. Cronbach's Alpha (α) is defined as follows.

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K} \sigma_{Y_i}^2}{\sigma_X^2}\right) \qquad \text{(Eq. 4-1)}$$

Where,

K is the number of components, items or testlets,
σ_X^2 is the variance of the observed total test scores, and
$\sigma_{Y_i}^2$ is the variance of component *i* for the current sample of subjects.

In general, a test with a Cronbach's Alpha (α) of 0.85 indicates the test will be 85% reliable in practice. A commonly accepted rule of thumb for describing internal consistency using Cronbach's Alpha (α) is listed in Table 4-4 (George & Mallery, 2003). Results from the usability and satisfaction questionnaire among the 17 visually impaired participants have a Cronbach's Alpha (α) value of 0.96, a relatively high internal consistency and reliability.

Table 4.4 Cronbach's Alpha Values for Internal Consistency

Cronbach's Alpha	Internal Consistency
α ≥ 0.9	Excellent
0.9 > α ≥ 0.8	Good
0.8 > α ≥ 0.7	Acceptable
0.7 > α ≥ 0.6	Questionable
0.6 > α ≥ 0.5	Poor
0.5 > α	Unacceptable

Van der Laan et al. (1997) developed a simple procedure to measure the perceived satisfaction and usefulness of a new system. The technique consists of nine 5-point rating items with bipolar adjective scales. These scales are summed to generate separate scores for the perceived satisfaction and usefulness measures. As listed in section 3.5.1(C) and Appendix B.2, score of individual item ranges from -2 to 2. Item 3, 6, and 8 are mirrored as compared to the other items. The usability score is calculated as the average of item 1, 3, 5, 7, and 9. The satisfaction score is computed as the average of item 2, 4, 6, and 8. Survey results from each participant on usability and acceptance are listed in Table 4-5. The scores for the perceived satisfaction and usefulness are 1.04 and 0.95, respectively. Results of the usability questionnaire indicated that the visually impaired participants considered the MAPS to be moderately useful and satisfying to use as shown in Figure 4-5.

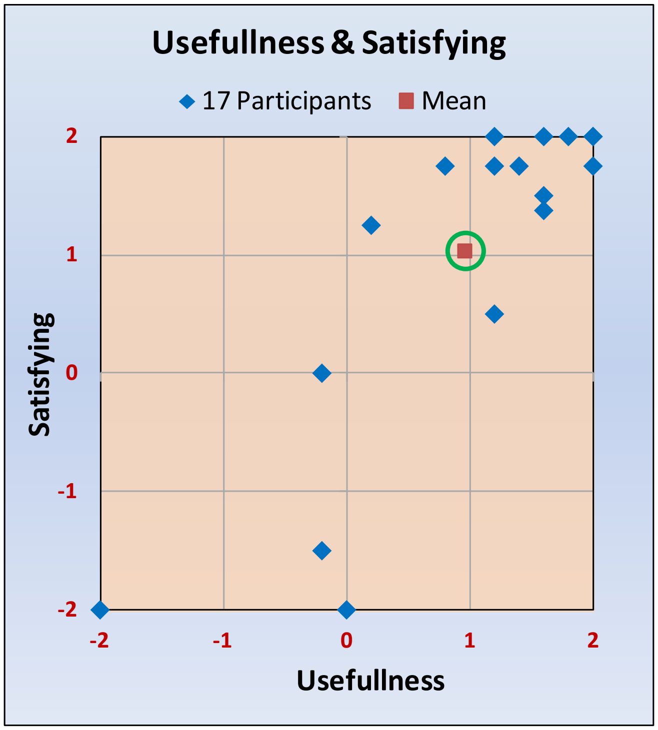

Figure 4.5 System Usability and Acceptance

Additional comments (in *italic* type) from the participants and responses from the research team are listed as follows.

"Like the device. Feel it will be helpful."

"Like the automation of pushbutton."

"Not sure how system would react when touch it while crossing."

The MAPS system will announce corresponding direction and geometry information when a single tap is performed.

"Louder.", *"No crispy sound when crossing w/o mobile device."*

The speaker volume was turned to the highest. However, due the traffic noises at busy intersection, it may be difficult to hear the auditory message. Possible alternatives are to, (1) bring the phone closer to one's ears after performing single or double tap on the screen in desired direction, or (2) use a Bluetooth earbud in one ear.

"Makes hands full."

"Make it hands free."

Potential solution is to wear the smartphone around neck using a strap with phone holder.

"*Make it vibrate more often while crossing.*", "*User configurable settings.*" , "*Provide alignment and wavering info.*"

These will be on our to-do list for next generation of MAPS.

"*Wrong info.*"

The MAPS was confused by incorrect GPS positioning information. Bluetooth geo-ID is needed to ensure 100% positioning reliability.

Table 4.5 Usability and Satisfaction Survey Results

Question #		1	2	3	4	5	6	7	8	9		
Subject ID	Guidance Type (Dog/Cane)	Useful	Pleasant	Good	Nice	Effective	Likeable	Assisting	Desirable	Raising Alertness	Usefulness (1,3,5,7,9)	Satisfying (2,4,6,8)
6	Dog	2	2	0	2	0	2	0	1	2	0.8	1.8
8	Cane	0	0	0	0	-1	0	0	0	0	-0.2	0.0
26	Cane	2	2	1	2	0	2	2	1	1	1.2	1.8
13	Dog	2	1	1	1.5	2	2	2	1	1	1.6	1.4
23	Cane	2	2	2	2	2	2	2	2	2	2.0	2.0
27	Cane	1	2	-1	1	0	1	0	1	1	0.2	1.3
4	Cane	2	2	0	2	0	2	2	2	2	1.2	2.0
21	Cane	1	0	0	0	2	0	1	2	2	1.2	0.5
2	Cane	1	2	1	2	1	2	2	1	2	1.4	1.8
18	Dog	0	-2	-1	-2	-1	-1	0	-1	1	-0.2	-1.5
17	Cane	1	2	2	2	2	2	2	2	1	1.6	2.0
10	Cane	2	2	2	2	2	2	2	1	2	2.0	1.8
19	Cane	2	1	1	1	1	2	2	2	2	1.6	1.5
15	Dog	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2.0	-2.0
12	Cane	2	2	2	2	2	2	2	2	2	2.0	2.0
16	Cane	2	2	2	2	2	2	2	2	1	1.8	2.0
1	Cane	0	NA	0	-2	-1	-2	0	NA	1	0.0	-2.0
AVERAGE		1.18	1.13	0.59	0.91	0.65	1.06	1.12	1.06	1.24	**0.95**	**1.04**

*Note: NA – Participant did not answer.

4.4.2 Trust and Confidence

The trust questionnaire (Appendix B.3) was used to measure different dimension of trust: purpose, process, performance, and overall trust (Lee & Moray, 1992). Questions 1 and 4 deal with performance, question 2 and 5 deal with process, question 7 and 8 deal with purpose, question 3 and 9 are overall questions, and question 6 deals with confidence. The performance dimension of trust measures the expectation of consistent, stable and desirable performance of the system. The process dimension of trust represents the understanding of underlying qualities that govern the system behavior. The purpose dimension of trust is the underlying motives or intent of the system. Survey results on system trust and confidence are shown in Figure 4-6.

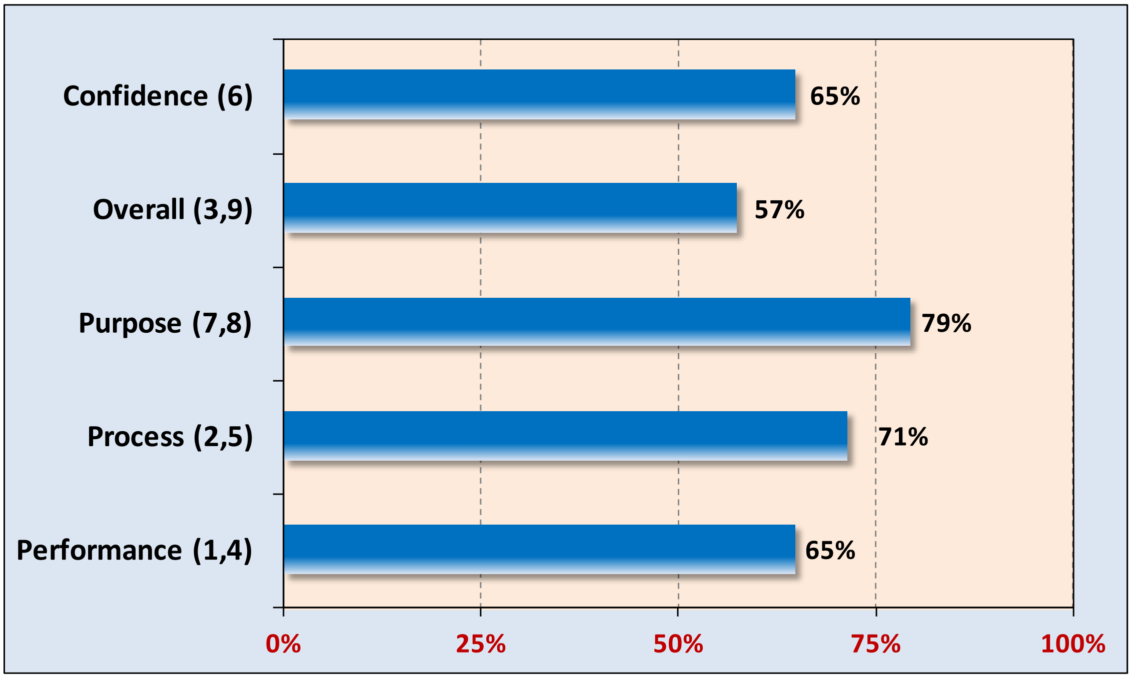

Figure 4.6 System Trust and Confidence

In average, the participants reported 65% of trust in system performance and confidence. Participants reported 79% and 71%, respectively, in understanding the purpose of the system and it underlying behavior. In overall, the visually impaired participants reported 57% of system trust. Individual responses from participants of trust questionnaire are listed in Table 4-6.

Additional comments (in *italic* type) from the participants are listed as follows.

"*Cool and nice to use.*"

"*Told a couple of people about it.*"

"*Like the idea of the project and very supportive of this idea.*"

"*A well done job.*"

"System was slow. "

"Not fair to evaluate for only using for 5-min."

"Not sure how it turns on."

"It took multiple attempts."

"Need better volume."

Table 4.6 Trust and Confidence Survey Results

Question #		1	2	3	4	5	6	7	8	9					
Subject ID	Guidance Type (Dog/Cane)	Enhance Safety	System Familiarity	Trust System	Reliable	Dependable	Confidence	Integrity	Intent	Confident to Cross	Performance (1,4)	Process (2,5)	Purpose (7,8)	Overall (3,9)	Confidence (6)
6	Dog	0.00	1.00	0.00	0.50	0.50	0.50	0.75	0.75	0.00	0.25	0.75	0.75	0.00	0.50
8	Cane	0.25	0.50	0.25	0.50	0.50	0.50	0.75	0.75	0.25	0.38	0.50	0.75	0.25	0.50
26	Cane	0.50	1.00	0.75	1.00	0.50	0.75	0.75	1.00	0.25	0.75	0.75	0.88	0.50	0.75
13	Dog	1.00	1.00	0.75	0.75	0.75	1.00	1.00	1.00	0.25	0.88	0.88	1.00	0.50	1.00
23	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.50	1.00
27	Cane	0.75	0.25	0.50	0.25	0.25	0.50	0.50	1.00	0.50	0.50	0.25	0.75	0.50	0.50
4	Cane	0.75	0.25	0.75	0.75	0.75	0.75	0.50	1.00	0.75	0.75	0.50	0.75	0.75	0.75
21	Cane	1.00	1.00	0.50	0.25	0.25	0.25	0.25	0.75	0.50	0.63	0.63	0.50	0.50	0.25
2	Cane	0.75	1.00	1.00	0.75	0.75	0.75	0.75	1.00	1.00	0.75	0.88	0.88	1.00	0.75
18	Dog	0.00	0.75	0.00	0.25	0.00	0.00	0.25	0.00	0.00	0.13	0.38	0.13	0.00	0.00
17	Cane	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	Cane	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
19	Cane	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	Dog	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.50	0.00	0.00
12	Cane	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
16	Cane	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.88	1.00	1.00	1.00	1.00
1	Cane	0.00	NA	0.00	0.25	0.50	0.00	0.25	1.00	0.50	0.13	0.50	0.63	0.25	0.00
AVERAGE		0.63	0.80	0.62	0.66	0.63	0.65	0.69	0.90	0.53	**0.65**	**0.71**	**0.79**	**0.57**	**0.65**

*Note: NA – Participant did not answer.

5 LESSON LEARNED AND FUTURE WORK

5.1 Lesson Learned

- Guide dog may be distracted by O&M specialist or other research team member nearby the intersection.
- The single and double tap user interface may seem relatively easy for the visually impaired participants. However, 15-minute of tutorial on how to properly use the device is not sufficient. There is still a learning curve for the users to understand how the system works. For example, in order to hear the auditory message clearly at a busy intersection, the participants usually point the phone to a desired direction and immediately bring the phone to their ears before the orientation measurement from the digital compass is stabilized.
- The system was tested at field site for several without GPS signal reception issue. However, a few participants experienced incorrect information due to the fact that the MAPS device was confused by user's actual location. A Bluetooth geo-ID, as we previously proposed, is absolutely needed to surely identify user's location at an intersection.
- In the future, design the experiment to evaluate participants' performance 3-month later. This is to evaluate the usefulness of the MAPS system and user's knowledge retention in learning new technology.

5.2 Future Work

Future research will focus on the following areas.

- Explore alternatives to make the system hands-free
- Include user configurable settings for vibration pattern, frequency and speech rate
- Navigation guidance solution such as work zone navigation guidance or bus stop information by incorporating Bluetooth Geo-ID
- Develop veering alert algorithm

In the future, when transportation infrastructure is equipped with dedicated short range communications (DSRC) technology, the Bluetooth device in our proposed system may be replaced by a DSRC device where appropriate. The DSRC network can certainly complement and enrich the proposed navigation system. Intersections equipped with DSRC technology will advance the capabilities of the proposed system to more complex mobility and safety applications for people with vision impairment. Our proposed solution can take advantage of the low-latency capability of DSRC to coordinate cooperative communication among pedestrians waiting at the crossing, traffic signal controllers, and approaching vehicles, thereby providing dynamic decision-making support to all travelers, not just individuals with vision impairment.

6 SUMMARY AND CONCLUSION

People with vision impairment generally have difficulty crossing intersections due to 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 or 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:

- Additional information needed about intersection
- Output: short auditory phrases
- Feedback should not interfere with pedestrians’ ability to use his or her canes or listen to traffic cues
- Tactile cues and short auditory message are recommended as warnings in a dangerous situation
- Be able to repeat warnings / output
- Automatic activation of walk signal or allow activation from the mobile interface

The MAPS system is a smartphone-based intersection crossing decision support system that is intended to provide geometry and signal timing information to the visually impaired at intersections. The MAPS system uses wireless communications, GPS, Bluetooth, and motion sensors embedded on the smartphone to determine orientation and location of a user at an intersection. Intersection geometry information, such as street name and street width in terms of number of lanes, is provided to users when tapping once on the screen of a smartphone while pointing the phone at a desired direction. Pedestrians can use the information contained in the audible messages to make more informed decisions in determining which street to cross. After determining which direction to cross, the visually impaired pedestrians can tap on the smartphone screen twice to request pedestrian walk phase and obtain signal timing information on the smartphone. Pedestrians can use the information contained in the audible messages to determine when to cross a street.

The MAPS system has employed pedestrian-centered design to incorporate survey feedbacks from previous study on user needs and preferred user interfaces. The easy-to-use inputs (single and double taps) and short auditory messages are intended to minimize additional task load for the visually impaired at signalized intersection crossings.

The primary goal of the current work was to validate the use and functioning of the MAPS system in real-world. The purpose is to identify if it could provide geometry and signal timing information and thus provide decision support for the visually impaired pedestrians. This was accomplished by first recruiting a representative sample of pedestrians (18, 11 male & 7 female) who are visually impaired from metro areas in Twin Cities across a range of ages (Mean = 44.2, SD = 15.2). Pedestrians were given brief tutorial on how to operate smartphone device including pointing to different direction for geometry and signal timing information. Participants were asked to perform one crossing task at an intersection already equipped with APS system and two crossing tasks at second intersection with and without the use of MAPS system. Objective measures, such as walk speed at sidewalk and crosswalk, in-position time, and time to step into crosswalk, are compared to evaluate users' performance using different type of assistances. In addition, the current work sought to evaluate the usability of the MAPS system to better understand users' perceptions of workload, satisfaction, usefulness, and willingness to use the information presented by the smartphone app.

Summary of results:

- 50% of the participants own and use a smartphone.
- Cane and guide dog are the preferred methods of navigation assistance.
- 95% of the participants considered their travel skills as average, above average or well above average (including sense of direction, independent travel, and signalized intersection crossing).
- Pushbutton locating tone at APS intersection is helpful.
- 65% of the participants preferred using MAPS system over regular pushbutton.
- 82% of the participants reported MAPS system provides helpful geometry information.
- 59% of the participants reported MAPS system provides helpful signal information.
- Crosswalk speed is significantly faster than the sidewalk speed at intersection #1, but no significant difference between the sidewalk and crosswalk speed at second intersection.
- Average pushbutton search time is 7.8 and 26.6 seconds for the APS and regular pushbutton, respectively.
- Average in-position time using the MAPS system (9.8 sec) is significantly lower than the in-position time using APS (14.5 sec) and regular pushbutton (34.8 sec).
- On average, the participants wait about 3.1 sec to step into crosswalk at APS intersection after walk sign is on. The average time to step into crosswalk at non-APS intersection is 7.1 sec without using MAPS device and 5.5 sec while using the MAPS assistance.
- Participants wait 2.5 sec longer to step into crosswalk when using MAPS than the APS system. Possible explanations are, (1) APS has shorter message and simple message types, and (2) MAPS is new and users are already familiar with APS system.
- No significant difference in number of veering at both intersections.
- The participants reported the MAPS system is moderately useful (0.95 using bipolar scales between -2 and 2).

- The participants reported that the MAPS system is moderately satisfying (1.04 using bipolar scales between -2 and 2).
- 79% of the participants understand the purpose of the system.
- 71% of the participants understand the process of the system.
- 65% of the participants are confident with the performance of the system.
- Overall, 57% of the participants trust the MAPS system.

The single and double tap user interface may seem relatively easy for the visually impaired participants to operate. However, 15-minute tutorial on how to properly use the device is not sufficient. There is still a learning curve for users to understand how the system works. For example, a common issue is that the participants usually point the phone to a desired direction and immediately bring the phone to their ears in order to hear the auditory message clearly at a busy intersection. The MAPS system was confused by the desired direction of information when users bringing the phone to their ears before the orientation measurements from the digital compass are stabilized.

The system was tested at experiment site for several times without GPS signal reception issue. However, a few participants experienced incorrect information due to the fact that the GPS receiver on the phone was not able to indentify user's actual location. A Bluetooth geo-ID, as we previously proposed for urban area, is definitely needed to reliably determine user's locations at intersections. Enhancements, such as reducing the latency of signal data communication and learning pedestrian walking time automatically, were made to existing system. This will allow the MAPS to provide walk time countdown information to the visually impaired pedestrians if they select to hear the countdown announcement from user configuration in the future.

In the future, we would like to explore and investigate alternatives to make the system hands-free and include user configurable settings for selectable vibration pattern, message frequency and speech rate as suggested by the participants. We also would like to use this smartphone-based approach to investigate solution for navigating visually impaired pedestrians at work zone or bus stop by incorporating Bluetooth Geo-ID or other positioning technologies.

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APPENDIX A: PARTICIPANT RECRUITMENT AD AND CONSENT FORM

A.1 Recruitment Ad

BLIND AND LOW-VISION VOLUNTEERS NEEDED

Researchers at the University of Minnesota have developed a Mobile Accessible Pedestrian Signals (MAPS) that provide signal timing and intersection geometry information to people who are visually impaired at signal intersections. They are recruiting individuals who are visually impaired to participate in an experiment at two locations involving signalized intersection crossing. Participants will be asked to cross signalized intersections with Accessible Pedestrian Signals (APS) and with a MAPS device that provide signal and geometry information. The participants will be followed by a certified Orientation and Mobility (O&M) specialist as a shadow at each location. The participants will have one-on-one discussions with a researcher before and after each crossing task to understand how blind and low vision individuals orient/navigate as a pedestrian, what types of information cue they use, and evaluate the usefulness of information provided by the MAPS device at intersection crossings.

Experiment will be conducted at two signalized intersections the Twin Cities Metro Area. It will require approximately 1 hour for each location. Participation in both locations is required for each participant and each participant will be paid $30 for each session.

There is no additional risk of injury to participants as compared to crossing existing signalized intersections. In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company.

To participate, individuals must:

- **Be 18 to 64 years of age,**
- **Have at best 20/70 acuity with correction in their better eye,**
- **Have completed Orientation and Mobility training,**
- **Be proficient in using a cane or guide dog,**
- **Be willing to have audio and/or video recorded during the interview and intersection crossing tasks.**

If you fit these criteria, you may be eligible to participate in the study. If you are interested, please contact

Linda Spaulding
Email: thekidisgood1@comcast.net, Phone: (651) 247-5553

Or, Chen-Fu Liao
Email: cliao@umn.edu, Phone: (612) 626-1697

Please provide your name and a phone number where you can be reached during the day.

A.2 Consent Form

Title of Study: Spatial Cognition of the Blind and Visually Impaired While Using a Mobile Accessible Pedestrian System (MAPS) at Signalized Intersections

You are invited to participate in a research study to evaluate the usefulness of a smartphone based traffic signal system designed for the visually impaired pedestrians. You were selected because you are considered legally blind or to have low vision, you have completed orientation and mobility training, and 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 Chen-Fu Liao who is a research staff at the University of Minnesota and assisted by Linda Spaulding who is a certified Orientation and Mobility (O&M) specialist. This study is sponsored by U.S. Department of Transportation through the University Transportation Center program at University of Minnesota.

Background Information

The purpose of this study is to provide intersection geometry and traffic signal information to the blind and visually impaired while waiting at a signalized intersection. The traffic information will be wirelessly broadcasted to a smartphone device that was developed by the research team.

Procedures

If you agree to be in this study, we would ask you to participate in an experiment involving crossing two signalized intersections in the metro area. At each location, you will be asked to perform crossing tasks and will be interviewed before and after the crossing. The crossing tasks and interviews will focus on your experiences while crossing signalized intersections, using audible pedestrian signals, and a smartphone based accessible pedestrian signal device provided by the research team.

For each crossing task, a certified O&M specialist will bring you to a starting point which will be located about 50~100 feet away from an intersection. You will be asked to travel along the sidewalk using your own navigational skills to reach the corner of the intersection. While at the intersection, you will need to find and use the pushbutton to request a pedestrian walk signal or use our smartphone based pedestrian signal device to determine when it is possible to cross. You will then cross the street that is perpendicular to the sidewalk you just travelled and arrive at the other side of street.

The pre and post experiment interviews 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 the new technology,
5. Your opinions of the smartphone based pedestrian crossing system,
6. Usability and acceptance of the smartphone system,
7. Trust of the smartphone based traffic information system, and

8. Demographic information.

Each session should last approximately one hour. The experiment and interviews will be recorded using video and/or audio equipments to record your responses and intersection crossing performance.

Risks and Benefits of being in the Study
There are no direct risks or benefits associated with this experiment. A certified O&M specialist will shadow each subject during each intersection crossing in order to provide assistance if needed or in case of emergency.

Research Related to Injury
In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company. If you think that you have suffered a research related injury, let the study staffs know right away.

Compensation
You will receive $30 for participating in each session. Compensation ($60 in total) will be paid after the completion of both experiment sessions.

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 participants. 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 this 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 researcher conducting this study is: Chen-Fu Liao. He is assisted by Linda Spaulding who is a certified O&M specialist. You may ask any questions you have now. If you have questions later, you are encouraged to contact Chen-Fu Liao at 500 Pillsbury Drive SE, Minneapolis, MN 55455, (612) 626-1697, or cliao@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: _______________________________

IRB Code Number: **1112S07962**
Approved on Feb. 2, 2012

APPENDIX B: EXPERIMENT PROTOCOL AND INTERVIEW QUESTIONNAIRES

B.1 Experiment Protocol

Experiment Protocol

Thank you for agreeing to help us with our research on technology that may assist the mobility of blind and low vision pedestrians. You will be asked to cross two signalized intersections. Two trips at each intersection will be conducted. In each experiment, you will be asked to travel from an origin which is about 50~100-ft away from the intersection.

The first intersection is equipped with accessible pedestrian signal (APS). You will cross the intersection twice (with and without the use of pushbutton). The second intersection is a regular intersection that you will cross with and without the assistance of a mobile device. The purposes of these experiments are to compare the performance of intersection crossing with or without using the pushbutton and a mobile assistive device.

In order to observe and capture multiple measurements and parameters in each experiment, we will video record each trip to better understand the potential challenges people who are visually impaired may encounter. A certified orientation and mobility (O&M) specialist will follow a few steps behind you in case of emergency or assistance needed during each task. The role of the O&M specialist is to ensure your safety during the crossing. If at any time during the experiment, you feel uncomfortable or unsafe, please let the O&M specialist know.

I. Pre Experiment Interview Protocol

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

A. Demographic information.

13. Age: ____________ years

14. Gender: ☐ Male ☐ Female

15. What is the highest level of education you have completed?
    - ☐ Some high school – no diploma
    - ☐ High school graduate or equivalent
    - ☐ Some college or Associate degree
    - ☐ Bachelor's degree
    - ☐ Advanced degree (MBA, PhD, etc.)
    - ☐ Other, please specify ______________________________________

16. In average, how often do you cross a signalized intersection?
    - ☐ More than 4 intersections a day
    - ☐ 1~2 intersections a day
    - ☐ 1~4 intersections a week
    - ☐ Less than 1 intersection a week

B. Self-ratings: Technology

17. Do you currently use a mobile phone?
    - ☐ No
    - ☐ Yes ➔ ☐ Smartphone ☐ Non-Smartphone

18. Do you currently use a mobile navigation assistant / GPS?
    - ☐ No
    - ☐ Yes

19. Have you experienced an Accessible 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

C. Navigation & mobility

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

- ☐ Cane ________________ years
- ☐ Guide dog ______________ years
- ☐ Other __________________ years

21. What is your preferred method of assistance while navigating to a destination?

- ☐ Cane
- ☐ Guide dog
- ☐ Asking other pedestrians I pass
- ☐ No outside assistance
- ☐ Other ____

22. How proficient are you are at each of these travel skills (on the scale from 1 to 5)

(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	☐	☐	☐	☐	☐
Signalized street crossings	☐	☐	☐	☐	☐

II. Post Experiment Interview Protocol

We would like to collect feedback from your intersection crossing experiences. 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.

D. APS intersection crossing (Intersection #1)

23. Do you prefer using a pushbutton for requesting walk phase at signalized intersection?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

24. Do you have difficulty locating the pushbutton?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

25. Does the APS system provide sufficient information to assist your intersection crossing?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

26. Do you feel you have sufficient time to cross this intersection?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

27. Do you feel you stay alignment with the crosswalk?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

E. Non-APS intersection crossing (Intersection #2)

28. Do you prefer using a pushbutton or the mobile assistive device for requesting walk phase at signalized intersection?
    - ☐ No
    - ☐ Yes

☐ Don't know

29. Do you have difficulty locating the pushbutton?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

30. Do you feel you have sufficient time to cross this intersection?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

31. Do you feel you stay alignment with the crosswalk?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

32. Does the mobile assistive device provide sufficient information to assist your intersection crossing?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

33. Do you feel the mobile device provide helpful information about the intersection geometry to support your wayfinding?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

34. Do you feel the mobile device provide helpful information about the intersection signal timing to support your intersection crossing?
    - ☐ No
    - ☐ Yes
    - ☐ Don't know

B.2 Acceptance and Usability

MOBILE ACCESIBLE PEDESTRIAN SIGNAL (MAPS)

SYSTEM USABILITY

What is your opinion about the system you just used? Please rate your opinion for each descriptive item below (please tick one box for each item):

For example, if you thought the system was very easy to use but required a lot of effort to learn, you might respond as follows:

Easy	☒	☐	☐	☐	☐	Difficult
Simple	☐	☐	☐	☒	☐	Confusing

Please continue to rate your opinion of the system for each descriptive term below:

	5	4	3	2	1	
Useful	☐	☐	☐	☐	☐	Useless
Pleasant	☐	☐	☐	☐	☐	Unpleasant
Good	☐	☐	☐	☐	☐	Bad
Nice	☐	☐	☐	☐	☐	Annoying
Effective	☐	☐	☐	☐	☐	Superfluous
Likeable	☐	☐	☐	☐	☐	Irritating
Assisting	☐	☐	☐	☐	☐	Worthless
Desirable	☐	☐	☐	☐	☐	Undesirable
Raising Alertness	☐	☐	☐	☐	☐	Sleep-inducing

Thank you for completing this questionnaire.

B.3 Trust

SYSTEM TRUST QUESTIONNAIRE

Below are statements relating to the system you just used, please indicate your level of agreement with the statement on the scales below each one.

1. The performance of the system enhanced my safety at signalized intersection crossings.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

2. I am familiar with the operation of the system.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

3. I trust the system.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

4. The system is reliable.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

5. The system is dependable.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

6. I have confidence in this system.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

7. The system has integrity.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

8. I am comfortable with the intent of the system.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

9. I am confident in my ability to cross a signalized intersection without the system.

Strongly Disagree				**Strongly Agree**
0	25	50	75	100
☐	☐	☐	☐	☐

APPENDIX C: INTERSECTION LAYOUTS

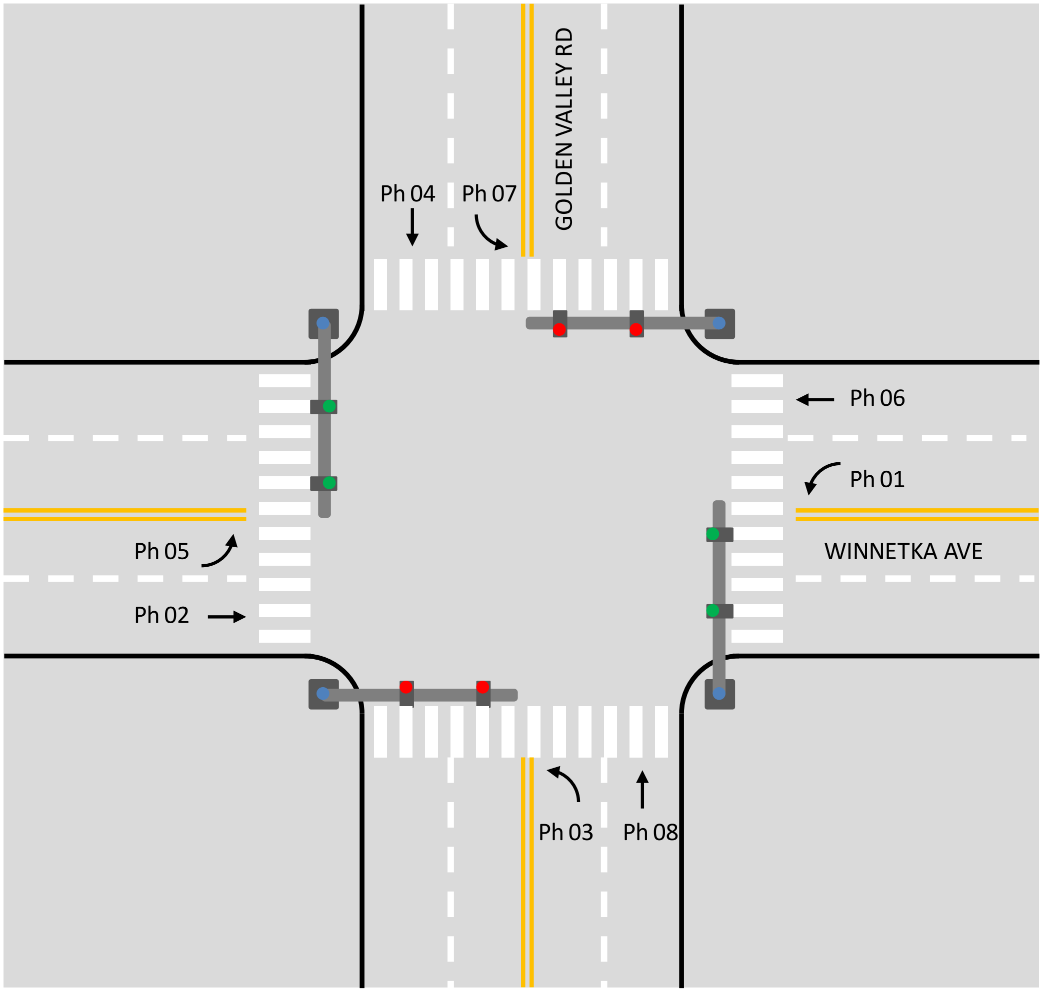

Figure C-1 Controller Phasing Layout at Winnetka Ave and Golden Valley Road

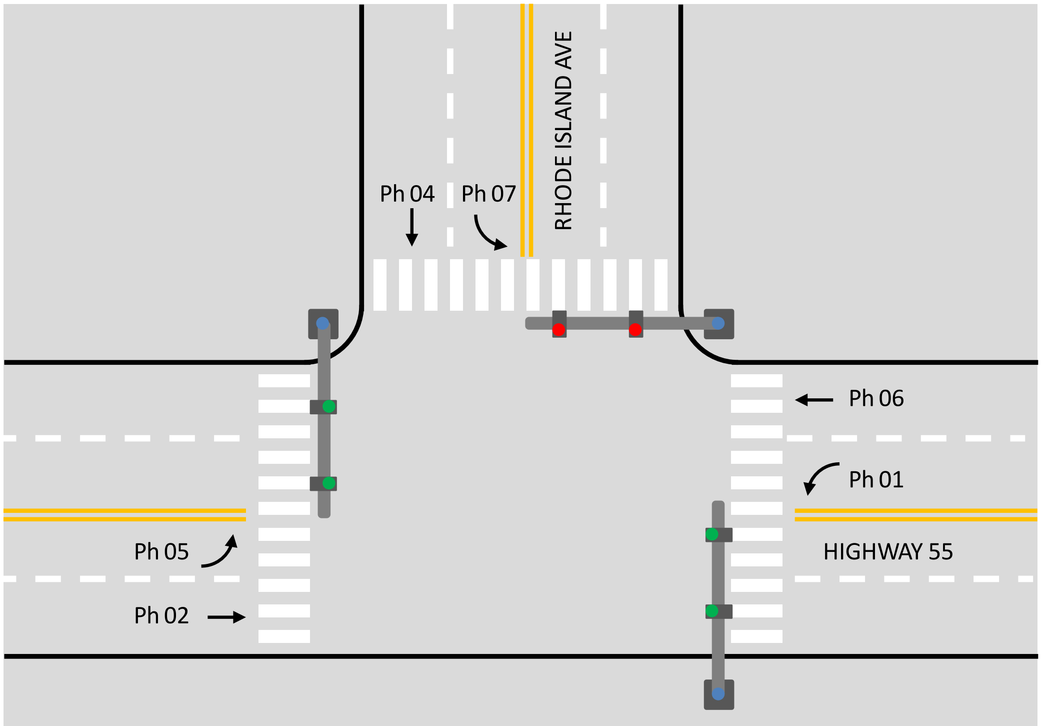

Figure C-2 Controller Phasing Layout at Highway 55 and Rhode Island Ave

Table C-1 AADT of Highway 55 & Rhode Island Avenue

Intersection / AADT	Highway 55	Rhode Island Ave
Highway 55 & Rhode Island Ave	33500	2550

Table C-2 AADT of Golden Valley Road & Winnetka Avenue

Intersection / AADT	Golden Valley Rd	Winnetka Ave
Golden Valley Road & Winnetka Ave	3850	2950

Table C-3 Controller Timing Plan of Highway 55 & Rhode Island Avenue

Controller Timing Plan (MM)2-1
Plan 1

GOLDEN VALLEY - TH 55 & Rhode Island Ave

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Min Green	0	20	0	8	7	20	0	0	0	0	0	0	0	0	0	0
BK Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CS Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delay Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk	0	0	0	18	0	7	0	0	0	0	0	0	0	0	0	0
Walk 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped Clear	0	0	0	15	0	24	0	0	0	0	0	0	0	0	0	0
Ped Clear 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped Clear Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle Ext	0.0	5.5	0.0	3.0	3.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle Ext 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max 1	0	60	0	40	30	60	0	0	0	0	0	0	0	0	0	0
Max 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYM Max	0	80	0	0	0	80	0	0	0	0	0	0	0	0	0	0
DYM Stp	0.0	10.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow	0.0	5.5	0.0	3.5	3.5	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Clear	0.0	1.5	0.0	3.5	2.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Revert	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
ACT B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEC/ACT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max Int	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cars Wt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STPT Duc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Min Gap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table C-4 Controller Timing Plan of Golden Valley Road & Winnetka Avenue

Controller Timing Plan (MM)2-1 GOLDEN VALLEY - Winnetka Ave & Golden Valley Rd
Plan 1

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Min Green	7	12	7	10	7	12	7	10	0	0	0	0	0	0	0	0
BK Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CS Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delay Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk	0	10	0	10	0	10	0	10	0	0	0	0	0	0	0	0
Walk 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped Clear	0	22	0	22	0	22	0	22	0	0	0	0	0	0	0	0
Ped Clear 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped Clear Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle Ext	3.5	4.0	3.5	4.0	3.5	4.0	3.5	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle Ext 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max 1	20	50	20	33	20	50	15	33	0	0	0	0	0	0	0	0
Max 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYM Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYM Stp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow	3.5	4.0	3.5	4.0	3.5	4.0	3.5	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Clear	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Revert	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
ACT B4	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0
SEC/ACT	0.0	2.3	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max Int	0	20	0	0	0	20	0	0	0	0	0	0	0	0	0	0
Time B4	0	17	0	0	0	17	0	0	0	0	0	0	0	0	0	0
Cars Wt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STPT Duc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Time To Reduce	0	17	0	0	0	17	0	0	0	0	0	0	0	0	0	0
Min Gap	0.0	3.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX D: OBJECTIVE MEASURES

Table D-1 Intersection #1 Objective Measures

Objective Performance Measures	Sidewalk Time (sec) / 102 ft	Pushbutton Search Time (sec)	Time to Step Into Crosswalk (sec)	Crosswalk Time (sec) / 94 ft	In-Position Time (sec)
Dog AVG	30.8	9.0	4.4	23.0	16.2
Cane AVG	27.3	7.8	2.7	22.7	14.3
All AVG	**28.1**	**7.8**	**3.1**	**22.6**	**14.5**
All SD	5.0	6.1	1.5	4.3	7.5
All MIN	23.0	2.0	1.0	18.0	7.0
All MAX	42.0	26.0	6.0	34.0	33.0

Travel Speed Comparisons	Sidewalk Speed		Crosswalk Speed	
	(ft/sec)	(mph)	(ft/sec)	(mph)
Dog AVG	3.4	2.3	4.3	2.9
Cane AVG	3.8	2.6	4.2	2.9
All AVG	**3.7**	**2.5**	**4.3**	**2.9**
All SD	0.5	0.4	0.6	0.4
All MIN	2.4	1.7	2.8	1.9
All MAX	4.4	3.0	5.2	3.6

Table D-2 Intersection #2 Objective Measures (Crossing Task #1)

Objective Performance Measures	Sidewalk Time (sec) / 238 ft	Pushbutton Search Time (sec)	Time to Step Into Crosswalk (sec)	Crosswalk Time (sec) / 111 ft	In-Position Time (sec)
Dog AVG	52.6	70.4	10.5	24.6	79.8
Cane AVG	54.7	29.5	5.5	24.6	37.4
All AVG	**53.5**	**26.6**	**7.1**	**23.8**	**34.8**
All SD	8.5	56.5	4.7	5.6	57.2
All MIN	36.0	2.0	3.0	14.0	6.0
All MAX	69.0	240.0	20.0	36.0	250.0

Travel Speed Comparisons	Sidewalk Speed		Crosswalk Speed	
	(ft/sec)	(mph)	(ft/sec)	(mph)
Dog AVG	4.7	3.2	4.9	3.3
Cane AVG	4.5	3.1	5.7	3.9
All AVG	**4.6**	**3.1**	**4.9**	**3.4**
All SD	0.8	0.5	1.2	0.8
All MIN	3.4	2.4	3.1	2.1
All MAX	6.6	4.5	7.9	5.4

Table D-3 Intersection #2 Objective Measures (Crossing Task #2)

Objective Performance Measures	Sidewalk Time (sec) / 238 ft	Pushbutton Search Time (sec)	Time to Step Into Crosswalk (sec)	Crosswalk Time (sec) / 111 ft	In-Position Time (sec)
Dog AVG	51.4	NA	8.5	23.8	15.0
Cane AVG	50.4	NA	4.5	23.1	7.6
All AVG	**50.7**	**NA**	**5.5**	**23.3**	**9.8**
All SD	8.8	NA	3.2	3.6	6.7
All MIN	36.0	NA	2.0	15.0	4.0
All MAX	62.0	NA	15.0	30.0	34.0

Travel Speed Comparisons	Sidewalk Speed		Crosswalk Speed	
	(ft/sec)	(mph)	(ft/sec)	(mph)
Dog AVG	4.8	3.3	4.8	3.3
Cane AVG	4.9	3.3	5.6	3.8
All AVG	**4.8**	**3.3**	**4.9**	**3.3**
All SD	0.9	0.6	0.9	0.6
All MIN	3.8	2.6	3.7	2.5
All MAX	6.6	4.5	7.4	5.0

APPENDIX E: SOFTWARE DESIGN AND DOCUMENTATION

E.1 Introduction

The purpose of this application is to help visually challenged people cross streets at intersections. The motive is to create an application for smartphones like iPhone, android based phones etc which can help the user do this more comfortably then existing solutions like chirping sounds at intersections.
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 of the phone that are used by the application are: ***Compass, GPS, TTS (text to speech), and Bluetooth.***

E.2 Client Code Description

Client Android phone will have the details about the intersections and the corresponding GPS and Bluetooth ID's (If present) along with neighboring intersection details in its database. When user is near intersection and wants to cross the street he has to double tap to confirm the same. Device will get the up to date signal information of the current intersection from the server (which reads from the DB which keeps track of latest signal information from the signal controller) after sending the details such as direction (from compass) and Bluetooth ID stored in DB from current latitude and longitude (from GPS and Bluetooth).

E.2.1 Single tap application:
On single Tap, the smartphone device gives street details of the intersection based on direction user is pointing the device to.

<u>TTS Messages:</u>

- If not near intersection "Not near intersection"
- If the direction can't be figured out from user's device angle then "Turn for data"
- If direction can be figured out and near intersection then "You are pointing to " + direction + street Info
- If the list for details about intersection and neighboring intersections is not formed then "Please wait while list is formed"

E.2.2 Double tap application:
On double tap, if the user is near intersection then request is sent to server to get the latest signal details by sending the direction the user is pointing the device and Bluetooth ID from DB got from current lat and long (from GPS and Bluetooth (if present)) for current intersection the user is at. Also once the request is sent to server until the signal information for walk is not got it will keep on sending the request to server every two seconds.
Double tap anytime will send the request to server with the current direction, lat and long.

<u>TTS Messages:</u>

- If not near intersection "Not near intersection"
- If the direction can't be figured out from user's device angle then "Turn for data"
- If near intersection and no crossing then "No crossing in this direction, no need to wait"

- If the list for details about intersection and neighboring intersections is not formed then “Please wait while list is formed”
- If request is sent to server then “Please wait while data is fetched”
- After the request is sent to server
  - o If network not available then “Wi-Fi not available in this area”
  - o User will be asked to “wait for signal”
    - If the current signal state is “Walk” but since we won’t have the time left for signal to turn red, to be on safer side user is asked to wait for next green signal turn
    - If current state is not walk then need to wait for walk signal
- If signal state is walk then “Walk now. X seconds left”
- When the signal is walk and user is asked to cross then every 2 seconds will inform to user “X seconds left”
- If walk time is over “Time over. Double tap again to confirm”

E.2.3 New classes and their descriptions:

The package mto.lab.navigation has the following classes (Please refer to the function description for more detailed description of the class):

PedestrianNavigation.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.

LogData.java
This class is used for logging purpose.

E.2.4 Classes with description of the new member functions and member variables added

PedestrianNavigation.java:
<u>NEW MEMBER FUNCTIONS:</u>
onTouchEvent is deprecated and hence new member function GestureListener is used.

a. onSingleTapConfirmed()
This function detects touches made on the screen of the android. It captures the single tap gesture and on detecting the single tap gives the street information details to user.

b. onDoubleTap()
This function detects touches made on the screen of the android. It captures the double tap gesture.
After detecting a double tap, a request is sent to server 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 Wi-Fi connection.
    - If the Wi-Fi 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. Current interval between sending request to server is 2 seconds.

<u>New MEMBER VARIABLES:</u>

- **Boolean** greenSignalFirstTime
  This variable controls if walk signal was ON first time the response is got from server.

- **Boolean** signalChange
  This variable indicates if the signal changed from walk to No walk. So if initially walk sign was ON then greenSignalFirstTime will be true but signalChange will be false. So next time when it becomes “No Walk” sign then signalChange will be set to true. So next time “Walk sign” is ON since signalChange is true now it will ask the user to cross. This logic is present to ask the user to cross only on second “Walk” sign on since if the walk sign was ON first time when the response is got from the server we are not sure if enough time is left for user to cross. So user will be asked to cross only when the “walk sign” is ON second time.

- **final int** TIMER_PERIOD;
  TIMER_PERIOD is the trigger time for timer running.

E.3 DATABASE stored locally on smartphone (Client)

E.3.1 DBOpener.java

<u>DATABASE Schema:</u>

DATABASE_NAME = "tts_speaker"
DATABASE_VERSION = 1
MY_DATABASE_TABLE = “tts”

```
_id text primary key,
latitude real not null,
longitude real not null,
id1 text not null,
d1 text not null,
d11 integer not null,
xing1 integer not null,
streetInfo1 text not null,
id2 text not null,
 d2 text not null,
```

d22 integer not null,
xing2 integer not null,
streetInfo2 text not null,
id3 text not null,
d3 text not null,
d33 integer not null,
xing3 integer not null,
streetInfo3 text not null,
id4 text not null,
d4 text not null,
d44 integer not null,
xing4 integer not null,
streetInfo4 text not null,
description text not null,
bt_present integer not null

- _id is the Bluetooth address of the Bluetooth device which uniquely identifies the record in database.
- Latitude and longitude columns correspond to lat and long of Bluetooth device at an intersection.
- id1, id2, id3 and id4 correspond to Bluetooth address of the neighboring Bluetooth devices in 4 directions.
- d1 corresponds to the direction (East, West, North or South) and
- d11 corresponds to the compass heading angle of the neighboring Bluetooth device id1. Similarly,
- d2 corresponds to the direction and
- d22 corresponds to the compass heading angle of the neighboring Bluetooth device id2;
- d3 corresponds to the direction and
- d33 corresponds to the compass heading angle of the neighboring Bluetooth device id3;
- d4 corresponds to the direction and
- d44 corresponds to the compass heading angle of the neighboring Bluetooth device id4.
- streetInfo1, streetInfo2, streetInfo3, streetInfo4 correspond to street details of each of the 4 intersections.
  xing1 tells whether there is a crossing or not between _id and id1. **Note: 0 for no crossing and 1 crossing is present.** Similarly
- xing2 tells whether there is a crossing or not between _id and id2;
- xing3 tells whether there is a crossing or not between _id and id3;
- xing4 tells whether there is a crossing or not between _id and id4.
- description column is just a text identifying the location.
- bt_present (0 if not present, 1 if present) indicates if Bluetooth device is installed or not at the given intersection. If Bluetooth device is put in intersections then bt_present should be set 1 for all such intersections for the Android Client so that it can use the Bluetooth. Database has to be modified with bt_present set to 1, program has to uninstalled and reinstalled again in Android Client for the DB changes to reflect.

- If there is no neighboring Bluetooth device **-1** is stored for id1, id2, id3, id4; and corresponding direction (East/West/South/North) for d1, d2, d3, d4.

E.3.2 Bluetooth device list

_id	latitude	longitude	description	bt_present
00:12:F3:0B:4A:11	44.9750372780,	93.2302341827	NE corner, BT-1	0
00:12:F3:0B:4A:27	44.9749896011,	93.2303951711	NW corner, BT-2	0
00:12:F3:0B:49:A6	44.974689,	93.230411	SW corner, BT-3	0
00:12:F3:0B:49:4C	44.974691,	93.230244	SE corner, BT-4	0

E.4 Server Code description

Android device sends request to Server to get the details of current signal information for the current intersection user is at. It sends the direction device is pointing to and Bluetooth ID of intersection (stored in DB along with lat and long of current intersection) queried from DB based on current lat and long (got from GPS and Bluetooth if present).

When server gets request from the client it gets the current signal information for the intersection requested. Intersection Id is got from the Bluetooth Id passed in HTTP request. Based on the direction got in the request it will fetch the details for given Bluetooth id and direction from the database and send the signal state information to user.

DB maintained at the server is periodically updated by signal controller program which will have the details about the current signal details. Server will read these details when it gets the request. Also it has a timer which runs periodically every 2 minutes and deletes all the signal records and deletes the records from previous cycle, i.e., keeps record only for 120 seconds.

E.4.1Tables maintained:

- Intx_geo
  < **Intx_ID** [text PK], **Walk_Phase** [smallint(6), PK], Walk_Time [smallint(6)], Cross_Street [text], Num_Lane [smallint(6)]>

  Data sample:

Intx_ID	Walk_Phase	Walk_Time	Cross_Street	Num_Lane
101	2	24	Rhode Island Avenue	4
101	4	15	Highway 55	7
101	6	24	Rhode Island Avenue	4
101	8	15	Highway 55	7

- Intx_xing_phase
  < Intx_ID [text] , **Bluetooth_ID** [text, PK], **Dir** [varchar(50), PK], Phase [smallint(6)]>

  Data sample:

Intx_ID	Bluetooth_ID	Dir	Phase
101	00:12:F3:0B:49:4C	East	-1
101	00:12:F3:0B:49:4C	North	8
101	00:12:F3:0B:49:4C	South	-1
101	00:12:F3:0B:49:4C	West	2
101	00:12:F3:0B:49:A6	East	2
101	00:12:F3:0B:49:A6	North	4
101	00:12:F3:0B:49:A6	South	-1
101	00:12:F3:0B:49:A6	West	-1
101	00:12:F3:0B:4A:11	East	-1
101	00:12:F3:0B:4A:11	North	-1
101	00:12:F3:0B:4A:11	South	8
101	00:12:F3:0B:4A:11	West	6
101	00:12:F3:0B:4A:27	East	6
101	00:12:F3:0B:4A:27	North	-1
101	00:12:F3:0B:4A:27	South	4
101	00:12:F3:0B:4A:27	West	-1

- Signal_state
  < **ID** [bigint(20) unsigned, PK], Date [date], TimeStamp [decimal(25,3)], Signal_State [smallint(5) unsigned zerofill], Time_Left [decimal(10,3)], Intx_ID [text]>

  Data sample:

ID	Date	TimeStamp	Signal_State	Time_Left	Intx_ID
377309	5/1/2012	20120201142760.000	72	359.185	101
395613	5/3/2012	20120203135940.075	136	42.031	101
395614	5/3/2012	20120203140029.981	0	49.907	101
395615	5/3/2012	20120203140035.966	34	59.391	101
395616	5/3/2012	20120203140100.606	0	24.641	101
395617	5/3/2012	20120203140108.137	72	145.063	101
395618	5/3/2012	20120203140118.091	0	9.953	101
395619	5/3/2012	20120203140124.106	33	19.453	101
395620	5/3/2012	20120203140131.184	32	7.078	101
395621	5/3/2012	20120203140136.216	34	31.562	101
395622	5/3/2012	20120203140156.278	0	32.172	101

- PushButton_Requests

< **Intx_ID** [varchar(50), PK] , **Phase** [smallint(6), PK], PB_State>

Data sample:

Intx_ID	Phase	PB_State
101	2	0
101	4	0
101	6	0
101	8	0

Server Request format**:** HTTP Post
Url: "http://xx.xx.xx.xx:8080/PedistrianNavigation/GetSignalInfo"
HTTP Parameters: Bluetooth ID, direction

Server Response format**:**
Response Code(200 for success or error code) Date
Phase = ,SignalState = ,TimeLeft =

E.4.2 Classes and Descriptions: PedistrianNavigation

- Constants.java
  Class to maintain the constants used in the project

- DAOImpl.java
  Class to interact with the DB.
  This Class has methods
  - getConnection
    Establish the connection with DB

  - disconnectDB
    Method to disconnect from DB

  - getSignalData
    Gets the latest signal information for the current intersection and phase (identified by Bluetooth Id and direction) sent from client from the DB.

  - deleteRecordsFromPreviousCycle
    Methods which deleted the signal information records from the previous cycle. Called whenever timer triggers.

- GetSignalInfo.java
  Servlet to process the HTTP request and return the HTTP response.
  This Class has methods

  - processdata

Servlet method to process the HTTP Post request from Android Client to get the latest signal information. Client passes the Bluetooth Id and direction with HTTP request. Server gets the corresponding intersection ID and phase based on Bluetooth ID and direction sent from Client. Based on the intersection ID and phase fetched the signal details from the DB and sends it in the response. If success it returns 200 success code else 500 error code.

For this logic to work DB maintained in Client and Server should be synced (i.e. corresponding data should match).

- SignalStateRecord.java
  Class for signal information.

- TimerSchedulerContextListener.java
  Timer which runs every 2 minutes and deletes the signal records from previous cycle. Class has method
  - run
    Method triggered every 2 minutes. This calls deleteRecordsFromPreviousCycle in DAOImpl to delete the signal records from the previous cycle.

E.5 Controller code changes

Controller code was modified to send the signal information periodically to the database maintained at the server side.

E.5.1 Class DBFunctionality is added

Methods introduced:

- AddData :
  Inserts the latest signal information to database table "signal_state". Details sent are <**Date, TimeStamp, Signal_State, Time_Left, Intx_ID**> . Intersection Id will be stored at Controller side in file "\InterID.txt". (0101 currently). Also Signal_State information is in decimal.

E.5.2 Program logic added in static private void loop method

E.5.3 Method static private string getTimeStringInDecimalFormat is added to process string format

E.6 Socket Server Description

The socket server is a java socket program running at the IP xx.xx.xx.41 in the port 5567. It receives the signal information from the DCU in the format specified in the previous section. It then parses the above information and updates the database in the database server. Currently the following logic is used for updating the "SIGNALSTATE" table.

- If "R" is received the corresponding bit for that phase is set to 1 since the current signal is "G"
- If any other signal is received, the bit of the corresponding phase is reset to 0.

There is one more table that is updated from the socket server i.e., the table “intx_geo” which has information about the walking time for the various walking phases in an intersection. Based on the information being received for the pedestrian phase, the time duration for the signals G, F and Y are summed up and updated in the database periodically. The current period is 24 hours. Hence if the previous update to the walking time in the database was more than 24 hours, the current pedestrian signal would be used to update the walk time information. This is to take into consideration the fact that the walking time for pedestrians could be changed now and then. The minimum duration required for the update is a configurable variable.

The various classes that have been used in this component are the following

- ***SocketServer.java:*** The object of this class listens to the socket at the particular port and accepts client connections. For every client connection it creates a new thread of the ClientWorker object which will start handling the client’s messages.
- ***ClientWorker.java:*** The object of this class receives all the signal information from the DCU once the connection is established. A separate thread of this class’ object is created for every DCU client.
- ***DBConnector.java:*** This class is used for connecting to the database at the database server and updating them. Every ClientWorker will have one DBConnector object associated with it.
- ***SignalData.java:*** An object of this class is created for every signal string received by the ClientWorker. This class is used for parsing the signal and storing the different values in different variables.
- ***WalkTimeInfo.java:*** This class stores information required for calculating the walk time information. This class has the walking phase number, info on when it was last updated and info on whether it is currently getting updated.

<u>Logic for Updating Walk Time Info:</u>

The pedestrian signals for a particular walk phase x come in the sequence RGFYFYFYFY.. till a G is received for (x-8)*2. This sequence can get intertwined with other signals too.

An object of type WalkTimeInfo is created initially for all the walking phases 9-12. Their values for lastUpdateForWalkTime are initialized to current time. Whenever the pedestrian walk signal information is received, a check is done on whether the walk time information should be updated. If it has to be, then the updatingWalkTime boolean variable is set to true. We keep summing the walk time value for the incoming pedestrian signals until we receive a “G” for the phase (WalkPhase-8)*2. This signal is considered the end of the incoming pedestrian signal. After this, the updatingWalkTime variable is set to false and the walk time values accumulated so far is updated in the database.

<u>Logging:</u>

Logging for the socket server has been done using log4j API. The external jar file is included in the project and is located at “C:\eclipse\apache-log4j-1.2.16\ log4j-1.2.16.jar.” The jar file can be downloaded in future too.

Currently it rolls out the log file every day at midnight. For example, if the **File** option is set to /foo/bar.log and the **DatePattern** set to '.'yyyy-MM-dd, on 2001-02-16 at midnight, the logging file /foo/bar.log will be copied to /foo/bar.log.2001-02-16 and logging for 2001-02-17 will continue in /foo/bar.log until it rolls over the next day. We can set the logger frequency to roll out after a particular size or time too. We can specify various logging levels too for either debugging purpose by specifying less restrictive levels or for performance improvement by reducing the IO through more restrictive levels.

Further descriptions have been provided in the properties file of the socket server. The sample properties files are available online at http://www.tutorialspoint.com/log4j/log4j_logging_files.htm and other links. We can use one of these templates and configure the parameters according to our need. The documentation for this logger is located at http://logging.apache.org/log4j/1.2/apidocs/org/apache/log4j/DailyRollingFileAppender.html.

Testing the SocketServer component:
To test the socket server part a light weight DCU kind of project has been created which is the **PedNav-SampleDCU** project that sends request to the socket server like the DCU. The explanations for the various test cases and the input have all been documented and included in the java source files.

E.7 Relay IO Description

The IIRO being used for the project is used to open or close the circuit for the corresponding walk phases. The description and documentation for it could be found from the link http://accesio.com/go.cgi?p=/usb/usb-iiro-16.html. The issues faced and the set up instructions have been separately documented in the following documents.

- "Changes & Issues Documentation - Spring 2012" located at C:\Documents and Settings\student\Desktop\PedistrianProjectDocumentation\ Changes & Issues Documentation - Spring 2012.docx
- "IIROSetupNotes" located at C:\Documents and Settings\student\Desktop\PedistrianProjectDocumentation\ IIROSetupNotes.docx

The C# code that currently runs under a windows environment is located on Desktop.
The C++ code which could be used to run in future under a Linux environment is located at C:\Chenfu\USB-IIRO4\aiousb-1.91\usb\aiousb\samples\USB-IIRO-16\mysample.cpp.
From the sample.cpp program it is easy to change it according to our requirement to do only the operations we want.

APPENDIX F: OTHER HARDWARE DEVICES

F.1 Virtual Cabinet

A virtual controller cabinet manufactured by Athens Technical Specialists, Inc. (ATSI), as shown in Figure F-1, was used together with a NEMA traffic controller for testing the signal data transmission through the SDLC interface (http://www.atsi-tester.com/).

The TS2 Virtual Cabinet (TVC-3500) provides the full emulation of a NEMA TS 2 standard cabinet. It connects to an SDLC port (Port 1) of a NEMA TS 2 standard Controller Unit (controller). TVC-3500 receives SDLC frames from the controller, processes those frames and sends responses back to the controller. It also runs a full simulation of TF BIUs 1-4 (Terminals and Facilities), DR BIUs 1-4 (Detector Rack BIU), and an MMU.

Through the interface software (TS2 Virtual Cabinet Interface), the user can change inputs and monitor outputs of the TF BIUs, and simulate detector calls. This allows the user to monitor the controller's "reaction" to various inputs such as emergency vehicle preempt call, pedestrian call on a particular phase or an actuation of any detector call.

The software will also automatically enable inputs/outputs for those BIUs that are programmed in the controller and show which BIUs should be present in the cabinet. This provides a visual presentation of how the controller is setup and what inputs/outputs are available for the given controller configuration.

Figure F-1 TS2 Virtual Cabinet Device

F.2 Cellular Modem

A cellular modem manufactured by MultiTech Systems (http://www.multitech.com), as shown in Figure F-2, was used to transmit signal data from traffic controller cabinet to MAPS database server.

Figure F-2 MultiTech Cellular Modem

F.3 USB IO Device

An USB I/O device, as shown in Figure F-3, was used to activate pedestrian call request in traffic controller cabinet. The USB-IIRO-4 module is manufactured by ACCES I/O Products Inc. (http:// http://accesio.com/),

Model USB-IIRO-4 is an ideal portable solution for adding easy-to-install isolated input and relay output digital I/O capabilities to any PC or embedded system with a USB port. Featuring 16 Form C (SPDT) electromechanical relays and 16 optically isolated digital inputs, the unit is the smallest of its kind for digital monitoring and control using USB.

The isolated, non-polarized inputs may be driven by either DC sources of 3-31 V (or higher by special order) or AC sources at frequencies of 40 Hz to 10 kHz. Optically isolating the digital inputs from each other, and from the computer, assures smooth, error-free data transmission in noisy, real-world environments. The input channels are available via a 34-pin IDC type vertical header. The relay outputs are de-energized at power-up to prevent an unintended control output signal. Data to the relays is latched. The relay contacts are available via a 50-pin IDC type vertical header.

The rugged industrial unit contains an internal, removable screw termination board (USB-STB-84) with onboard removable screw terminals to simplify wiring connections. The USB-STB-84 mounts directly into the vertical IDC connectors of the USB-IIRO-4 PCB. The USB-IIRO-4, like the PC/104 and PCI versions, is excellent in applications where on-board relays are required and inputs must be isolated such as in test equipment, instrumentation, and process control. The USB-IIRO-4 is a USB 2.0 device, offering the highest speed available with the USB bus. It is fully compatible with both USB 1.1 and USB 2.0 ports. The OEM version provides just the board without the enclosure and internal screw termination board and is ideal for a variety of embedded OEM applications.

Figure F-3 USB I/O Module

F.4 SMART-SIGNAL DCU

A Smart-Signal DCU (http://www.smartsignaltech.com/), as shown in Figure F-4, was used to obtain signal timing and phasing information from TS2 controller cabinet. The DCU is developed based on a network-enabled 32-bit ARM9 ConnectCore 9M 2443 core module manufactured by Digi International Inc. (http://www.digi.com).

Figure F-4 Smart-Signal DCU

F.5 Field Experiment Setup

Figure F-5 shows the MAPS system installed in a TS2 traffic controller cabinet.

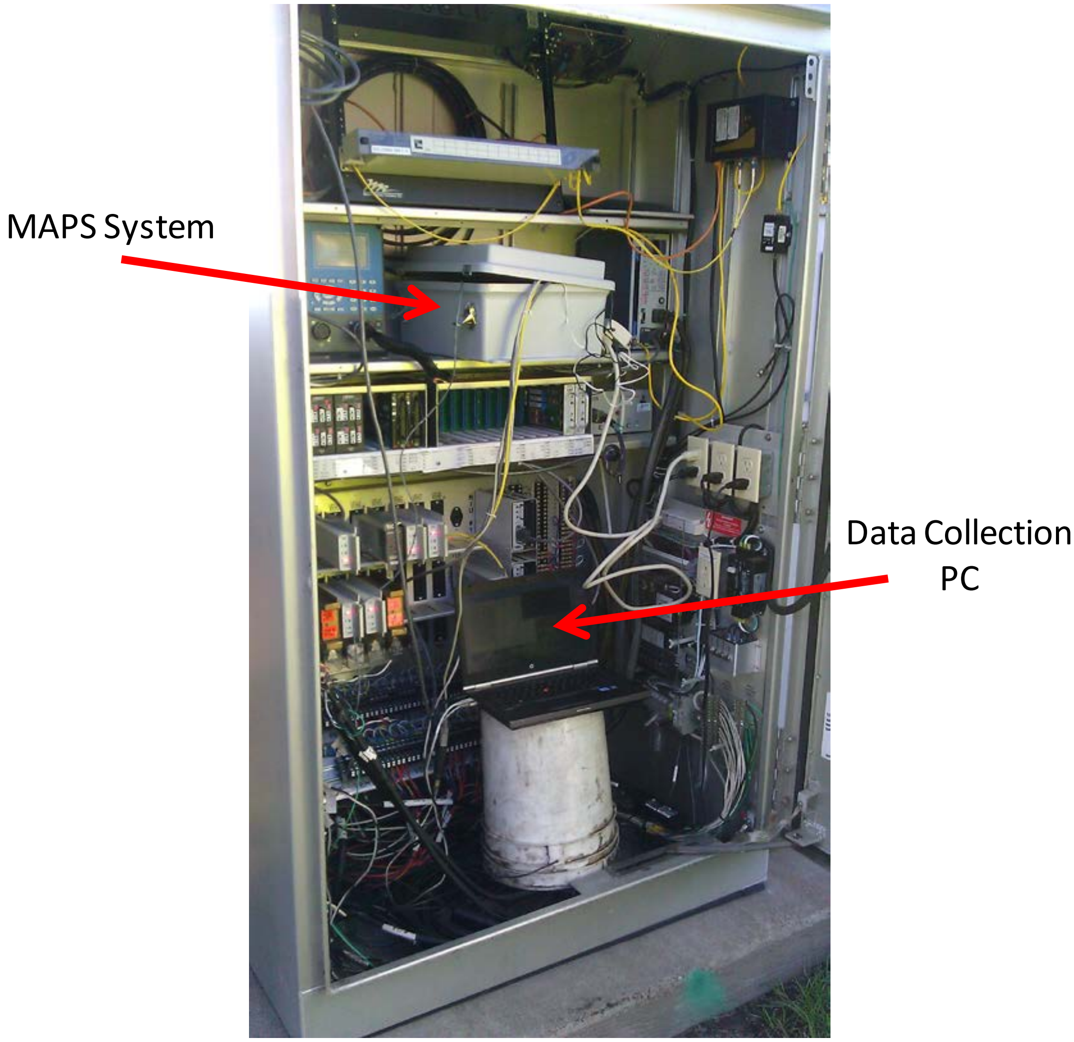

Figure F-5 MAPS installed in a TS2 Traffic Controller Cabinet