Using Smartphone App to Support Visually Impaired Pedestrians at Signalized Intersection Crossings

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ABSTRACT

People with vision impairment 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 visually impaired, 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 system 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. Field experiment at two signalized intersections was conducted among 18 visually impaired participants 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. Objective and subjective measures were developed to evaluate the performance of visually impaired users while using the MAPS. Participants reported that the MAPS system provides helpful geometry information (82%) and helpful signal information (59%).

KEYWORDS

Pedestrian, Blind, Mobility, Safety, Smartphone, Traffic Signal, Wireless Communication
INTRODUCTION
The blind and visually impaired usually travel on foot or use public transit as their primary mode of transportation to attend their daily activities. Due to differences in spatial perception as compared to sighted people, they usually encounter physical and information barriers that limit their transportation accessibility and mobility.

Individuals with vision impairment often have difficulty crossing intersections due to insufficient information available to them about traffic, signal timing and intersection geometry. Among the intersection crossing sub-tasks, locating the crosswalk, determining when to cross and maintaining alignment with the crosswalk while crossing are the most difficult tasks for the blind and visually impaired to execute. A Federal Highway Administration (FHWA) Accessible Pedestrian Signal (APS) settlement [1] stated that “The ADA regulations at 28 Code of Federal Regulations Part 35.130(b)(1)(iii) requires that the aids, benefits, or services provided to individuals with disabilities must be as effective in affording equal opportunity to obtain the same result, to gain the same benefit, or to reach the same level of achievement as those provided to others. The FHWA finds that the lack of accessibility for blind pedestrians is a violation of the ADA.”

Current actuated intersection requires the blind to search for a pushbutton, if one even exists. It usually requires the pedestrians to move away from their path of travel, which is often used as an alignment cue for crossing. Because of the additional cost of the APS installation, most agencies usually do not deploy them at all signalized intersections. In addition to the installation and maintenance costs which accrue to the local traffic agency, current APS systems contribute “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.

Challenges at Intersection Crossings
People with vision impairment primarily use auditory, white cane and limited visual information that they can gather to make safe crossing decisions at a signalized intersection. They generally have difficulty crossing intersections due to the lack of information available to them about the traffic and geometry at intersections [2]. A study of blind pedestrians’ intersection crossing behavior in three cities found that only 49% of crossings started during the walk interval without APS [3]. A follow-up study, after newer types of APS were added, had different results [4]. The follow-up study found that the rate of crossings ended after the onset of the perpendicular traffic decreases from 27% to 7% [4].

At signalized intersection crossings where using a pushbutton is required, Barlow et al. [3] 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 pedestrian to move away from their path of travel, which is often used as an alignment cue for crossing. In addition, Barlow et al. [3] found that although 72% of blind participants started with an appropriate alignment, location, or both, 42% ended their crossing maneuver outside the crosswalk.

Therefore, enhancing blind pedestrians’ ability to perceive useful cues at signalized intersections may be an effective method of reducing potential conflicts. 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.

At intersection crossings, pedestrians typically need to understand traffic patterns for crossing safety and then select a strategy to cross with lower risk. Giudice and Legge [5] reviewed various technologies developed for blind navigation. They concluded that no single technology can provide both indoor and outdoor navigation and guidance for the blind. It is critical to gain more insight from perception study in order to have a clear understanding of the cognitive demands on the blind when they interpret information received by the sensory system.

As noted earlier, blind people’s transportation choices are mostly limited to walking, taxi and transit. In order to improve mobility, accessibility and their level of confidence in using the system, it is important to remove not only the physical barriers but also the information barriers that potentially impede their mobility.

Blind pedestrians face higher risk of being involved in a crash when they veer toward the center of an intersection [6]. Blind people tend to veer when crossing quiet streets and the spatial characteristics of the veering tendency differ between and within individuals [6]. Kallie et al. [7] 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. They found humans tend to veer without guideline (or visual feedback) to walk along or a target to walk toward [7].

Although there are many aids (such as electronic, Braille map, etc.) to assist wayfinding, blind people tend to use their cognitive map and spatial knowledge as primary guidance [8]. 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 [9]. 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.
Though not always reliable, many environmental cues are available, 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 [9].

**Pedestrian Navigation and Guidance**

In order to provide signal information to blind users, Bohonos et al. [10] demonstrated a Universal Real Time Navigational Assistance (URTNA) system using Bluetooth beacons incorporated into a traffic controller to transmit signal timing to a user’s cell phone. URTNA has proven that appropriate software can be developed, but a review of the literature yielded no further research in this area. Barbeau et al. [11] developed a Travel Assistance Device (TAD) using a GPS-enabled smartphone to assist transit riders navigating the public transpiration system. The TAD prompts the rider in real-time with a recorded audio message, visual images, and vibration alerts when the rider should pull the stop request cord to exit the bus.

Some regions in Europe have begun to develop pedestrian navigation technology to assist the visually impaired or disabled. For example, the city of Stockholm’s e-Adept project [12] has developed a digital pedestrian network, consisting of pedestrian paths, sidewalks, signs, stairs and many detail features based on an open platform that integrates pedestrian navigation technology in order to assist the 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 [13, 14 & 15].

Finland’s NOPPA [16] project 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 [17].

The ASK-IT project [18], partly funded by the European Commission under the 6th Framework Programme, uses personal profiling and web services to provide users 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 their 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 [19 & 20].
The Mobiville project [21] aims to develop a real time multimodal transportation information service and provide location based navigation service for pedestrian using GPS mobile phones. In addition, GeoVector® (http://www.geovector.com) developed an application called World Surfer™ to allow compass-enabled GPS smartphone users to point their phone in a particular direction and search for information about points of interest. This service allows travelers to utilize their smartphone device as a personal travel guide [22].

Accessible GPS devices, such as Sendero GPS for the BrailleNote, StreetTalk, Mobile Geo, Trekker Breeze, Loadstone, and others (www.accessibleGPS.com), are commercially available to provide routing information and basic intersection descriptions for the visually impaired. In addition, there are smartphone based applications, such as WalkyTalky and Intersection Explorer on Android platform, and Ariadne GPS and Sendero LookAround GPS for iPhones, that can provide navigation and wayfinding information to assist the visually impaired. But, these systems do not provide traffic signal information.

To overcome the lack of accessibility of touch-screen-based mobile platforms, Apple Inc. (http://www.apple.com) has included assistive technology as standard features for people with disabilities. The VoiceOver screen reader feature on Apple products allows the device to speak the names of the onscreen menu. It also allows people with vision impairments to interact with the device via gesture combinations.

ACCESSIBLE PEDESTRIAN SIGNALS (APS)

APS systems that indicate the onset of the pedestrian phase are usually deployed at selected intersections to assist blind people with intersection crossing. A typical APS system generates auditory cues continuously to help the blind pedestrian locate the pushbutton. After an APS pushbutton is activated, the APS system announces an auditory message such as “Broadway. Walk sign is on to cross Broadway” [27] when the visual pedestrian signal display is in the “WALK” phase in the corresponding direction.

Traditional Systems

Audible pedestrian signals first appeared in 1920 in the United States. However, they were not included in the U.S. standard, Manual on Uniform Traffic Control Devices (MUTCD) until 2000 [23]. In the mid 1970’s, audible signals were mounted on top of the pedestrian signal display (also called pedhead-mounted APS). Two different auditory tones were used to distinguish the north/south (Cuckoo) and east/west (Chirping) directions in the U.S. In Canada, the high-pitched "chirp, chirp" of a small bird, inaudible at busy intersection, is being replaced recently by a four-note tune known as the Canadian Melody.

The audible signal mounted above the pedestrian walk signal has several shortcomings. The “Walk” signal indication is ambiguous and it requires blind pedestrians to know their direction of
travel at all times. The audible sound is active only when the “Walk” signal is on and there is no indication of pushbutton location if a pushbutton even exists.

Furthermore, there are several common problems with traditional APS, including the volume of announced messages, not knowing which street has the “WALK” signal on and confusion of alerting tones with traffic noises [24]. Respondents to a survey [25] indicated that “direction taking at the starting position” and “keeping direction while walking in the crosswalk” were problems, even with an APS. Other problems cited in the literature include: confusing acoustic signals from the APS system [26], pushbuttons that are difficult to locate [3].

**Newer Systems**

The 2009 MUTCD (section 4E.09 to 4E.13) includes specific ADA standards, guidance and options for APS devices [27]. The newer generation of APS system addresses many of the shortcomings of the earlier system. It provides audible and vibrotactile indication of the “Walk” signal. A pushbutton locator tone that repeats continuously every second is added to provide information about the presence and location of a pushbutton. The pushbutton includes a tactile arrow that points in the direction of travel on the crosswalk. Some of the latest APS system can automatically adjust the volume of audible cue with respect to the ambient noise level.

There are concerns about noise of APS from residents near the installations. The repeating tone adds 5 decibels of noise within 6 to 12 feet of pushbutton. Ongoing maintenance and Braille verification require additional effort for the public agency. An additional stub is often required for installing pushbutton station poles. In 2009 MUTCD section 4E.08, it requires the pushbutton to be installed “between 1.5 and 6 feet (or no farther than 10 feet) from the edge of curve, shoulder, or pavement”. However, there is no standardized pushbutton pole location.

In France, E.O. GUIDAGE (http://eo-guidage.com/eng/) uses APS device that is working “on demand” to reduce the noise pollution. The user, using a special remote control, a smartphone or a pedestrian GPS (with Bluetooth), can activate the APS device and get audio messages regarding the status of the pedestrian signal at a fixed-time intersection. The Bluetooth is not used to transmit the status of the pedestrian signal to the user but as a protocol to activate or program APS devices wirelessly.

**New Obstacles**

In addition to aforementioned challenges for the visually impaired at intersection crossings, two new obstacles are becoming more frequent on US roadways, namely the modern roundabout intersection and quieter Electric Vehicles (EV). Both of which make it even harder for pedestrians with low vision to determine walking direction, select a safe gap between vehicles, and maintain alignment [9]. A study from the National Insurance Institute for Highway Safety [28] reported that intersections converted to roundabouts show a 39% decrease in all crashes and...
an 89% decrease in fatal crashes. In addition to reduction of vehicular injury crashes when intersections were converted to roundabouts, NCHRP report 672 found a reduction in pedestrian injury crashes in British and Dutch [29]. However, the impact on pedestrian accessibility and safety at roundabout crossings, particularly for the elderly, disabled, blind and visually impaired, is still debating. Modern roundabout is aimed to reduce potential conflicts between vehicles but it may not necessarily reduce the conflicts between vehicles and pedestrians.

**OBJECTIVE**

The objective of this study is to provide intersection geometry and signal timing information via a smartphone for the blind and visually impaired pedestrians. Needs analysis was first assessed to better understand current challenges and what information may be needed to improve mobility. Secondly, a smartphone based accessible pedestrian signal system was developed by taking advantages of sensors on smartphones and incorporating surveyed user needs to effectively provide intersection information to users. Finally, subjective and objective measures were collected through a field experiment to evaluate system performance, usefulness and user satisfaction.

**APPROACH**

Blind and low-vision pedestrians often report being dissatisfied with their general lack of situation awareness while crossing intersections. A survey was conducted prior to designing the user-interface to better understand the challenges experienced by blind pedestrians and the types of information they use at intersection crossings. Various information modalities that can assist them were also identified. A small sample of visually impaired pedestrians (10 people) was interviewed with several questions regarding their vision, navigation and orientation experience, and use of assistive technologies in wayfinding [30]

**Criteria Identified for Accessible Mobile Decision Support**

Key recommendations of 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 a mobile device
5. Decision support system should not interfere with user’s wayfinding ability

**System Design**

A Mobile Accessible Pedestrian Signal (MAPS) system for the blind and visually impaired was developed. System communication diagram was illustrated in Figure1. The objective of the system design is to integrate information from sensors that are commonly available on a
smartphone in determining a user’s location and orientation. The mobile system wirelessly
communicates with the traffic signal controller to obtain real time Signal Phasing and Timing
(SPaT) information, which together can then inform the blind pedestrian as to when to cross and
how to remain aligned with the crosswalk. A roadside device is installed inside a traffic
controller cabinet to obtain SPaT and activate a “pedestrian call”.

For field experiment, a Data Collection Unit (DCU) was installed in a NEMA TS2 traffic
controller cabinet to obtain real-time signal timing and phasing information through the
Synchronous Data Link Control (SDLC) interface, i.e., Bus Interface Unit (BIU) [31]. The SPaT
information is wirelessly transmitted to a signal database server located in the 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 provide available intersection geometry information by referencing to a
digital map loaded on the phone. After determining which direction to cross, the pedestrians can
simply perform a double-tap on the screen to submit pedestrian crossing request. The double-tap
action then immediately sends the request to the traffic signal controller through the signal
database server.

The pedestrian call interface, residing in a Virtual Private Network (VPN), handles the requests
from smartphones 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 in the future when the signal
data can be accessed through the MnDOT's firewall as illustrated in Figure 1.

A digital map, containing intersection geometry, street name, crossing width in 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 determine a pedestrian’s location with
respect to an intersection.

Knowing a crosswalk exists and finding the beginning of a crosswalk are the two key
challenging tasks for blind pedestrians approaching an intersection. The ADA ramp and the
tactile dome surface often provide useful cues for blind pedestrians to identify the beginning of a
crosswalk. However, they do not necessarily provide directional cues for crosswalk alignment.
Blind pedestrians usually listen to traffic and use the sidewalk boundaries as a natural alignment
for determining the direction of crosswalk. A geo-reference ID can be used to help inform (when
geometric clues are not available) and confirm blind pedestrians that they are at a particular
corner of an intersection. Blind pedestrians will still need to use their wayfinding skills they
already learned from orientation and mobility training to find the beginning of the crosswalk.
**User Interface**

We have developed a Bluetooth geo-ID using commercially available Bluetooth modules. Each Bluetooth module, operating in non-pairing discoverable mode, has a unique Media Access Control (MAC) address. The MAC address of each module is referenced by the smartphone app to identify the corner location of an intersection. The relationship of a geo-ID and corresponding coordinates of an intersection corner are prerecorded and stored in a geospatial database as part of the digital map. The geo-ID can be installed at intersections where GPS reception is weak or unreliable such as an urban canyon environment.

The smartphone app continuously monitors the location of the phone through GPS after initialization. Initial position and direction of travel are used to search for the initial destination node in the geospatial database. When a user is within the range of a geo-ID tag, the application transmits a Bluetooth scan to identify a nearby tag.

While standing at a corner of an intersection, a user points the smartphone to a desired direction and taps on the phone once to obtain intersection information announced via Text-To-Speech (TTS) technology. The application then responds with an auditory message, such as “Heading north to Washington Ave, 4 lanes” as illustrated in Figure 2 or “No information in this direction” if the pointed direction is not aligned with a crosswalk within 15 degrees.

After determining which direction to cross, the user points the phone toward the desired direction and taps twice on the smartphone screen to confirm direction of crossing. Request for a walk signal (“pedestrian call”) is then sent to the traffic signal controller through wireless network after the user’s confirmation. The MAPS system then requests and monitors current signal timing from the signal controller, and updates latest signal status with “Wait for signal” or informs the user with 1-sec vibration alert followed by an auditory message such as “Harvard. Walk sign is on to cross Harvard, 20 seconds to cross” as illustrated in Figure 3.

**FIELD EXPERIMENT**

**Locations**

Two intersections in Golden Valley, west of the City of Minneapolis were identified and selected for the field experiment. The Winnetka Avenue, 5 lanes, goes in north-south direction and the Golden Valley Road, 4 lanes, is in the east-west direction. This intersection is equipped with APS system manufactured by Polara Engineering, Inc. ([http://www.polara.com](http://www.polara.com)). The second intersection, two blocks away from the first intersection, is located at Rhode Island Avenue and Highway 55. The Rhode Island Avenue, 4 lanes, goes in north-south direction and Highway 55, 7 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.
Participants

The research team randomly selected 20 potential participants from 31 visually impaired adults who contacted us after the advertisement. Among the 20 names selected, 18 (11 male and 7 female) individuals responded and participated in the experiment, with mean age of 44.2 years and standard deviation of 15.2 years. Among the 18 participants, two are veterans. 10 participants have total peripheral blindness and the others have low vision. 13 of the participants use a long cane and 5 use a guide dog. All participants have completed orientation and mobility training during their lives. Regarding intersection crossing frequency, 9 of the participants cross more than 4 intersections a day, 5 of the participants cross 1 to 2 intersections a day, 2 of the participants cross 1 to 4 intersections a week, and the other 2 participants cross less than 1 intersection a week. 9 (50%) of the participants own and use a smartphone, 8 of the participants have regular cell phone, and 1 person does not have a mobile phone.

Procedures

At each location, participants were asked to perform intersection crossings and then interviewed by a research assistant 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 orientation and mobility specialist brought each participant to a starting point located about 100-200 feet (north) away from the northeast corner of the intersection. The 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.

Each experiment session is about 30 minutes for each participant. The field experiment and interviews were recorded using video and audio equipments to effectively capture participants’ responses and the crossing performance, such as walking speed, in-position time and time to step into crosswalk after the walk sign is on.

RESULTS

Self Assessment

Self-reported travel skills and preference of navigation assistance from the participants were reported in the self-assessment questionnaires (multiple choices) prior to the field experiment. The results indicated that white cane was selected as the most preferred method of assistance (44%) followed by asking other people (26%) and using a 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%). For travel independence, 4 participants (22%) responded as average independent traveler, and 14 participants (78%) considered their independent travel skill is above (5 participants, 28%) or well above average (9 participants, 50%). The survey result 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%).

**Objective Measures**

APS pushbutton is required at intersection #1, operated under actuated signal control plan, to request walk signal. At intersection #2, participants were asked to use existing pushbutton for crossing in the first task and then to use the smartphone device to request signal information for the second crossing. Participants’ travel speed as observed from video data 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 pedestrians, the participants spent 26.6 seconds (SD 56.5 sec), in average, to locate the regular pushbutton. The pushbutton station pole at intersection #2 is located behind the ADA ramp on grass; 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, two guide dogs led the participants toward the camera man at the last quarter of crosswalk instead of staying on the crosswalk path.

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 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. The average time for the visually impaired participants to step into crosswalk at non-APS equipped intersection will vary depending on parallel traffic volume 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 the audible message from the smartphone app when users were trying to listen to 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. Shorter APS message may also contribute to the shorter step-into-crosswalk responding time. We expect the average step-into-crosswalk time will decrease when users are more familiar with the MAPS system.

Subjective Measures
Survey results from both intersections were analyzed. Most of the participants (89% or 16 out of 18) do not use any accessible 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. Two 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 prefer more time for crossing. 14 participants felt they were aligned at the beginning of the crosswalk. 4 individuals veered outside crosswalk path during the crossing task.

At second intersection, 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.

During the second crossing task while using the MAPS device, a few participants experienced unreliable GPS signal that led to the result of the smartphone app 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 inconsistent information.

As compared to the 2 crossing tasks at intersection #2, 11 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 due to the GPS positioning difficulty.

Usefulness and Satisfaction
Van der Laan et al. [32] 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. Score of each individual question ranges from a bipolar scale -2 to 2. Survey results from each participant on usability and acceptance were analyzed. The scores for the perceived satisfaction and usefulness were 1.04 and 0.95, respectively. Results of the usability questionnaire indicated that the visually impaired participants considered the MAPS system to be moderately useful and satisfying as shown in Figure 4.

System Trust and Confidence
The trust questionnaire was used to measure different dimension of trust: purpose, process, performance, and overall trust [33]. 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 displayed in Figure 5.

In average, the participants reported 65% of trust in system performance and confidence. Participants reported 79% and 71% in understanding the purpose of the system and its underlying behavior, respectively. Overall, the visually impaired participants reported 57% of trust in using the system. The system trust and confidence scores from the participants are not as high as we hope for. We believe improving the positioning reliability together with additional training and instruction on using MAPS will help improve users’ trust and confidence in the future.

SUMMARY AND CONCLUSION
We have interviewed 10 blind and low-vision people to understand what types of information they use at intersection crossings and identified information types that could assist them. 6 high-level recommendations were included for the design of MAPS.

The MAPS system is a smartphone based 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 in the smartphone to determine orientation and location of a user at an intersection. Intersection geometry information is provided to users when tapping once on the screen of a smartphone
while pointing the phone to 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 perform a
double-tap on the smartphone screen to request pedestrian walk phase and receive signal timing
updates. Pedestrians can use the audible messages to better determine when walk sign is on.
The MAPS system has employed human-centered design by incorporating survey feedbacks
from previous study on user needs and preferred user interfaces. The simple and easy-to-use
inputs and short auditory messages are intended to minimize additional task load for the visually
impaired at intersection crossings.

One of the goals is 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
recruiting 18 visually impaired participants for a field experiment. Pedestrians were given brief
tutorial on how to use smartphone app including pointing to different direction for geometry and
signal timing information. Participants were asked to perform 1 crossing task at first intersection
already equipped with APS system and 2 crossing tasks at second intersection with and without
the use of MAPS system. Objective measures were compared to evaluate users’ performance
using different type of assistances. In fact, 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.

Although, the input interface of using single and double-tap may seem relatively simple and easy
for the visually impaired participants to operate. 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, 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 better listen
to the auditory message at a busy intersection. The MAPS system was confused by the desired
direction of information when users brought the phone to their ears before the orientation
measurements from the digital compass were finalized.

The system was tested at experiment site (relatively open sky) by the research team for several
times without GPS signal reception difficulty. However, during the 10-hour of field experiment,
a few participants experienced incorrect information due to the fact that the GPS receiver on the
phone was not able to indentify user’s correct location. A Bluetooth geo-ID, as previously
proposed for urban area, is definitely needed to reliably determine user’s location at
intersections. Enhancements, such as reducing the latency of signal data communication and
adaptively learning available pedestrian walking time from the signal controller, were made to
the existing system after field experiment. This will allow the MAPS to provide walk time
countdown information to the visually impaired pedestrians if they prefer 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 solutions for navigating visually impaired pedestrians around work zones or at bus stops by incorporating Bluetooth Geo-ID or other positioning technologies.

ACKNOWLEDGMENTS

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REFERENCES


## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System Diagram of MAPS</td>
</tr>
<tr>
<td>2</td>
<td>Single-Tap for Obtaining Intersection Geometry Information</td>
</tr>
<tr>
<td>3</td>
<td>Double-Tap for Confirming Crossing and Obtain Signal Information</td>
</tr>
<tr>
<td>4</td>
<td>System Usefulness and Satisfaction</td>
</tr>
<tr>
<td>5</td>
<td>System Trust and Confidence</td>
</tr>
</tbody>
</table>
Figure 1 System Diagram of MAPS

Figure 2 Single-Tap for Obtaining Intersection Geometry Information
Figure 3 Double-Tap for Confirming Crossing and Obtain Signal Information

![Image of a crosswalk with a diagram showing how to use the double-tap feature to confirm crossing and obtain signal information. The diagram includes icons for tapping the screen and a speech bubble with the text: "Wait for walk signal." Another speech bubble says: "Harvard. Walk sign is on to cross Harvard, 20 sec to cross."

Figure 4 System Usefulness and Satisfaction

![Image of a scatter plot graph showing the relationship between usefulness and satisfaction. The x-axis represents usefulness, and the y-axis represents satisfaction. The graph includes data points for 17 participants and the mean.]

Figure 4 System Usefulness and Satisfaction
Figure 5 System Trust and Confidence

- Confidence (6): 65%
- Overall (3,9): 57%
- Purpose (7,8): 79%
- Process (2,5): 71%
- Performance (1,4): 65%