Abstract-Pedestrians with special needs encounter accessibility challenges and are exposed to even greater risks when using signalized traffic intersections. Even modern accessible pedestrian stations present significant challenges for pedestrians with physical and sight disabilities. This paper describes an interactive traffic controller for allowing the intersection to receive pedestrian call requests from users with special needs and for providing the user with guidance and signals status feedback information from the intersection. Feedback from the intersection enables individuals with low vision to know the state of the intersection, as well as receive guidance from the traffic controller based on the pedestrian's location.

I. BACKGROUND

A recent report by the Federal Highway Administration (FHWA) dispels a misconception that commuting on foot is the safest mode of transportation [1]. According to this report, on a per 100 million miles traveled basis, pedestrians are 15 times more likely to be involved in a fatal traffic accident than a motorist.

Intersections represent the part of a pedestrian commute where he is the most vulnerable. While pedestrians and vehicles contend for the same road space, when the two entities come into contact, the pedestrian is almost always the injured party. These risks are further exacerbated when the pedestrian has low visual acuity.

The Pedestrian Safety Audit [1] identifies six pedestrian characteristics: walking speed, spatial needs, mobility, vision, cognitive ability, and crossing choices and waiting times. Traffic engineers make broad generalizations concerning the physical capabilities of pedestrians when designing the intersection layout and the traffic signal timing plans. Apart from recent efforts in Accessible Pedestrian Station (APS) installations motivated by the Accessible Disabilities Act (ADA) legislation, little is done to make allowances for pedestrians with less than 100% capability in one or more of the afore listed pedestrian characteristics. Even the extended press capability available on newer APS pedestrian stations limit the affect on control to audible signals provided by devices in the pedestrian button and pedestrian signals. Apart from drivers seeing a pedestrian with a white cane, such as those shown in Fig. 1, drivers using the intersection are unaware of a pedestrian with special needs is anticipating crossing the intersection. Even more disconcerting is the fact that there is no change in traffic signal operations to improve the safety of this at-risk group who are often constrained to walking as their primary mode of independent transportation.

II. INTRODUCTION

There are two common approaches to coordinating pedestrian movements with motorized vehicles at signalized intersections (intersections with electric control signals). The “barn dance” is a term generally associated with an exclusive pedestrian phase where pedestrians are free to cross the intersection in all directions including diagonally. The other more predominant method is where pedestrians are given permission to cross the street that is parallel with through traffic movement.

Even though legal in many instances, right and left turning traffic generates conflicts that require special caution by both the driver and pedestrian to avoid accidents. The burden of caution is primarily on the party who is least vulnerable, the driver, when the pedestrian is visually impaired.

For lack of information, present day traffic control systems treat all users as if they have equal ability. This applies to motorized vehicles as well as to pedestrians. There is no differentiation between the acceleration and decelerations of a lightweight passenger car and a fully loaded three-trailer freight truck.

Likewise, all pedestrians are considered equally capable of locating the pedestrian call signal and determining the proper place to initiate their travel across an intersection.

Fig. 1. Pedestrians with impairment of multiple pedestrian characteristics.
Even though the Manual for Uniform Traffic Control Devices (MUTCD) specifies the location of call buttons and placement of wheelchair ramps, in reality, there are highly diverse implementations of those standards [2].

Modern technology has made great strides in providing aids for people of varying ages with visual and mobility impairments. These devices use electronic compasses, global positioning systems, as well as acoustic and light detection and ranging systems to provide the user with additional orientation and positioning cues. Although these devices interact with existing infrastructure, they generally do not have control capability such as opening doors.

The focus of our research has been to investigate methods of improving access and safety for pedestrians with low vision acuity and/or mobility impairments. Embedded in this research focus statement is the question of given today’s technology capabilities, why is it incumbent upon the pedestrian with disabilities to seek the mechanism by which to be recognized. Whereas previous technology based navigation aids are user oriented, our research strives to make the pedestrian part of the traffic control system in the same manner that vehicles would interact with the system under the FHWA initiatives VII and CICAS [3] [4].

III. CURRENT TECHNOLOGY

Currently, several electronic aids exist for assisting people with impairments. These devices provide users with location information, distance and direction to points of interest, and directions to desired destinations. Such devices are the Sendero GPS [5] and the Trekkker [6]. Software packages for cell phones and PDAs also exist, such as Loadstone [7]. Research has also been performed on tracking users in places where GPS is either blocked or weakened [8] [9]. These environments include indoors and cities with tall buildings.

Although existing aids are useful for navigating around cities and finding routes to destinations, they do not provide the capability of creating pedestrian calls at signalized traffic intersections. Also, they lack the ability to provide the user with the pedestrian information that able pedestrians receive to make decisions of the safest nature. An additional feature they lack is the ability to guide a user through the crosswalk. The research presented in this paper discusses a system for providing a remote user with the information displayed by the pedestrian signals, tracking and guidance through the crosswalk, and the ability to request for service without needing to find the traditional pedestrian call button.

IV. DESIGN OBJECTIVES

The overall objectives are to provide navigation and orientation aid for pedestrians, provide a mechanism for remotely creating a pedestrian walk request, and to change traffic controller operations if the pedestrian is determined to be at risk. Specifically, the objectives are to provide navigation across a traffic intersection while enabling the user to create a pedestrian walk request via a handheld device.

The handheld device solution eliminates the need for a visually impaired user to spatially search for the pedestrian call button. Creating pedestrian requests and providing user navigation requires a closed loop connection with the intersection traffic controller. The intersection traffic controller receives a request for service and user position information, and the traffic controller provides navigation information to the user requesting service. After considering the deficiencies of current pedestrian signals and in cooperation with the National Federation of the Blind (NFB) and the Idaho Division of Vocational Rehabilitation (IDVR) organizations, we established the operational specifications for an APS.

V. SMART SIGNALS

The ability to exchange complex data described above does not exist in present intersection traffic controller systems. Detectors are limited to indicating to the controller in a binary (on/off) fashion the presence or absence of a vehicle in the street or a pedestrian who has activated the call button. However, due to the nature of the interface between these devices and the controller, no information beyond the presence of a vehicle or status of a request for service can be communicated regardless of the capability of the detector.

Researchers and engineers at the National Institute for Advanced Transportation Technology at the University of Idaho have developed a new traffic control concept, called “smart signal technology” to advance traffic signal technology to new levels of safety and efficiencies for both pedestrian and vehicles [10]. This smart signal technology, based on computer network technology, enables exchange of information from around the intersection that can identify users with special needs. This technology is capable of communicating with smart traffic signals to display correct and accurate directions for safe and efficient traffic control.

Shown at the bottom of Fig. 2 are the components used in existing signalized intersections, including the traffic controller, MMU/conflict monitor, and load switches, all located inside the Traffic Controller Cabinet.

Fig. 2. System block diagram for Smart Signals network.
Modern traffic controllers include an Ethernet port for ease of configuration and diagnosis, but the potential power of this port has yet to be exploited [11]. The Smart Signals Architecture compensates for this by adding low-cost computing modules, consisting of only a CPU, memory, and network interface, to serve as an intelligent interface between the traffic controller and a full-featured network run over the existing intersection wiring. This allows intersection nodes, including loop detectors, pedestrian stations, and other sensors to communicate using rich and complex messaging to improve safety, functionality, and performance, turning the entire intersection into a networked control center, where multiple intelligent entities are capable of working in concert on a common application via messaging over a network, and is therefore capable of collecting and processing complex information. This information can also be distributed via a wide-area network (WAN) to a central collection facility for a metropolitan area.

The interface between the Remote Handheld PED Device and the intersection relies on the Smart Signals network. It consists of an Ethernet network to provide communications with the traffic controller and real-time control of the distributed smart signals. The Pedestrian Smart Signal Controller interfaces with the traffic controller using the National Transportation Communications ITS Protocol (NTCIP) [12]. Standard objects received from within the phaseStatusGroupEntry management information base (MIB) that provides state information for signal phases, and pedestrian service calls. In support of this project, Econolite created a custom version of the ACS/3 firmware to process objects for the pedestrian timing data. The information contained in the custom objects consists of the pedestrian crossing state and walk timer.

The Pedestrian Smart Signal Controller collects data regarding pedestrian crossing state and walk timer from the traffic control using NTCIP, then rebroadcasts the data to the Smart Pedestrian Signals shown in Fig 3.

The Smart Pedestrian Signal has a two digit countdown display, hand and man pedestrian lights, Maxstream XStream9X [13] radio modem for communicating with the System Performance Monitor, and a 802.15.4 radio modem for communicating with the Remote Pedestrian Unit. The System Performance Monitor is only intended for development purposes. The System Performance Monitor periodically polls the Smart Pedestrian Signals for the states of their outputs and records the information displayed by the Smart Pedestrian Signals.

When the Smart Pedestrian Signal receives a request from the Remote Pedestrian Unit, the Smart Pedestrian Signal sends a Simple Network Management Protocol message (SNMP) to the traffic controller to create a pedestrian call. As mentioned earlier, the state of the pedestrian service calls is one of the variables that the Smart Signal Controller receives from the traffic controller. The Smart Pedestrian Signal detects that the traffic controller received the call by checking the data provided by the Pedestrian Smart Signal Controller. By observing that the traffic controller has received the call, pedestrian call acknowledgement becomes possible.

VI. DESIGN OF THE HANDHELD PEDESTRIAN UNIT

Fig. 4 is a block diagram of the Remote Handheld PED Device hardware implementation. Based on the objectives of providing navigation across a traffic intersection while enabling the user to create a pedestrian walk request, the technologies utilized are magnetic compass, GPS position, radio modem communications, and audible user feedback.

The handheld device detects which direction the user intends to travel using the magnetic compass. Remote user position is calculated using GPS. Direction sensing is combined with position data to derive where the user is requesting from and which direction they intend to travel.

Radio modem communications provide bi-directional communications between the handheld device and the intersection. User feedback in the form of audible tones and frequencies inform the user with navigation and intersection status information without hindering the user’s ability to focus on their surroundings.

User orientation is derived from a magnetic compass using a 3 axis magnetic sensor and a two axis accelerometer. If the device is level, the heading can be calculated using the X and Y axis values. If the device is not level, then the X and Y axis magnetometer values are compensated for the offset caused by the roll and tilt angles.

The X and Y axis accelerometers provide roll and tilt, thus enabling roll and tilt compensation of the magnetometer readings. After compensating the magnetometer readings for roll and tilt, the compensated heading can be calculated.

The Xbee modem from Maxstream, an IEEE 802.15.4 compliant communications modem [14], is used to communicate with the intersection. IEEE 802.15.4 was chosen because it allows 128 bit AES encryption of both the data and the source and destination addresses.
Once an encryption key has been written, the XBee modem does not allow the key to be read out again. IEEE 802.15.4 defines a unique 64 bit hardware address, thus allowing multiple remote users to be at the intersection at the same time. IEEE 802.15.4 also defines mechanisms for detecting transmission failures and the XBee modem is able to automatically retry on failure. The XBee radio can transmit up to 300 ft (100 m) line-of-sight. Assuming a square intersection with 12 ft lanes, the XBee radio can transmit diagonally across up to 17 lanes. The large radius of communications allows the intersection to implement its Remote Handheld interface using only one receiver in the intersection. GPS positioning can be used to determine whether the user is at the current intersection or a different one. Otherwise, if there is no GPS data available, the received signal strength can be alternatively used to infer whether or not the user is at the current intersection.

Fig. 5 shows three hypothetical tracking regions that the intersection can be divided into. GPS tracking is used to determine the region that the user is located in. The Lassen IQ GPS receiver [15] provides tracking. It is preferable for handheld applications due to its low cost and small form factor, 1.02 inches wide by 1.02 inches long by 0.24 inches tall. Also, it is a 12 channel receiver that supports DGPS and is capable of acquiring a fix within 8 meters in 90% of the manufacturer’s test cases.

Although there are multiple frequency GPS receivers available on the market that advertise centimeter resolution, they generally cost more than $3000. User feedback is performed by pulsing a piezoelectric speaker. The length of the pulse is varied according to the state of the walk and don’t walk symbols as shown in Table I.

The frequency of the pulse is varied according to tracking region data (Fig. 5) as shown in Table II.

**VII. REMOTE PEDESTRIAN BUTTON OPERATIONS**

Table III describes the Remote Pedestrian Button software states. Initially, the Remote Handheld PED Device is in the Sleep state. When the user approaches the intersection and presses a button on the handheld device, the handheld enters the Pending state. The adjusted magnetic compass heading is calculated, and the GPS position data is retrieved from the GPS receiver. The XBee IEEE 802.15.4 unique address, heading, and position are sent to the intersection controller and it then responds with the state of the walk and don’t walk symbols. After the initial button press, the handheld device updates the intersection with its position data once every second until the service has been completed.

Every time the intersection controller receives the position data, the controller sends a response with the state of the walk and don’t walk symbols and the user’s position in the intersection. The Remote Pedestrian Button stays in the Pending state until the walk symbol is activated. After which the remote user’s service enters the tracking state and the handheld device reports a long beep.
In the tracking state, the user is reported which tracking zone they are in (green, yellow, and red zones in Fig. 5) and the status of the pedestrian signals. When either the user reaches their destination or they press the button again, the user’s service returns to the Sleep state, causing the user feedback to terminate and the remote button device to power down to a sleep mode until the next button request. If the user steps into the red zone, the handheld device reports a solid beep until the user presses the button.

VIII. TESTING AND RESULTS

Using the GPS data from the handheld for tracking requires that the GPS receiver in the handheld reports the same position as the GPS receiver that was used to map out the intersection. Since GPS position estimation is based on the satellites visible in the sky at that specific point in time, the position readings from two GPS receivers next to each other were recorded at the same time for approximately one hour.

During that hour, the mean and median number of satellites was 7 for both receivers. Despite having a large number of satellites to estimate position, the average difference between each receiver’s position estimation was 11 feet. This error is expected because the GPS receiver being used is rated for 8 meter (approximately 26 feet) accuracy. According to MUTCD, the minimum cross walk width is 6 feet. It is worth noting that 6 feet is less than one quarter of the advertised GPS receiver error. Although a small, low-cost GPS receiver is inadequate for providing an absolute position for guiding a pedestrian through an intersection; precise navigation can be provided relative to a known initial point [16]. Fig. 6 shows results from 25 trials of tracking a user starting at an initial point. The dotted lines show the edges of the cross walk, and the dashed lines show the boundary between the yellow and red zones in Fig. 5. From the initial point, the user walks directly to a point that is 7 feet north and 20 feet west. After reaching that point, the user walks directly to a point that is zero feet north and 40 feet west of the initial point. This test simulates a user walking from the curb of an intersection, directly to a point that is 7 feet away from the center of the cross walk, and returning back to the center of the cross walk when the user returns to the destination curb.

In a sequence of 80 trials using various paths of travel, the GPS receiver was able to detect that the user was within 3 feet of their destination in 50% of the cases, 7 feet in 96% of the cases, and 8 feet in 100% of the cases. By knowing the initial position of the pedestrian, the GPS position reported by the Remote Pedestrian Button can be shifted to match the GPS measurements that define the intersection’s geometry.

IX. CONCLUSION

We are capable of communicating with the traffic controller to create pedestrian call requests for remote users with handhelds and inform the remote users of the intersection status. Given a method for tracking the user’s position, we are capable of giving the user guidance through the intersection.

Low cost single frequency GPS receivers can be used to provide user tracking from a known initial location, such as the corner of an intersection. As GPS and other tracking technologies advance, the capability of tracking and guiding a user will only improve.

By allowing the user to create pedestrian call requests remotely, users with visual impairments no longer need to locate the mechanism for being recognized by the intersection, thereby eliminating reorientation issues. Closed loop communications with the intersection provides navigation capability as well as reporting intersection status information to the user.

The features required for a Remote Pedestrian Button are very similar to the features on many cell phones and PDAs. In many cases, adding a magnetic compass and proper software to the design of an existing device is sufficient.

X. FUTURE WORK

Many cell phones and PDAs have features similar to the Remote Pedestrian Button, such as GPS and Bluetooth. With the added feature of a magnetic compass, a Remote Pedestrian Button can be implemented using existing devices. Some newer cell phones, such as the Nokia 6210 Navigator, are designed for pedestrian navigation and include all of the necessary features for creating a Remote Pedestrian Button [17].

Using the Location (JSR 179) [18] and Bluetooth (JSR 82) [19] java Application Programming Interfaces (APIs), the Nokia 6210 Navigator merely requires additional software to become a Remote Pedestrian Button. Integrating Remote Pedestrian Button capability into existing devices via software provides proof of the feasibility of the concept discussed in this paper.

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>REMOTE PEDESTRIAN HANDHELD TRACKING STATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>State</td>
<td>Description</td>
</tr>
<tr>
<td>Sleep</td>
<td>Low power state, waiting for the user to request for service</td>
</tr>
<tr>
<td>Service Pending</td>
<td>User requested service, waiting for the walk light to turn on</td>
</tr>
<tr>
<td>Tracking</td>
<td>Walk light is on, user is guided to across the intersection to their destination</td>
</tr>
</tbody>
</table>

Fig. 6. Remote Handheld PED Device Hardware Implementation
ACKNOWLEDGMENT

Funding provided to the National Institute of Advanced Transportation Technology (NIATT) by the U. S. Department of Transportation, Research and Innovative Technology Administration, Grant No. DTRS98-G-0027. Equipment and engineering support was provided by Econolite Control Products, Inc. 3360 East La Palma Ave. Anaheim, CA, 92806 and Campbell Company, 221 W 37th St., Ste. C, Boise, ID, 83704. Microprocessor development parts and development equipment was supplied by Cypress Microsystems, 198 Champion Ct., San Jose, CA 95134, USA

REFERENCES


