Universal Real-Time Navigational Assistance (URNA): An Urban Bluetooth Beacon for the Blind

S. Bohonos*, A. Lee*, A. Malik*, C. Thai**, R. Manduchi*
*Department of Computer Engineering
**Department of Electrical Engineering
University of California, Santa Cruz, CA 95064

ABSTRACT
We describe a complete hardware/software system, dubbed Universal Real-Time Navigational Assistance (URNA), which enables communication of relevant location-aware information to a blind person carrying a Bluetooth-enabled cell phone. Although URNA can be used for a number of different applications (e.g., an information kiosk at a shopping mall or public transit information at a bus stop), we concentrate on the challenging case of an urban intersection. Information provided to the user as he or she approaches the intersection includes a description of the intersection topology and real-time notification of the state of the traffic lights. The main FPGA-based control board (NavCon) interfaces with a traffic controller and with the Bluetooth modules, which are each mounted atop the intersection's pedestrian heads (pedheads) - the lights signaling a pedestrian when to 'WALK' or 'DON'T WALK'. The cell phone software (PedNav), written in Java 2 Micro Edition (J2ME), uses Text-To-Speech (TTS) for presenting the information transmitted by NavCon to the blind user.

Categories and Subject Description
J.m [**Computer Applications**]: Miscellaneous

General Terms
Design

Keywords
Bluetooth, cell-phoned, assistive technology.

1. INTRODUCTION
The National Eye Institute estimates that "almost 1 million" people in the US are legally blind (best corrected visual acuity 20/200 or less, or visual field less than 20 degrees) [4,10,12]. At least 200,000 are totally blind and cannot use any of the techniques sighted people use for safe ambulation. Although short-range mobility can be effectively managed by means of the long cane or a guide dog, wayfinding remains a serious problem for a blind person moving in an unfamiliar environment. A blind person cannot, for example, read which lines serve a certain bus stop, or even read the number of an approaching bus. He or she cannot access information from a kiosk in a shopping mall. Likewise, a blind person cannot make use of street signals or regular traffic lights when crossing an intersection.

This paper describes a complete hardware/ software system meant to enable a blind person access to location-aware information via a Bluetooth-enabled cell phone. This work was born out of the observation that cell phones have become a commodity of widespread adoption, and that most current models are Bluetooth-enabled. Indeed, cell phones have been well received by the disabled community [11] and have often been hailed as an ideal mobile computing device for increased access [9]. Although concerns about the accessibility of phone features remain [2], the emergence of screen readers such as TALKS and MobileSpeak and of voice–activated commanding is quickly filling the usability gap. The fact that there is no stigma attached to using a cell phone (as opposed to other specialized equipment) bodes well for its widespread adoption as an assistive technology device by the visually impaired community [9].

The use of Bluetooth for data beaconing has been proposed in different contexts (see e.g. [13,8,1]). Due to its limited range, Bluetooth is an ideal solution for location-aware information broadcasting. For example, a Bluetooth transmitter located at a bus stop could transmit the schedule of the lines serving that stop. Several transmitters embedded in the traffic light pedheads of an urban intersection could broadcast a static description of the location (e.g., the names of the streets in the intersection, whether the traffic is one-way or two-way, whether there is an island in the middle, etc.), as well as real-time information about the traffic light status at each crosswalk. This information would be very useful for a blind person negotiating the crossing of the intersection, notoriously a difficult and dangerous undertaking [2].

Our system, dubbed Universal Real-Time Navigational Assistance (URNA), addresses exactly this last application. We have built a prototype controller, based on a Field Programmable Gate Array (FPGA) that interfaces with an actual traffic controller (Econolite ASC/3) and with a number of Bluetooth modules. Static and real-time information transmitted via Bluetooth is then presented to the user on his/her cell phone via a suitable interface using Text-To-Speech (TTS). Our prototype has been tested successfully on a mock-up intersection that makes use of real traffic and pedestrian lights.

1.1. Previous work
Several wayfinding strategies for blind individuals traveling in an urban environment have been proposed [13]. For example, a GPS, combined with a geographic information system (GIS), can provide helpful for wayfinding. However, the

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accuracy and reliability of GPS is not always acceptable in environments with tall buildings obscuring one or more satellites.

pedestrian traffic lights and provide alternative information using acoustic and possibly tactile interface. Loudspeakers are mounted either at the pedhead or, more recently, at the pushbutton location. A sound (bell, buzz, birdcall or voice) is produced by the speakers at both ends of the crosswalk when the 'WALK' sign is on. The purpose of the sound is twofold: informing the user of when to cross, and providing some orientation information via beaconing. However, experimental tests have shown that the acoustic signals in typical APS are often confusing [14]. In addition, acoustic APS contribute to noise pollution and are not always acceptable.

The Talking Signs system [34] uses an infrared (IR) beacon that can be placed near a pedestrian traffic light. A speech message is transmitted by modulation of the IR light, and decoded by a hand-held receiver carried by the user. Since the receiver has a limited field of view, only when the user points the receiver towards the beacon is the recorded voice heard. Thus, Talking Signs allows one to estimate the pointing direction toward the beacon. This feature is absent in our system, since the Bluetooth antenna in a cell phone is typically omni-directional. A drawback of the Talking Signs system, however, is that it requires one to purchase and use a dedicated device. This results in an economic burden, the inconvenience of carrying yet one more gadget, and the stigma associated with the use of a "special" device. Indeed, the Public Rights-of-Way Access Advisory Committee (PROWAAC), in its recommendation to the U.S. Access Board regarding APS in 2001, observes that: "The committee did not want travelers to be required to carry a single, function-specific receiver in order to access intersection information" [15].

Our approach is based on the observation that directionality information is in many situations not necessary, and that the

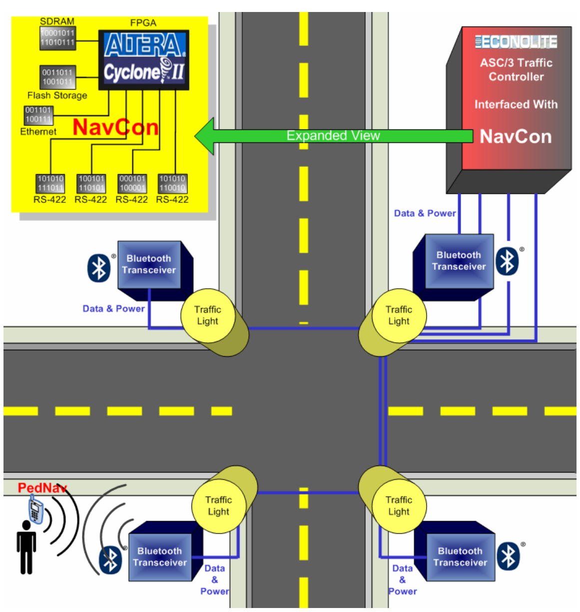

Figure 1: The layout of the URNA architecture in a traffic intersection.

Accessible Pedestrian Signals (APS) are simple devices that have been deployed widely to assist blind and low vision individuals at intersections. These systems are connected to simple self-localization provided by the Bluetooth system is sufficient in most cases. The convenience of using one's own cell phone cannot be neglected, and may indeed be key to wide diffusion of the proposed architecture. When directionality information is indeed desirable, the system described in [6,5] using the camera onboard a cell phone to detect color tags placed in key locations can be conveniently used.

2. SYSTEM DESCRIPTION

This project specifically addressed the issue of static and real-time information communication at an urban intersection. The same technology can be used for other applications as mentioned in the Introduction. Besides conveying a static description of the location, URNA provides timing information about the light status. In particular, when the pedestrian light is green ('WALK'), the user is constantly updated about the number of seconds remaining before the light will turn flashing ('DON'T WALK'). A similar type of information is already provided by currently available APS, however, acoustic APS have a number of drawbacks as discussed in Sec. 1.1.

In order to develop a realistic prototype, we created a mock intersection utilizing an actual traffic control and traffic lights. We used an Econolite ASC/3 controller, which supports the NTCIP 9001 set of protocols for traffic equipment interoperability. At the heart of our system is the *Navigation Controller (NavCon)*, an FPGA-based board that interfaces with the traffic controller (via Ethernet) and with a number of Bluetooth modules. Whereas NavCon is located in close proximity with the traffic controller, the Bluetooth modules are located at the different pedheads in the intersection (see Fig. 1). NavCon communicates with the Bluetooth modules via RS-422, a serial protocol using differential signaling. RS-422 was preferred to the more popular RS-232 because it allows for cable length of up to 350 ft. while the latter limits the cable length to 50 ft. Connection cables can be extended to the pedhead modules making use of existing conduits. Using wireless communication between the Bluetooth modules and the main board would have eliminated the data transmission problem, but power wiring would still be required, not to mention the security of the wireless protocols between NavCon and the modules.

The Bluetooth modules communicate with the cell phone of a user entering the radio range. We developed a software module (*Pedestrian Navigator* or *PedNav*), which is a J2ME application written for mobile devices supporting the Connected Limited Device Configuration (CLDC) 1.0 specification and higher. The application runs on the Mobile Information Device Profile (MIDP) version 2.0 and later, which includes all smartphones on the market today and most conventional mobile phones as well. The role of PedNav is to accept incoming connections from nearby NavCon beacons, authenticate them, and relay useful information to the user. Information is presented via TTS (text to speech). During our initial development, we used a TTS feature built-in the latest Symbian S60 devices. However, the voice quality was low and mostly suitable for single words. We then opted for the TTS produced by Loquendo for Symbian phones. Other possible solutions include pre-recorded voice (which however severely limits the type of information that can be communicated) and audio streaming (which imposes much more stringent bit-rate requirements). It is reasonable to expect that good quality TTS will be a built-in feature in mainstream cell phones in the future.

In the following, we describe the hardware and software components of the URNA system in detail.

2.1. Hardware design

The central core to NavCon is a system-on-a-programmable-chip (SOPC) implementation using an FPGA. We chose an FPGA architecture due to its flexibility and the requirement to control at least 5 UART components directly on the processor. For development purposes we used the Altera Nios II Development Board, which contains the Cyclone II EP2C35 FPGA, on which we run the Nios II soft-processor. The availability of a port of the Linux operating system, as well as a support community for the Nios II made this an attractive design choice.

The NavCon board acts as the central hub for all communication in our system.

2.1.1 NavCon main board. The NavCon custom Printed Circuit Board contains an EP2C8 Altera FPGA, SDRAM, non-volatile serial flash memory (EPCS) to store the FPGA configuration, Ethernet support for connection to the traffic controller, a JTAG UART for FPGA programming and four RS-422 UART interfaces for connections to the Bluetooth modules.

2.1.2 Bluetooth modules. We chose the connectBlue OEMSPA333 module with external antenna support for Bluetooth communication. This module has low-level firmware support for multiple connections and UART logic-level support. This last feature is important because it allowed us to choose a differential signaling communication protocol (RS-422), that can accommodate for long distance data transfers across larger intersections.

2.2. NavCon software architecture

The Nios II processor on NavCon runs the μClinux flavor of the Linux kernel version 2.6.17. The applications that run outside the kernel in the userland were made up of mostly BusyBox utilities for basic system utilities. We bundled our own NavCon software to communicate with the traffic controller and mobile phones, inside this userland to create a complete package.

The two major software components in NavCon are the *Pedestrian Session Manager (PSM)* and the *Traffic Controller Interface (TCI)*. The TCI polls the traffic controller ten times a second (configurable) to check for intersection updates. The TCI then creates an alert that the PSM processes and sends to the appropriate NavCon beacons. The PSM and TCI processes communicate using the file system. The TCI create one file per alert that is to be sent to the phone; the PSM gets notification of the creation of this new file, and subsequently reads it and processes it (see Fig. 2). Note that the desired communication flow is always from TCI to PSM because we are only reading information from the traffic controller.

2.2.1. NavCon TCI. The Econolite ASC/3 traffic controller provides traffic light information via TCP/IP over the application layer in SNMP. The ASC/3 uses Object IDentifiers (OIDs) to identify different data elements such as traffic light status. The NavCon TCI retrieves state and timer information about the relevant traffic lights. This information is then processed for use by the main program, NavCon PSM.

2.2.2. NavCon PSM. Once data has been acquired from the traffic controller and an alert has been created in the file system by TCI, PSM must process this alert and send it out to any connected users to whom it might be relevant. PSM is asynchronously notified whenever a new file is created in a particular directory via the file system change notification subsystem known as *inotify*. PSM then uses Infineon/Ericsson's proprietary Embedded Communications Interface (ECI) to communicate with the Bluetooth module over the UART.

Before any alerts can be delivered, connections must be established to remote devices. The first step is to perform a device inquiry. A device inquiry is a time-limited search for any discoverable Bluetooth devices in range of the antenna. When an inquiry is complete, a list of Bluetooth devices is returned. This list includes the unique 48-bit Bluetooth device address, as well the Class of Device (COD), which describes whether the device is a mobile phone, computer, headset, etc. Once a list of discovered devices is available, a service search is performed on them. A common service on Bluetooth devices is the OBEX (OBject EXchange) Object Push, which allows one to send address book contacts, calendar entries, and messages to other devices. For our project, we chose a bidirectional service that emulates a serial port over a stateful connection between two devices. This service uses the Serial Port Profile of the Bluetooth specification to create a service that allows two applications on different devices to exchange data in a socket-like manner.

Once a connection has been established with a remote device, data can be simultaneously sent and received. The amount of data that can be sent at once is only limited by the Bluetooth module's buffers. Because the available transmit buffer space with the chosen device was only 2 kilobytes, we decided not to implement streaming audio. In addition, some mobile phones do not support data packets larger than 512 bytes for Serial Port Profile services. Thus the communication between the PSM and the mobile phone software (PedNav) is entirely packet-based. We created a suitable PedNav Protocol to handle requests and responses between NavCon and PedNav.

When a connection is established to the PedNav service, NavCon PSM sends a 'Hello Request' packet containing a list of supported PedNav Protocol versions. The PedNav application on the phone acknowledges the requested protocol version with a 'Hello Response' packet. If there is a version mismatch, the connection is dropped by either side. The PSM then transmits an X.509 certificate encoded using DER (Distinguished Encoding Rules). This certificate has been cryptographically signed by a Certificate Authority (CA) that is trusted by the PedNav software. This certificate is used to verify the authenticity of the traffic intersection, to prevent a malicious party from setting up a fake intersection. If at this time the phone is unable to verify the intersection's authenticity, it will alert the user with a warning message, and disconnect without receiving any further information.

Once a trusted connection has been established, NavCon PSM transmits a list of static and dynamic data item definitions. A static data item is a key and value pair that remains constant for the duration of the connection, for example, a variable defining the name of the street. A dynamic data item is a variable whose value can change during the connection, such as the value of a pedestrian crosswalk timer. After data items have been defined, the phone enters a passive mode where it does not transmit any more information; it merely listens for incoming alerts (in the form of new data item values) and processes them accordingly. If no data is received at either side for a specified amount of time (a timeout value of a couple of seconds), then the connection is closed. This allows for a device to move out of range and be ready to accept a new connection from another NavCon device. The connection can also be closed at any time by the user's request.

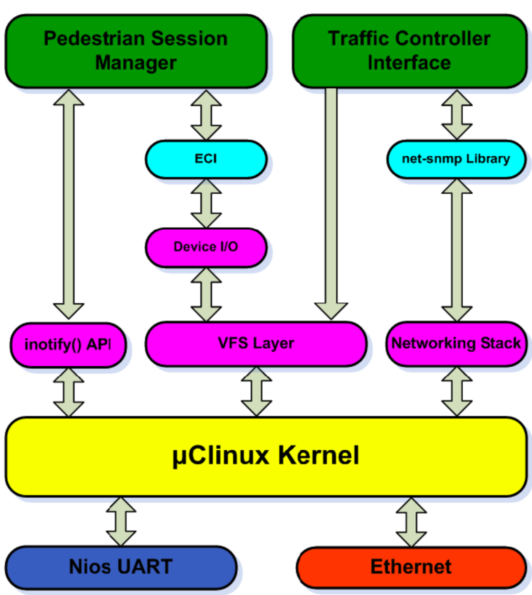

Figure 2: NavCon software structure. Linux processes are represented in green, third-party libraries in cyan, and Linux kernel subsystems in magenta.

2.3. Mobile phone software

The second major software component, Pedestrian Navigator (PedNav), is installed and runs on the user's cell phone. The role of PedNav is to communicate to the end user (using TTS) any information that is received from a NavCon beacon.

PedNav accepts incoming connections from nearby NavCon beacons, authenticates them, and relays useful information to the user. PedNav uses specific Java APIs defined by Java Specification Requests (JSR) to use certain hardware-level functionality. To access the Bluetooth hardware from Java, we use JSR-82 (which needs to be supported by the phone's Java Virtual Machine (JVM)).

PedNav provides an intuitive TTS-based user interface that is accessible to a visually impaired person. When the PSM first connects to PedNav and the authentication is complete, the phone plays a short beeping tone at short intervals. At this point the user can either ignore the beep, or acknowledge it by pressing a button. Once a button has been pressed, a general announcement is spoken, for example:

"This is the intersection of Mission Street and Bay Street. Press LEFT for Mission Street, or press RIGHT for Bay Street."

After the user has pressed either button, real-time traffic updates are sent, which may look like the following:

"Mission Street is now safe to cross."

"5... 4... 3... 2... The light is turning red."

"Red... Red... Red..."

At this point, the user may go back to the previous announcement to choose another crosswalk, or to go back into the Alert menu. From the Alert menu, the user can always temporarily disable NavCon beacon reception if they do not wish to be disturbed.

3. CONCLUSIONS AND FUTURE WORK

The URNA prototype described in this paper has been successfully implemented in a mock intersection with a number of traffic and pedestrian lights. The power of the Bluetooth transmitter was set to a level that minimizes the risk of radio range overlap between different transmitters. We are currently working on a custom antenna design to limit the signal dispersion for each of the four Bluetooth modules that would be installed at the corners of a traffic intersection. The goal is to minimize the field of coverage to allow a person to cross one street, seamlessly disconnect and subsequently reconnect to the beacon that is on the other side of the street, without signal overlap. As an alternative, we may improve multiple-connection support in PedNav and send a topological map of the intersection to the phone to allow it to know when a new module is attempting to connect, and alert the user that they have successfully crossed the street.

Another area that needs further expansion upon is the user interface for PedNav. We are planning to make it more generic for non-traffic applications. This means adding support for a more complex text interface with user input capabilities. A more ambitious idea would be to create a very generic version of PedNav that would dynamically adapt itself to the current application, such as having a traffic intersection mode, store directory mode, etc. In order to accommodate users who have mobile phones that support Java but do not have any TTS software available, we are considering implementing audio streaming on both NavCon and PedNav.

4. ACKNOWLEDGMENTS

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