SECOND GENERATION ACCESSIBLE PEDESTRIAN SYSTEMS

FINAL PROJECT REPORT

by

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16. Abstract

The Americans with Disabilities Act of 1990 has had a great impact on the implementation of Accessible Pedestrian Systems that target accessible and safety impediments faced by pedestrians with mobility and visual impairments. Intersection geometries are not uniform, and the traffic signal timing varies widely from one intersection to the next as well as days of the week and even hours of the day. The customization of the traffic signal operations is generally oriented to improving the performance of the vehicular traffic; the resulting changes in traffic patterns almost always impact the pedestrian access. Longer cycle lengths require pedestrians to cope with inclement weather or become impatient resulting in crossing without a WALK signal. For pedestrians who have vision impairments, the challenges become daunting. No longer is vision the primary means of communicating information that directly affects the safety when crossing a street.

To allow safer and more reliable pedestrian access at signalized intersections, the pedestrian systems should be able to be customized easily and quickly. Pedestrians can be faced with confusing or conflicting directions resulting in unsafe actions and could be tempted to assume increased individual risks if there is no ability to tune the pedestrian information for each intersection. . These systems are intended for use by pedestrians possessing a wide range of physical and cognitive abilities, and our research seeks to provide direction and alert these pedestrians of potential dangers in ways that are clear and quickly comprehended.

This research leverages off Smart Signals Research that started in 2004. The goal from the beginning was to develop a system that can provide capability for advanced technologies to improve the safety for pedestrians at signalized intersections. At early stages in this research, it was realized that the technologies currently being used do not provide the necessary infrastructure. Hence, past research focused on an enabling technology that has resulted in an innovative highly customizable pedestrian control system that has been commercially offered to a national market since 2010. Feedback from transportation agencies, pedestrian advocacy groups, and transportation equipment manufacturers has directed the research in areas that can provide the enhanced capabilities for precise and reliable systems to assist the general pedestrian population. Through workshops with an advisory group, extensive dialogs with experts, and technology development, we have developed a second generation of accessible pedestrian systems capable of being expanded to include direct interaction with selected pedestrians. We also conducted a pilot test to determine an appropriate tone for our second speaker navigation.

Technical reviews involving the research designers and the engineers with equipment manufacturers for the first generation pedestrian control system hardware and software brought out several key elements that needed improving. The hardware and software underwent extensive redesign, testing and performance evaluation. The resulting equipment has lower cost and improved capability and performance. The major system design improvements are wider operating temperature range, independent audio outputs, simplified power circuit design, extensible communications capability using diverse wireless and direct wired network technologies, and equipment that is less expensive to install. The results of the pilot testing gave us direction for future larger-scale testing and insights on how individuals cope without vision.

The benefit of the advanced features will be realized when the pedestrian navigation and guidance features are integrated with the second generation hardware.

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List of Abbreviations

ADA: Americans with Disabilities Act

APC: Advanced Pedestrian Controller

APB: Advanced Pedestrian Button

APS: Accessible Pedestrian System

AAPS: Advanced Accessible Pedestrian System

CPLD: Complex Programmable Logic Device

EoP: Ethernet over power line

EMI: Electro-Magnetic Interference

ESI: Electro-Static Interference

I2C: Inter-Integrated Circuit

I2S: Inter-IC Sound

MMU: Malfunction Management Unit

MUTCD: Manual for Uniform Traffic Control Devices

NEMA: National Electrical Manufacturers Association

NIATT: National Institute for Advance Transportation Technology

PacTrans: Pacific Northwest Transportation Consortium

PED: Pedestrian

RF: Radio Frequency

RFI: Radio Frequency Interference

RTOS: Real-Time Operating System

SDLC: Synchronous Data Link Control

SPI: Serial Peripheral Interface

SSIO: Signal Status Information Observer

UI: University of Idaho

VHDL: VHSIC Hardware Description Language

VHSIC: Very-High-Speed Integrated Circuits.

WSDOT: Washington State Department of Transportation

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Executive Summary

The Americans with Disabilities Act of 1990 has had a great impact on the implementation of Accessible Pedestrian Systems that target accessible and safety impediments faced by pedestrians with mobility and visual impairments. Intersection geometries are not uniform, and the traffic signal timing varies widely from one intersection to the next as well as days of the week and even hours of the day. The customization of the traffic signal operations is generally oriented to improving the performance of the vehicular traffic; the resulting changes in traffic patterns almost always impact the pedestrian access. Longer cycle lengths require pedestrians to cope with inclement weather or become impatient resulting in crossing without a WALK signal. For pedestrians who have vision impairments, the challenges become daunting. No longer is vision the primary means of communicating information that directly affects the safety when crossing a street.

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Technical reviews involving the research designers and the engineers with equipment manufacturers for the first generation pedestrian control system hardware and software brought out several key elements that needed improving. The hardware and software underwent extensive redesign, testing and performance evaluation. The resulting equipment has lower cost and improved capability and performance. The major system design improvements are wider operating temperature range, independent audio outputs, simplified power circuit design, extensible communications capability using diverse wireless and direct wired network technologies, and equipment that is less expensive to install. The results of the pilot testing gave us direction for future larger-scale testing and insights on how individuals cope without vision.

The benefit of the advanced features will be realized when the pedestrian navigation and guidance features are integrated with the second generation hardware.

Chapter 1 Introduction

Regardless of the mode of transportation, travelers and commuters are pedestrians at sometime during each trip. Recent reports show that the risk of the traveler when he or she is a pedestrian is an order of magnitude higher than when the traveler is an occupant or operator of a vehicle. Why should the walk from the parking lot or bus stop be the most dangerous part of the daily commute? While elderly pedestrians suffer from loss of visual acuity that may put them in danger, younger pedestrians are placing themselves at ever-increasing risk due to technology-based distractions (1).

In addition, various traffic pattern changes are being made to help with traffic flow but with a cost to the pedestrian. Signal timing plans and intersection infrastructure are getting more complex in attempts to reduce vehicle delays at intersections. Pedestrians are confronted with pedestrian operations that are shoehorned into traffic plans so that pedestrians have minimal impact on the travel time for vehicles. Wide-radius right turn lanes and roundabouts are long recognized as pedestrian-dangerous intersection designs. Just as traffic controllers are programmed for customized operations at each intersection, so too must the systems that interact with pedestrians be customized to provide a consistency of expectation for operations.

Without consistent expectation, pedestrians, regardless of physical capability, lose confidence in the traffic controls and eventually enter the intersection based upon their own assessment of risk. Drivers who unexpectedly find a pedestrian in the street reactively slow down thus disrupting the flow of traffic or precipitating into a rear-end crash. Even worse, the situation can evolve to a vehicle-pedestrian crash.

Modern accessible pedestrian systems require operations that can be customized easily and quickly to allow safe and reliable pedestrian access at signalized intersections. Without the ability to tune the pedestrian information for each intersection, pedestrians will be tempted to assume increased individual risks or are faced with confusing or conflicting directions resulting in unsafe actions. Our research sought to provide direction and alert pedestrians of potential dangers in ways that are clear and quickly comprehended. The systems are for indented use by pedestrians possessing a wide range of physical and cognitive abilities.

Pedestrian buttons are no longer a simple mechanical switch that indicates to the traffic controller that someone wants to cross the street. This research aimed to investigate new technologies to assist pedestrians as well as aid traffic agencies and engineers in communicating with the signal more easily and allowing customization. The immediate goals were:

1. Continue the development of the Advanced Accessible Pedestrian System (AAPS) to communicate unambiguously and accurately the state of the visual traffic signals with a minimum of distraction.
2. Investigate new technologies for assisting pedestrians with limited physical and vision abilities to cross safely at signalized intersections.
3. Provide additional opportunities for intersection customization to improve safety for pedestrians at intersections.
4. Assess customization capabilities and recommend practices to help traffic agency engineers and technicians to determine when, how and where to use the advanced customized operations.

Chapter 2 Background

Our experience is based upon the development of the Advanced Accessible Pedestrian System that is now being produced, marketed, and distributed by Campbell Company of Boise, Idaho. The number of advanced features requested by the customers after the initial introduction in February 2010 indicates that either traffic agencies perceive or users request a much wider range of operating characteristics than can ever be provided by the fundamental open-contact pedestrian button. Our original client base for the advanced controls was the low vision community of pedestrians. With complex intersection geometries, pervasive distractions, and dynamic signal timing plans, the pedestrian stations are now required to provide more site-specific information to all classes of pedestrian.

The Americans with Disabilities Act of 1990 has had a great impact on the implementation of Accessible Pedestrian Systems that target accessible and safety impediments faced by pedestrians with mobility and visual impairments. In addition, there is a new evolving class of impaired pedestrians blinded by pervasive distractions (2). We must consider both of these pedestrian groups in our research as well as all other pedestrians when designing the next generation of audible pedestrian signals.

2.1 Smart Signals

Initially, pedestrian buttons consisted of a normally open push contact. Pedestrians placed the call by pressing the button that caused a circuit to be completed allowing electrical current to flow. This current flow was detected by the traffic controller indicating that a pedestrian desired to cross at the intersection. The ADA of 1990 established access requirements for pedestrians whose mobility is otherwise constrained. The disability that has the most significant impact on pedestrians is low visual acuity.

The ADA of 1990 made it imperative that information concerning the state of the traffic signals be communicated by multiple human sensory modes. The alternative modes are mechanical in nature (auditory and vibra-tactile). The result is that the complexity of pedestrian call systems radically increased. Bidirectional communications between the traffic controller and the pedestrian call button is needed to make the state of the pedestrian WALK and wait signal available to be sensed by human touch or hearing. The degree to which this complexity has extended will be made apparent in the Methodology and Results sections of this paper. It is curious to note that the development of the pedestrian controls took on a life of its own after the ADA of 1990 that resulted in control equipment that is separate and distinct from the traffic controller electronics.

The Smart Signals concept was first investigated in 2004 to generate a computer-based architecture of an enabling technology that supported advanced capability for traffic signals based on distributed control concepts (3). Starting in 2005, based upon the recommendations of traffic professionals, we turned our research focus on accessible pedestrian controls. There were five guiding objectives dictating our design decisions and methodology for the Smart Signals based accessible pedestrian system.

1. The resulting system had to maintain or improve the existing level of pedestrian safety at signalized intersections.
2. The system must be able to be integrated with existing traffic controllers in such a way that traffic controller operation was not compromised.
3. The system must be able to use existing pedestrian signal infrastructures.

4. The system design must provide capability to address current and future pedestrian control needs. (audible count down for example)
5. The installation and maintenance of the system must be simple and low cost.

Since then, we have been improving upon the system and exploring the introduction of new technologies such as a second speaker, passive pedestrian detection, and preemption warnings.

2.2 Accessible Pedestrian Systems

The 2009 Manual for Uniform Traffic Control Devices (MUTCD) Section 1A.13 (4) defines an accessible pedestrian signal as being a device that communicates information about pedestrian signal timing in non-visual formats such as audible tones, speech messages, and/or vibrating surfaces. An accessible pedestrian signal detector is defined as a device designated to assist the pedestrian who has visual or physical disabilities in activating the pedestrian phase. The modern pedestrian station where an individual generates an action or places his or her self in a position to be detected is responsible for relaying the calls to the traffic controller as well as providing information concerning the state of the visual traffic and pedestrian signals. The need for Accessible Pedestrian System (APS) installations at intersections using fixed time controls are sometimes overlooked because a WALK phase is always included in the traffic control scheme. However, visually impaired pedestrians still would benefit from the audible and vibrotactile indications to assist them in crossing at signalized intersections.

The timing of the audible messages provided at each pedestrian station at the intersection must be coordinated with the traffic signal lights. There are two conventional practices for controlling pedestrian movements. One practice is what is referred to as a Barnes Dance, which provides an exclusive pedestrian phase where all vehicles are stopped and pedestrians are permitted to cross in any direction including diagonally. The more common scheme is to coordinate pedestrian movements with parallel traffic movements, which can vary in the details. Some parallel schemes use a leading pedestrian phase that displays the WALK signal a few seconds before right or left turns are permitted. Other parallel signals will not display WALK signals during protected left turn phases. It is also common to platoon pedestrians by displaying the WALK sign for only a portion of the parallel traffic movement. Which practiced is used can vary widely from one intersection to the next and can even be different at adjoining intersections.

The practice of using chirps and cuckoo audible tones to indicate that the WALK signal is active has recently fallen out of favor since the limited information provided by the two tones was easy to misinterpret due to non-uniform intersection geometries. The audio signals are also subject to distortion from surrounding mechanical barriers, such as buildings, landscaping, vehicles at the intersection, and even wild life. More recent APS systems provide verbal messages that are more descriptive and less ambiguous to indicate the state of the signal controls as well as the corresponding direction.

Regardless of physical capability, pedestrians are finding it more challenging to cross safely at signalized intersections. Traffic timing schemes are now tailored to accommodate the needs for efficient vehicle movements. Unconventional intersection geometries and roundabouts are becoming more common. Pedestrians with low vision now face a daunting task of learning and remembering the peculiarities of numerous intersections.

Common practices for visual pedestrian signals are now being challenged. Recent research has shown that people with average visual acuity have difficulty determining the state of the pedestrian signals when displayed across the intersection, as is normally the practice. Factors such as background visual noise, signal size, light contrast, and signal orientation contribute to readability. Hence pedestrian signals present challenges for even people who are considered to have normal vision.

As our research on AAPS continues to evolve, we are finding that traffic agencies are requiring a higher degree of capability to tune the pedestrian systems for each individual intersection to serve the safety and accessibility of pedestrians better. Even as traffic timing plans change based upon the time of day, so is the need to change the audible messages and/or volume levels. There must be a means to quickly and economically integrate new orientation and travel assistance concepts. The AAPS hardware and software architecture is specifically designed to be adaptable and easily reconfigured to accommodate a wide range of traffic situations and pedestrian needs.

2.3 Advanced Accessible Pedestrian Controls

Figure 2.1 provides a concept diagram for implementing the advanced accessible pedestrian control system. The diagram illustrates how the human is in the control loop by both creating the system inputs and reacting to the system outputs. There are multiple control loops in operation depending upon the pedestrian’s ability to receive and process the feedback from the pedestrian and traffic control electronics. From a human perspective, the pedestrian input is easily understood: press the button and wait for notification.

Feedback is provided by both the traffic controller and the pedestrian system. The traffic controller is responsible for controlling the visual signals. The pedestrian control system provides feedback based upon the traffic controller signal status. The pedestrian control system also provides feedback based upon the type of pedestrian notification. The feedback from the pedestrian controller is critical for individuals who cannot get the needed information from the visual signals.

It is obvious from figure 2.1 that the APS signals have evolved into a highly complex control system that requires specialized coordinated audible, visual and tactile feedback to humans that is unambiguous and quickly understood. The next sections of this paper describe the design methodologies needed to achieve the design objectives for this complex control.

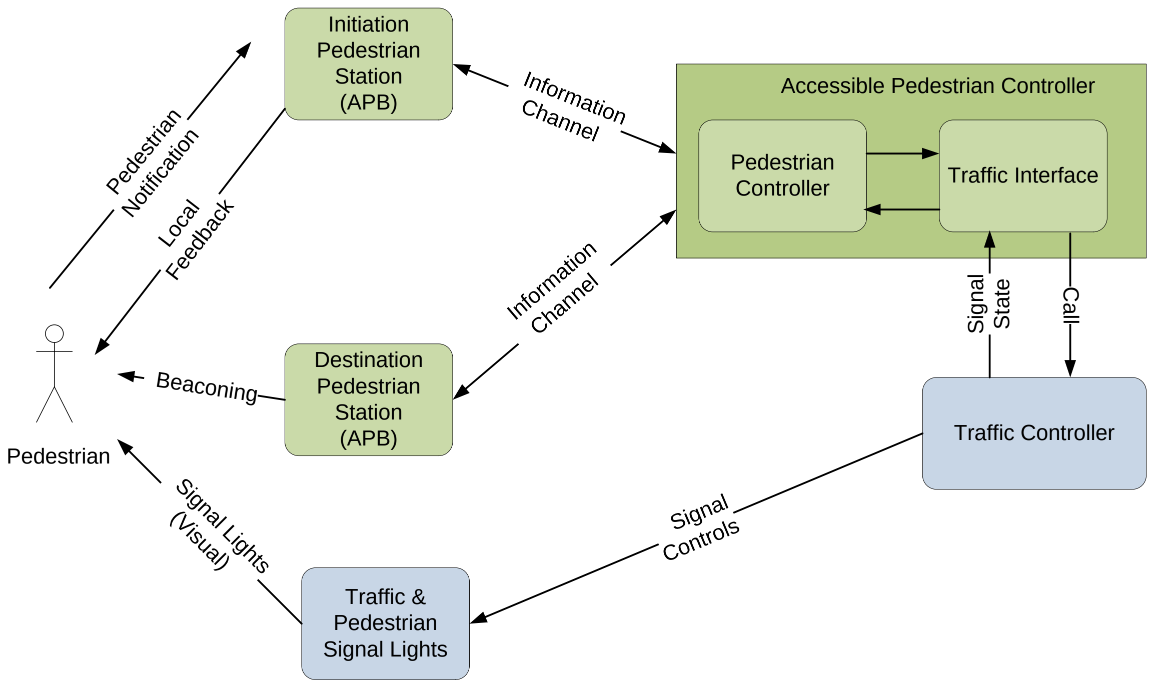

Figure 2.1 Data flow diagram for the Advanced Accessible Control System

Chapter 3 Methods

The methodology used to achieve objectives one through three is described in this chapter and was driven by the block diagrams shown. Much of the work was an iterative process to test and redesign the hardware and software and insure the interface circuitry did not fail. Objective four (assess customization and recommend practices) is an on-going process that involves interactions and feedback from traffic engineers and technicians.

The overall objective of the research was to establish a hardware platform that is extensible and useable in a wide range of environments and applications by defining the system operations, to the extent possible, in software. Figure 3.1 provides a block diagram of the AAPS II system. The key element in this design is the Synchronous Data Link Control (SDLC) interface between the pedestrian controller and the traffic controller. Although the bus type network is comparable in structure to the first generation AAPS, the hardware that uses the network is a new design with much higher capability. In this design, the pedestrian button station can now serve as a communication hub for higher-level functions such as pedestrian guidance assistance.

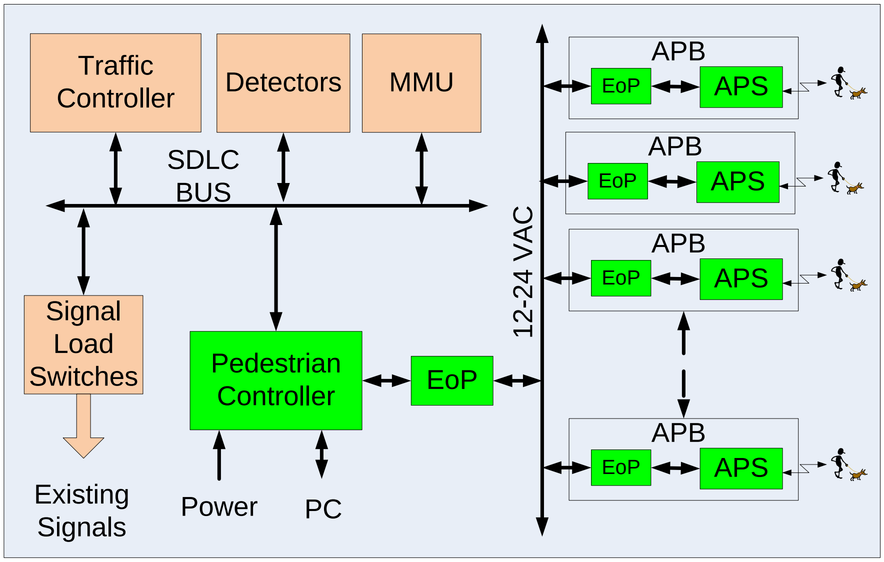

Figure 3.1 Second Generation Advanced Pedestrian System block diagram

The Advanced Pedestrian Controller (APC) consists of four functional elements: the system control computer, the traffic cabinet interface, the Ethernet communications interface, and a local status display. The function of the APC is to manage the system operation parameters, report the status of the intersection WALK and DON'T WALK signals, and place pedestrian calls to the traffic controller. Although the APC communicates pedestrian signal status with each pedestrian button four times a second, a pedestrian call initiated by a button press is initiated by the pedestrian button station instantly. The single board computer used in this design is commercially available from Technologic Systems (5,6). Although there are many suitable single board computers that use a Linux operating system, the special requirements include two Ethernet ports and having hardware that is compliant with operating at industrial temperatures. The front panel display is unchanged from the first generation AAPS design (figure 3.2).

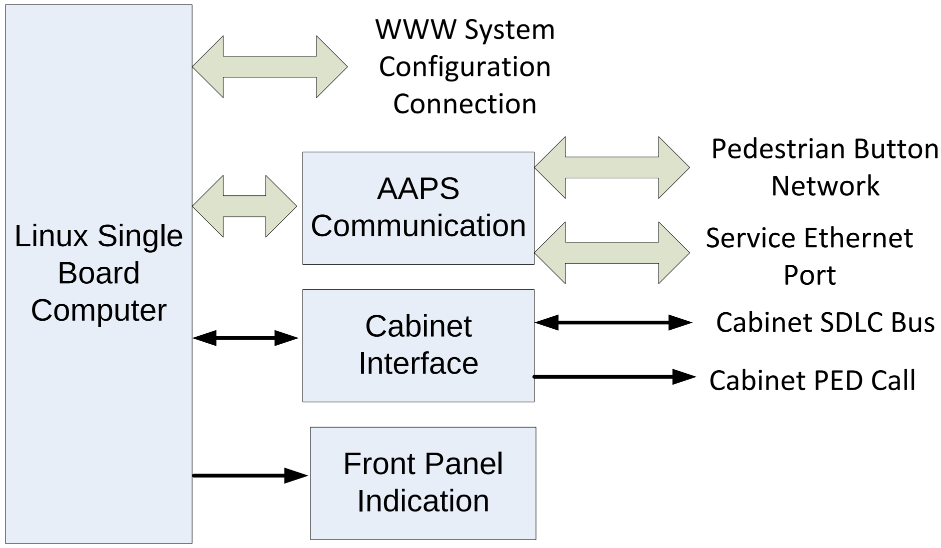

Figure 3.2 Second Generation Advance Accessible Controller block diagram

3.1 Objective 1

To communicate unambiguously and accurately the state of the visual traffic signals with minimum distraction, the AAPS II cabinet interface unit was designed. Current versions of APS systems need to check the current state of pedestrian signals, so they are wired directly to field terminals within a traffic cabinet that control the pedestrian signals; this information is communicated to each pedestrian station. However, this method of signal sensing is complicated to install, and because of the connection to live 120VAC signals at the field terminals, it requires special certification in some states within the US. Furthermore, connecting to 120VAC signals require that APS systems include transient voltage protection. The protection circuitry creates a load in parallel with the load of the signal light. Additional loading on the load switch outputs of any type is to be avoided whenever possible to prevent the Malfunction Management Unit (MMU) from sensing a voltage that otherwise results from an inoperative signal.

An interface to the National Electrical Manufactures Association (NEMA) TS2 Traffic Controller Standard (7) SDLC (8) bus to monitor the SDLC Type 129 Response message generated by the MMU was designed. A block diagram of the AAPS II cabinet interface unit is shown in figure 3.3.

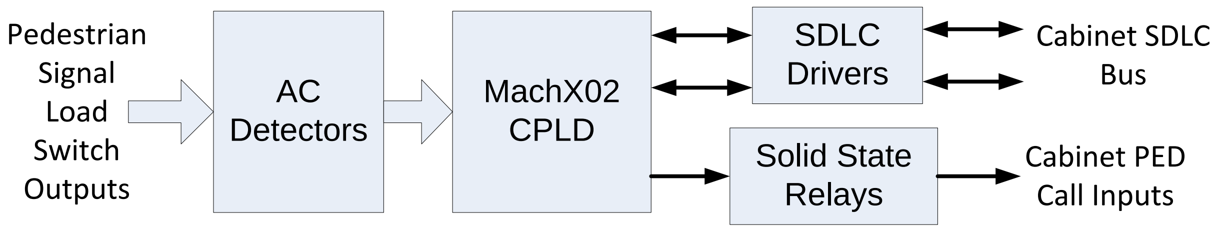

Figure 3.3 AAPS II Cabinet Interface Unit

3.2 Objective 2

We not only redesigned the Advanced Pedestrian Button but also conducted a pilot study on guidance sounds and patterns to investigate new technologies that will assist pedestrians with limited physical abilities, such as vision and hearing, cross signalized intersections.

3.2.1 Second generation Advanced Pedestrian Button

The redesign of the Advanced Pedestrian Button proved to be a challenge from a technological perspective. The enhancements needed for the anticipated capability required both a hardware and software redesign. Although the basic functionality of the pedestrian button remained the same, the architecture for the software had to provide for efficient and effective code modification. The hardware redesign is represented in the block diagram shown in figure 3.4. The processor selection was based upon the on-chip hardware for communications. These include Ethernet, SPI, L3Bus, I2C, and I2S serial protocols. Although the sensor network technologies come standard on most microcontrollers, we choose to use the LPC1768 NXP processor for this design because its smaller foot print was easier to design into the circuit board that has constrained size. The addition of the 10/100 Ethernet switch (9) along with the aforementioned sensor networks now allows the pedestrian button to serve as a communications hub. The new design also provides the option of implementing a second speaker for communication to the pedestrian in the crossing.

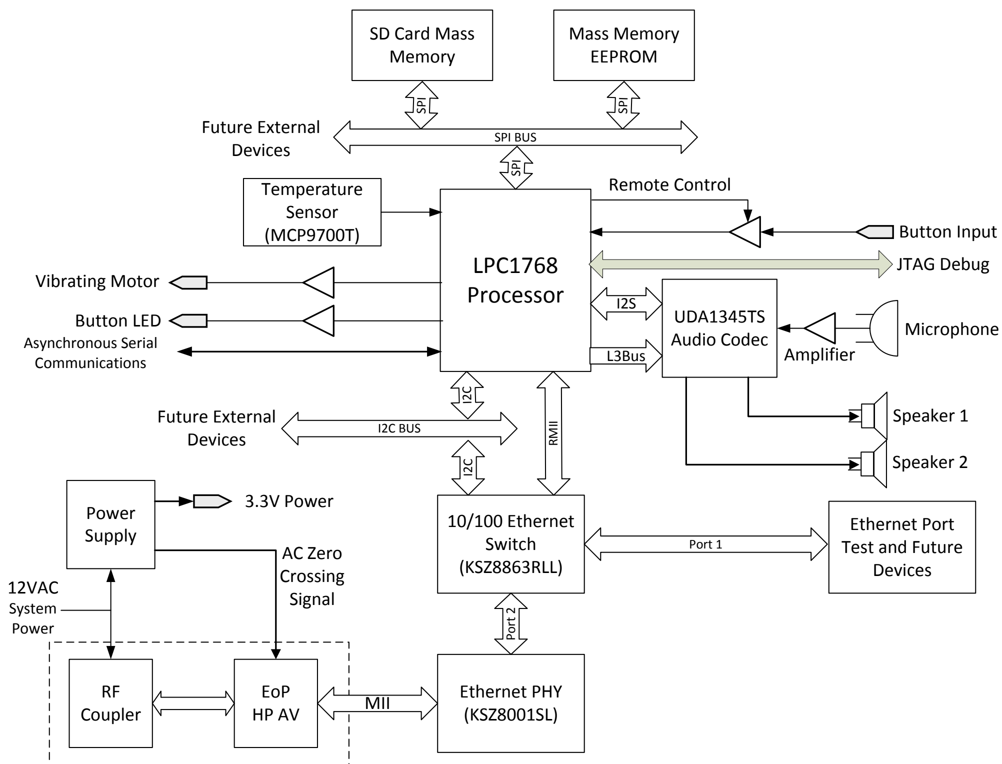

Figure 3.4 Second Generation Accessible Pedestrian Button block diagram

3.2.2 Pilot Testing of Second Speaker Tone

A pilot test was conducted to help in determining an appropriate tone to be broadcast by the second speaker. This tone would be used to aid visually impaired pedestrians while crossing the intersection. Four groups of college-aged students (13 total subjects) were recruited to point to the tone or walk towards the tone while blindfolded. One group also wore an earplug in the right ear to emulate an individual with partial hearing. The experiment was conducted in the ballroom at the University of Idaho Student Union Building, and a pedestrian button speaker (figure 3.5) connected to a computer was used to generate the sounds; the speaker was turned on and off with the toggle switch located below the "HI" indicator lights. A diagram of the testing layout can be seen in figure 3.6.

Figure 3.5 Pedestrian Button Speaker

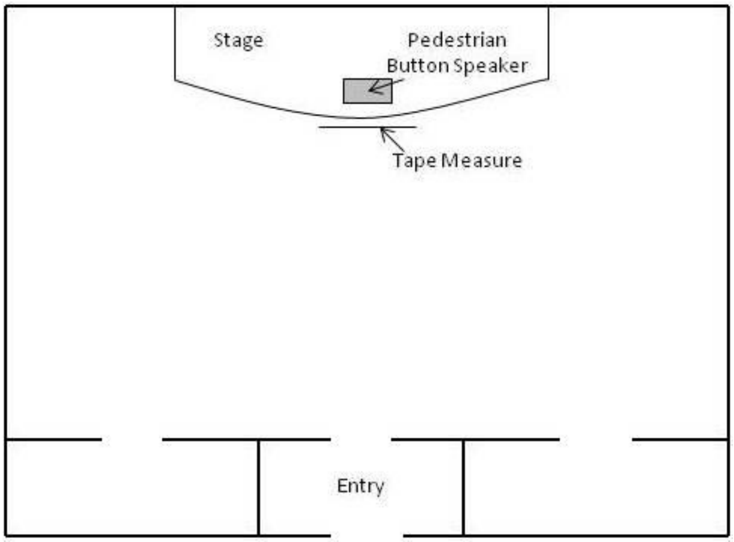

Figure 3.6 Diagram of Pilot Test Setup

Outside of the testing room, the procedure was explained to the group, and each subject was asked to put on a blindfold (and insert an earplug into the right ear for one group). The subjects were then lead into the room by a guide. Once in the testing room, the guides walked the subjects around so that they would lose sense of where they were in the room. This procedure was repeated after every tone test. Some subjects were even placed with their backs to the pedestrian button speaker. The subjects were also placed at various distances from the speaker.

After the subjects were in place, one of three tones (current locator tone, percussion, and cowbell) was played either continuously or intermittently (three tone repetitions with a 2 second pause). Each subject would then either point to the tone while standing at their present location or walk towards the tone until we stopped them (see table 3.1). Each tone/length combination was repeated two times and the order was randomized. A test was completed when all subjects were pointing (in any direction) or they had walked the equivalent of crossing a three-lane intersection.

	Test	Number of Subjects
Group 1	Point	2
Group 2	Walk	4
Group 3	Point	4
Group 4	Walk w/ Earplug	4

Table 3.1 Pilot Test Groups

Whether they accurately located the pedestrian button speaker was recorded as “yes” or “no” for each subject for each trial. A “yes” would be pointing or ending the walk within 3 feet to the left or right of the device. The total length of 6 feet (width of a crosswalk) was measured with a tape measure on the floor. Notes on if the subject corrected him or herself or had difficulty locating the tone were also taken. At the end of the testing, each subject was asked to give their thoughts on the tones, such as which one was easier or harder, and whether they used any other cues in the room to help guide them to the pedestrian button.

3.3 Objective 3

The decision was to develop a proprietary communication module that is functionally organized as shown in figure 3.7. The new design would allow either HomePlug I or HomePlug AV2 modules to be used thus allowing the less expensive design to be used for the majority of the intersections that do not require the data rate provided by the HomePlug AV2 communications modules. A ruggedized three port managed switch provides Ethernet communications between the single board computer and the EoP network. The additional port allows a maintenance service port that will permit a PC or laptop PC to be used to monitor the EoP communications without requiring special communications hardware. Since the communications module provides the interface to the AAPS power line, the power supply for the entire AAPS II system is provided with this module.

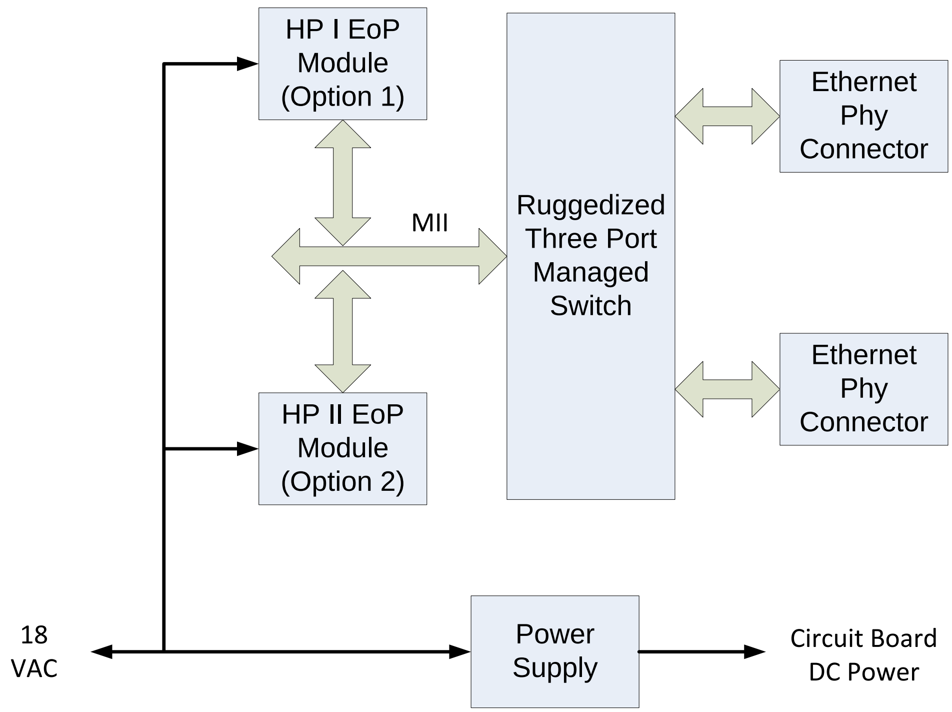

Figure 3.7 Design block diagram for the AAPS II communications module

Chapter 4 Results

The AAPS II design resulted in proprietary custom hardware and many tens of thousands of lines of computer code. The system is a true distributed computing platform that provides processing power as physically close to the actuators and sensors as possible to improve reliability and reduce infrastructure cost. The software-based system is extensible allowing the system capability to be adapted and expanded to suit future requirements.

The hardware was specifically designed to be easily adapted to changing functional requirements. For example, portioning the pedestrian controller into three modules allows upgrading one hardware module and reusing the remaining modules. The three custom circuit boards discussed in Chapter 3 were thoroughly tested in the course of this project. The significant design enhancements are:

- Enhanced EoP communications allows for a tenfold increase in the number of pedestrian stations and information exchange
- Modular design allows for parallel of hardware
- No-cost software development tools reduces development costs
- Using advance semiconductor technologies reduces both system equipment and installation costs
- Additional hardware capability provides a system platform for investigating pedestrian assistance through tracking and guidance

The improvements relating to the three hardware units are discussed in the following sections. These circuit boards were designed such that technicians employed at the University of

Idaho were able to populate the circuit board in phases to allow thorough testing. As such, we are limited in circuit trace spacing and component sizes.

4.1 Objective 1

The proprietary printed circuit board shown in figure 4.1 was designed and tested. The Cabinet Interface Unit is a proprietary circuit to interface with the NEMA TS2 SDLC bus. The Cabinet Interface Unit has been tested using both simulated SDLC Type 129 messages as well as actual SDLC Type 129 messages from a NEMA TS2 traffic controller cabinet. The new SDLC interface uses a low cost complex programmable logic device to decode messages and allow the data contained within the SDLC Type 129 message to be accessed over a common I2C network.

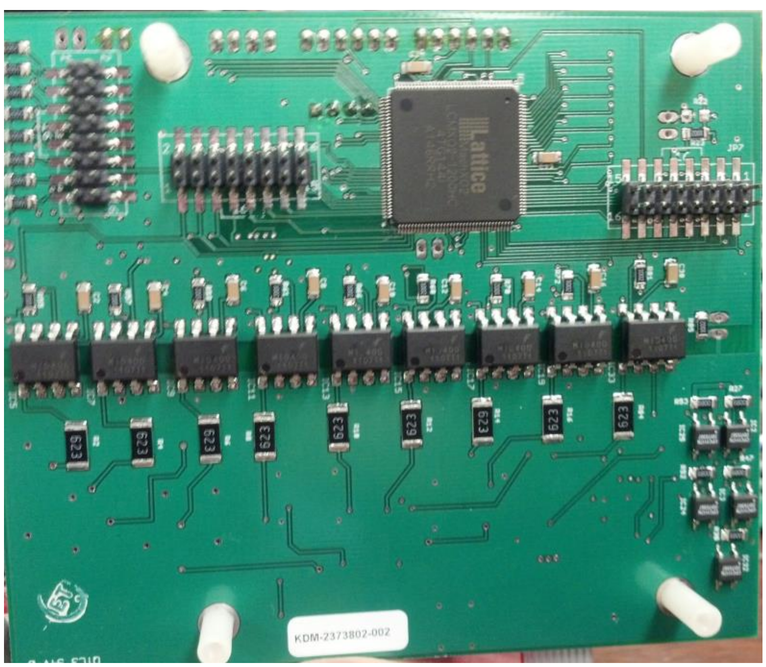

Figure 4.1 NEMA TS1/TS2 Cabinet Interface Unit printed circuit board

Figure 4.1 shows only one side of the printed circuit board cabinet interface board. The dual-system board has significant requirements for handling both industrial voltages (over 100 volts) and voltages used to supply sensitive electronics. EMI, ESI and RFI issues were considered and these circuit boards underwent compliance testing to show that they meet safety requirements.

4.2 Objective 2

4.2.1 Second Generation Advanced Pedestrian Button

Figures 4.2 and 4.3 show the two sides of the second generation pedestrian button. Volumetric size restriction dictated that components that extend more than 0.25” above the surface of the circuit board be mounted of the same side of the circuit board. This size restriction is imposed by the desirable physical size of the pedestrian button. As one concludes from figure 4.2, we are close to if not actually at the maximum number of electronic components. As it is, there are components sandwiched under the EoP module that has the “bel” label as seen in Fig. 4.2. (The “bel” label identifies the manufacturer of the EoP module, Bel Fuse Corporation of Jersey City, NJ). The four-layer circuit board uses the surface layers as heat sinks dissipate heat produced by electronic components. Using the circuit board conductors to dissipate component generated heat saves circuit board real estate and part cost.

Software has been developed to verify that all hardware components are functional. Software drivers have been developed that allow the various hardware components to be included in the operations of the button.

Figure 4.2 Second Generation ABP printed circuit board - side A

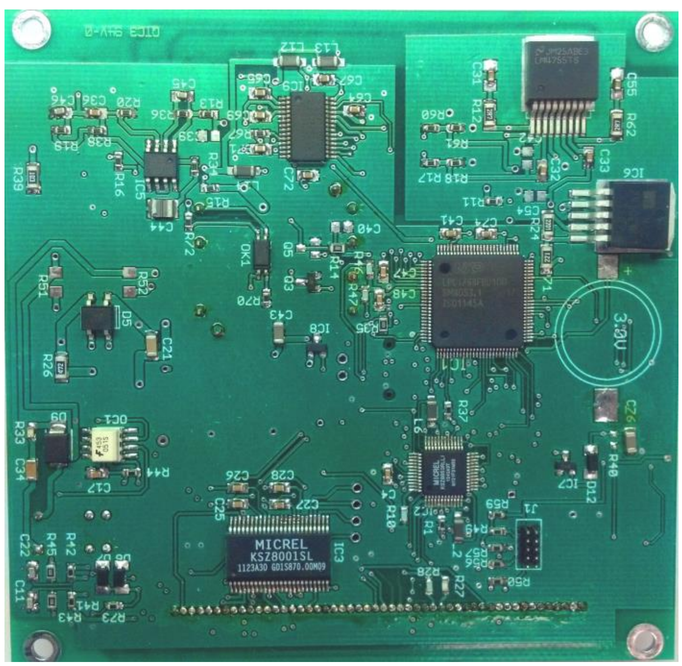

Figure 4.3 Second Generation ABP printed circuit board - side B

4.2.2 Pilot Testing of Second Speaker Tone

As this was an exploratory experiment to guide future design setup and testing, no statistical analysis was conducted on the results. However, we analyzed the overall findings and reactions of the subjects to evaluate the tones and the testing setup. Figures 4.4, 4.5, and 4.6 show the number of subjects that correctly located the tone, and those that did not for pointing, walking, and walking with an earplug, respectively. The overall results of all groups are shown in figure 4.7. The "corrected" category indicates those subjects that located the tone but only after correcting while waiting for the others to point or re-aligning their path while walking. "Cont" is the continuous tone and "Int" is the intermittent tone. Tables 4.1, 4.2, and 4.3 list some of the subject feedback from each test.

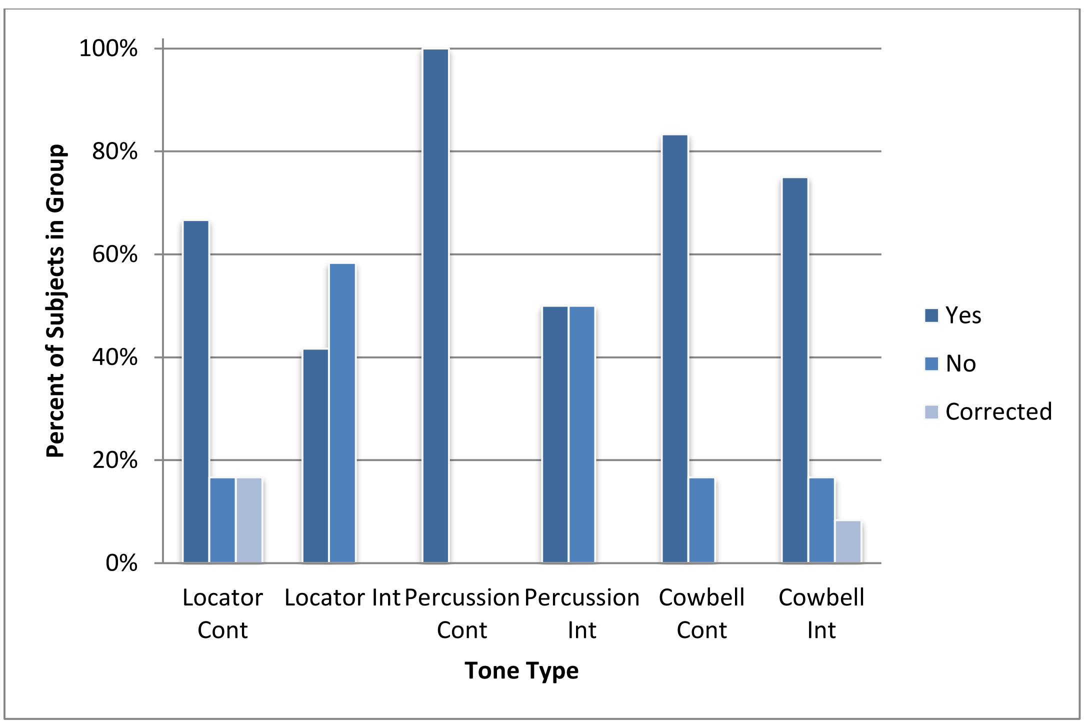

Figure 4.4 Results of Point Test

Table 4.1 Feedback from Point Test

Best tone to locate was cowbell with first group and percussion with second group
Locator tone was confusing – echoed off walls
Percussion tone was not associated with a crosswalk
Listened to the fan in the room to locate where they were

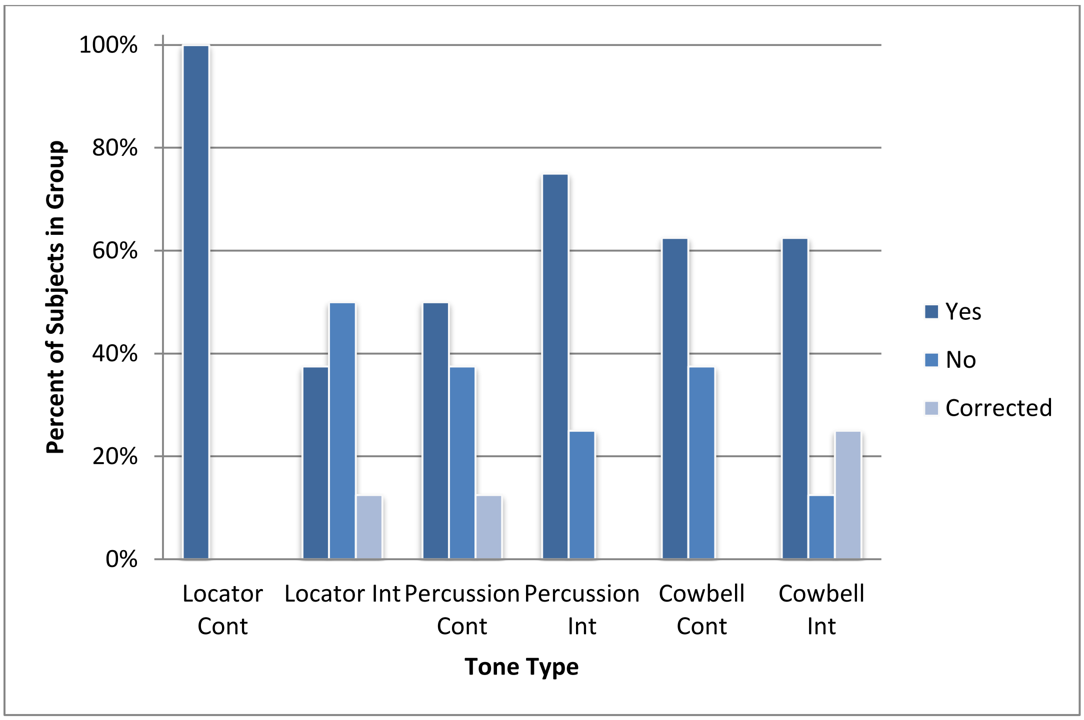

Figure 4.5 Results of Walk Test

Table 4.2 Feedback from Walk Test

Best tone to locate was percussion
Locator tone was confusing – echoed off walls
Cowbell tone echoed a little
Used toggle switch clicking to orient themselves to the pedestrian button speaker

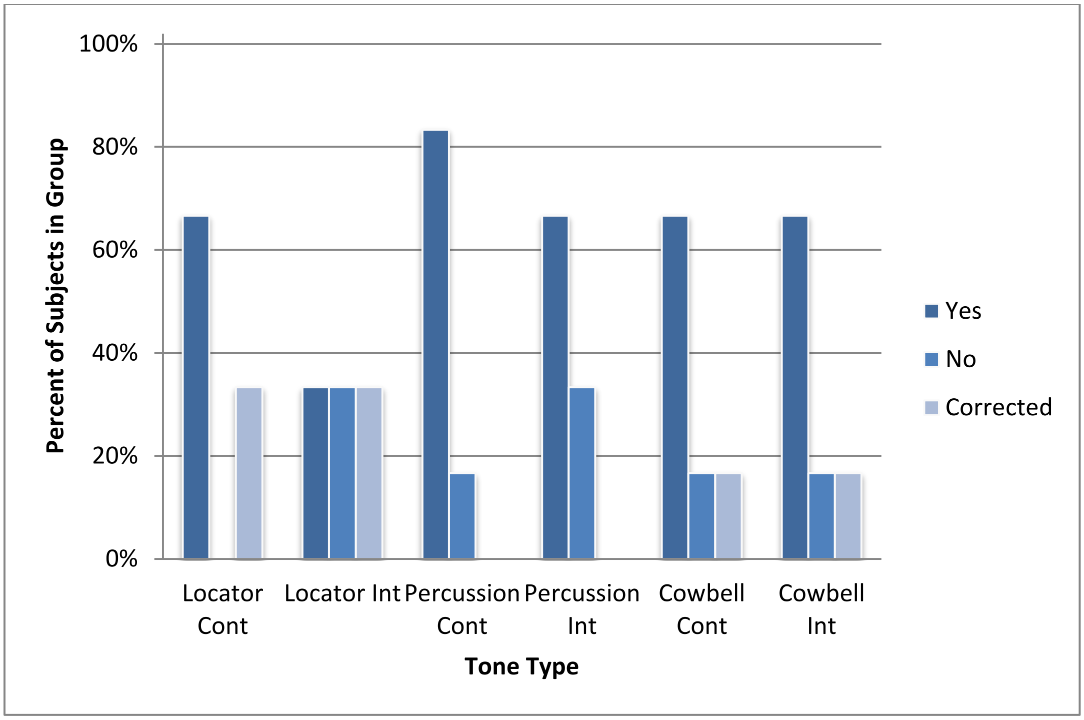

Figure 4.6 Results of Walk with Earplug Test

Table 4.3 Feedback from Walk with Earplug Test

Best tone to locate was percussion
Most difficult tone was the locator
Earplug made it a little harder to determine the direction
Started walking until they could hear the tone, then corrected

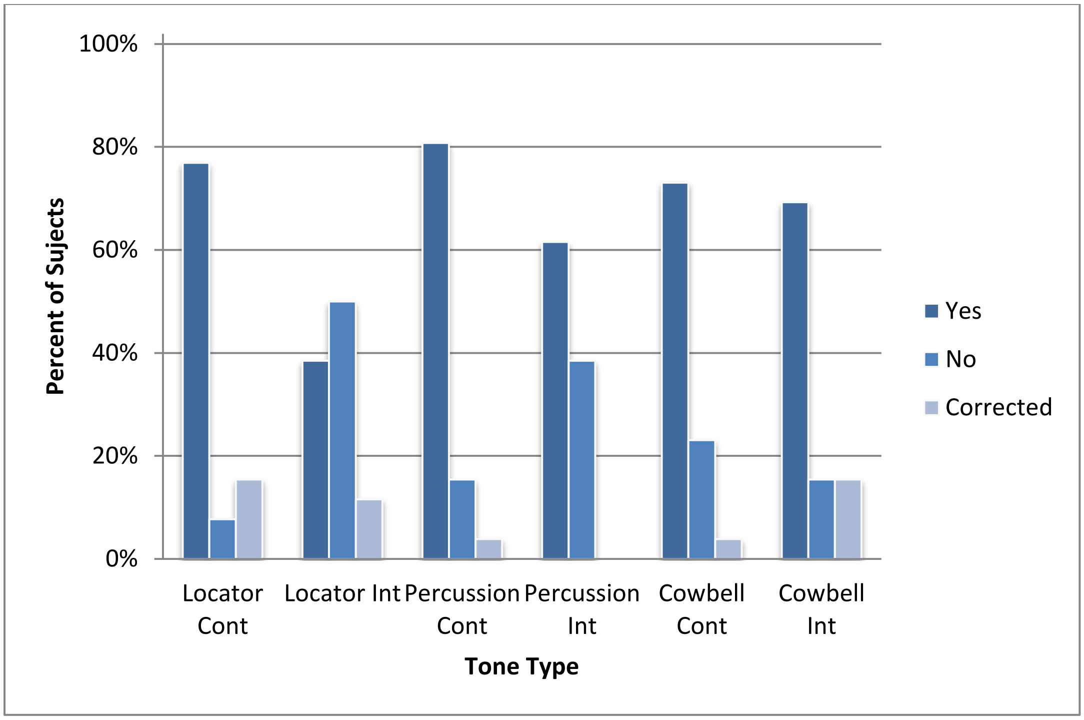

Figure 4.7 Overall Results of All Tests

4.3 Objective 3

The proprietary communications board was designed and tested with both HomePlug (HP) 1 and HP AV2 EoP communications modules. The printed circuit board shown in figure 4.7 is populated with the HP AV2 module. There were no significant design challenges associated with this unit. Since this unit uses no programmable devices, there are no software design requirements. The testing consisted of connecting the Ethernet connections to a university Ethernet and running connectivity tests. Secondly, we were able to use commercial HP AV1 devices to test the Ethernet to EoP connections.

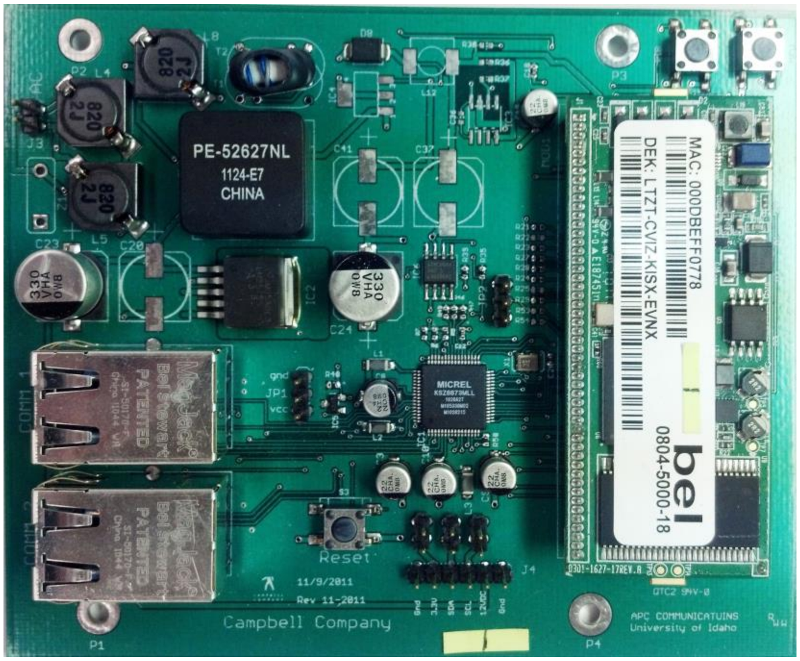

Figure 4.8 Second Generation AAPS Communication Unit printed circuit board

Chapter 5 Discussion

The performance goals for the hardware design for AAPS II were all met. Testing was limited to a laboratory environment for an 8-button system, and the hardware complexity of the pedestrian button challenged the ability of the University of Idaho to develop such a complex circuit board with limited production tools and technician skill. The software for integrating the pedestrian controller modules was completed and sufficiently tested to indicate that these modules are ready to be transitioned into beta testing in an intersection used by the public. The software for the second generation pedestrian button has verified all hardware is functioning. The software that controls the button operations has also been verified and documented as a series of hierarchal state diagrams. In addition, we have used the pilot testing to develop a larger scale experiment to test with a variety of subjects.

5.1 Objective 1

The design is legacy compatible, transitional, and futuristic. The legacy compatibility provides all the interface capability of the original AAPS design and can be used at any US traffic controller cabinet. The complex programmable logic device contains the logic to provide all of the device functionality. The cabinet interface unit hardware needs no modification to accommodate the various modes of operation: only reprogramming the logic within the Complex Programmable Logic Device (CPLD).

The transitional capability allows the pedestrian signals to be monitored without connection to the 120VAC outputs from the pedestrian signal load switches. In both cases, the pedestrian calls are placed using optically isolated, normally closed model CPC1117N (10) solid-state relays capable of switching up to 60V AC or DC at 150ma. The relay outputs that are normally closed are specifically selected to place constant calls on the pedestrian inputs. The SDLC interface uses two pairs of RS485 (11) transceiver driver ICs that monitor the two SDLC buses in the NEMA Type 2 traffic controller cabinet. At this point in the AAPS design, the Cabinet Interface Unit only monitors the SDLC messages sent from the MMU to the traffic controller.

The motivation for this effort is to provide a safer, lower cost, and more reliable method to sense signal states. Moreover, this method avoids connections to 120VAC signals. The SDLC Type 129 Response message contains the current state of all signals within a signalized intersection. Using the SDLC bus interface, the APS no longer needs the extra circuitry and transient voltage protection components normally needed for interfaces to the 120VAC load switch outputs. The SDLC interface approach reduces hardware cost and installation time.
The Lattice Semiconductor MachX02 CPLD (12, 13) is programmed using the hardware description language VHSIC Hardware Description Language (VHDL) (14) that allows simulation and testing with proven design methodologies. The CPLD logic architecture uses an internal Wishbone System-on-Chip Interconnect, maintained by OpenCores Organization (15), for a data path between macro logic blocks. The Wishbone Interconnect allows for a simple interface of custom data registers to embedded registers within the CPLD such as the I2C interface. Once all the desired signal information has been extracted from the SDLC Type 129 message, the information is stored in custom data registers attached to the Wishbone Interconnect. Other custom data registers contain configuration options and status information obtainable over the I2C interface. A finite state machine that is controlled via I2C was developed and tested using VHDL to complete data transfers between registers. A single-board computer

running a Linux operating system accesses the information on the registers via I2C and then communicates the signal states to each pedestrian station.

The improvement in information consistency is attributed to the method the new APS system uses to decode pedestrian signal states. The Signal Status Information Observer (SSIO) implementation of APS systems detects pedestrian signal status via the SDLC network within NEMA TS2 traffic controller cabinets. Specifically, the Type 129 Response message from the MMU to the traffic controller is passively sensed on the SDLC network and decoded to obtain pedestrian signal information by the SSIO. The Type 129 Response message contains all signal information as deciphered by the MMU. The MMU transmits the Type 129 Response message every 100 milliseconds. Using the Type 129 message, the APS system avoids inconsistency in signal decoding that could arise due to the different voltage thresholds between devices discussed earlier.

5.2 Objective 2

5.2.1 Second Generation Advanced Pedestrian Button

Unlike the communications unit, the second generation pedestrian button uses only HP AV2 EoP communications. This has the advantage of reducing the requirements for the power supply that powers the digital electronics saving both board real estate and circuit board complexity. There are also two memory options for storing the binary files used to produce the various audio messages and tones. The LPC1768 NXP processor is able to use direct memory access that transfers the binary data directly from the memory devices to the audio codec without requiring processor action. The temperature sensor has no application at this time beyond recording the internal environmental temperature to which the electronics is exposed.

The second generation pedestrian button included many changes in the hardware design to accommodate future anticipated and unanticipated technology needs to improve pedestrian safety continually. The audio out capability now includes two speakers: one for playing the conventional APS messages and one for being used for pedestrian guidance. The MUTCD states that the orientation on the tactile arrow on the button indicates the physical direction of travel for the specific crosswalk. Speakers are to play an audible locator tone that directs the pedestrian to the button. As such, this speaker directs the audio sound that is orthogonal to the direction of travel. The MUTCD also directs that the audible sound be constrained to a 10-foot radius around the button presumably to reduce noise pollution. Hence, this speaker is ill suited for providing an effective navigational beacon. The second audio output will drive a speaker that is mounted such that the sound is directed in the direction of the crosswalk thus providing an effective navigational audible signal.

Changing the real-time operating system from a hardware-specific RTOS to one that is in the public domain reduced the maintenance cost by eliminating the cost of software license maintenance and upgrades. We adopted the FreeRTOS (16) not only because it is available for no cost (it is truly free) but because the documentation and the community of users provide beneficial development assistance. An additional advantage that FreeRTOS has is the availability of SafeRTOS (17) which is a safety certified kernel for microcontrollers.

5.2.2 Pilot Testing of Second Speaker Tone

From the pilot test, we made several observations about the subjects during the test and items that need to be considered in a larger experiment. During the testing, it was obvious when an individual was having trouble locating the tone. One subject would delay his response at least 30 seconds after the other subjects had started pointing in the direction of the tone. He also would orient himself so that the same ear was on the side of the tone. We believe he had a hearing impairment but he was unaware of it. Another possibility is that he just favors one ear. This observation led us to add earplugs in the last group. An implication of having both a visual and hearing impairment is that only a tone may not be enough to help guide a pedestrian across the street while staying within the crosswalk. It may even lead some to wander into traffic if their hearing limitation was in a certain ear. This confirmed our thoughts that some sort of tactile feedback would also be necessary.

Another observation was that all subjects had difficulty finding the tone when they were placed towards the back half of the room or near a wall. When the subjects were in the back of the room, most of the time they just began walking in a direction until they heard the tone. This could be problematic for longer intersections; visually impaired pedestrians could begin to wander until they heard the tone. Broadcasting the tone from both sides of the street may help remedy this. We would just need to ensure that the speaker volume on the starting side was adjusted accordingly so not to interfere with environmental sound cues.

When the subjects started near a wall, they usually walked or pointed in different directions before deciding on the final location of the speaker. This was due to the sounds bouncing off the walls and creating echoes. One individual walked along the wall until he was close enough to hear the true direction of the tone. This could be especially troublesome in an area with many buildings, such as an urban intersection. However, since the idea is to have the second speaker directed parallel with the crosswalk, there may not be as many echoes in an open area. This would be something that should be tested in the future studies.

Overall, from the subject testing results and feedback, it appears that any of the three tones played continuously would correctly lead a pedestrian across the street. However, since the locator tone is already in use at signalized crossings and the subjects indicated that it was confusing (mainly due to echoing), we have decided to eliminate the locator tone from any further testing. The percussion tones may be the most appropriate according to the results and subject feedback; however, the cowbell did not show much difference in correctly locating the tone between continuous and intermittent. The reason the cowbell was not the first choice among the subjects was the echoing, just as with the locator tone. These two tones and possibly a new tone will be used in further testing. If we are to use the cowbell or a similar tone, the echo affect will have to be examined.

The last observations we had from the testing are improvements to the testing environment. It was obvious that testing indoors was not the appropriate setup. However, due to equipment limitations (we needed a power source), we were forced to conduct the pilot study in the ballroom. We choose this room due to the size, but the design proved to be an issue with echoes. We are currently working on a wireless speaker that would be able to run on a battery. This would allow us to test in any outdoor area that is safe for our test subjects to walk blindfolded. We also noticed unusual walking patterns (e.g., zig-zag, turning 180 degrees), which confirmed our earlier idea of creating a crosswalk for the subjects to navigate. This would allow us to observe whether the subject strays outside of the designated area and into "traffic". We also would want to set a maximum perimeter so that we are simulating a specific road width. The last major change we will make in the testing is the use of two second speakers. We would compare using the speaker on the opposite side of the street only to using both speakers with the one on the starting side at a lower volume.

If we were to continue only testing college-aged students, we would not be able to make inferences on the overall pedestrian population. Therefore, when we conduct the second round of testing, we will include older and younger pedestrians as well as involve the local visually impaired community.

5.3 Objective 3

One of the key technologies of AAPS is the use of EoP for communications between the pedestrian controller and each pedestrian button (18). Our implementation of the HomePlug I EoP (19) communications for the original AAPS is limited to 16 stations on a single power line network. Additionally, the effective data rate of the HomePlug I is well below the specified peak data rate of 14 Mbps (20). Complex intersection geometries resulting from traffic designs that include pedestrian safety islands to accommodate excessive number of traffic lanes at crossings (21), and diamond intersection designs (22) require pedestrian systems that can control in excess of the 16 station limit. Secondly, as the number of stations increases, the communications loading on the network and the addition of anticipated Ethernet-based instrumentation at each the pedestrian stations was fast approaching the peak HomePlug I data rate. HomePlug AV2 specifies a peak data rate of 200 Mbps with effective data rates of 80 Mbps. The 16 station limitation imposed by the HomePlug I design is eliminated by using HomePlug AV2 communications. However, the cost of the HomePlug AV2 communications modules is approximately five times that of $20 for a HomePlug I communications module.

Chapter 6 Conclusions and Recommendations

The SSIO implementation of sensing pedestrian signal status for APS systems shows many advantages to current methods. The SSIO can be used in any traffic controller cabinet that contains an SDLC network with the Type 129 message. The CPLD allows for customization for use in different intersections that may conform to different standards other than the MUTCD. The SSIO method uses less hardware than current methods of pedestrian signal sensing, which can reduce cost and lower the amount of volume the APS system utilizes within a traffic controller cabinet.

We were unable to complete the internet interface that allows the pedestrian controller to download the operating parameters (such as audio files) to the button. This will be proposed as future work. Additional future work will include a larger testing of the second speaker and the appropriate tone. The subjects would include younger and older pedestrians in addition to the college-age subjects and those that are hearing and/or visually impaired. We are presently creating a survey to distribute to the visually impaired communities in Moscow and Boise asking about preferences for feedback at the intersection.

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