COMMERCIALIZATION AND FIELD DISTRIBUTION OF SMART PEDESTRIAN CALL SIGNALS

Final Report

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National Institute for Advanced Transportation Technology

University of Idaho

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16. Abstract:

The research on this project resulted in a new design for an accessible pedestrian system (APS) that uses Ethernet communications to implement a distributed control system. Present APS designs represent a safety risk factor by APS systems having undetectable failure modes that may play incorrect audible messages.

The systems consists of a controller unit housed in the traffic controller cabinet and interfaces to existing NEMA TS1 and TS2 traffic controller cabinets at the field terminals. It supports from one to 16 pedestrian stations. The controller unit uses a Linux based single board computer with dual Ethernet ports. The pedestrian stations use a resource rich NXP processor reducing the number of components and size of circuit board.

All configuration and diagnostics is accomplished using a PC with a standard web browser and an Ethernet connection. This interface reduces the size and cost of the unit mounted in the controller cabinet. The web page provides real-time status of all controller inputs and the state of all pedestrian stations and the audio message currently being played.

SNMP and STMP custom objects are used in such a way that each communications transaction is verified. A network protocol is implemented that follows the guidelines for NTCIP custom objects.

17. Key Words

Traffic control devices; traffic signal control systems; signalized intersections; warning devices for the handicapped; physically handicapped persons; pedestrian safety; pedestrian areas; pedestrian vehicle interface

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EXECUTIVE SUMMARY

Smart Signals is a term we have coined that refers to an enabling technology that allows for more effective intersection control and adaption to real-time traffic operation requirements to enhance highway performance and/or improve safety. Research in this area supports the NIATT objective 1 under the strategic initiative 1.4 that specifically identifies taking a revolutionary approach to interfacing traffic controllers to field devices.

Innovative research on “Smart Signals” concepts started in the fall of 2005 when it was noted that current traffic signal devices display only a limited set of symbols, i.e. walk and don’t walk icons for pedestrians and the common green, red, and yellow balls and arrows for vehicles. Signals and sensors that utilize the Smart Signals technology can be used to display a wide range of symbols and information that can change dynamically to reflect current road operations. The difficulty of changing signal displays for temporary traffic patterns often confuses drivers and generates unsafe intersection operations.

The integrity of traffic control systems today depend upon the malfunction management units (MMU) or conflict monitors (CM) to be able to observe the state of all traffic and pedestrian signals. This is accomplished by monitoring the voltage on the wires that connect the signal lights to the load switches controlled by the traffic controller. Spatially distributing intelligent control makes some of the automated controls unobservable by the MMU or CM. This is certainly the case for signals that operate using Smart Signals technology. Early in 2008, the Smart Signals research tested and implemented a secure distributed real-time control system for safety critical systems by overlaying time precision protocol on the National Transportation Communications for ITS Protocol (NTCIP).

However, representation for pedestrians who are blind or have low vision helped us realize that the audible tones and messages that accessible pedestrian systems (APS) employ have the same required degree of integrity as do the visual walk and wait signal for those with good visual acuity. The microprocessors that are currently used in APS that controls what audible message the pedestrians hear are based upon sensors in the pedestrian signal heads. This alone represents a lapse in observability by the CM or MMU that can result in playing the incorrect audible message thus putting a visually impaired pedestrian at risk.

Because of the risk to blind and visually impaired pedestrians that is not being addressed by current industry designs, the research for the 2008 – 2009 project was initiated to develop an advanced accessible pedestrian system (AAPS) based upon Smart Signals technology where the audible messages can be verified and then provide an indication to the traffic system MMU or CM. One of the specific objectives of this research effort was to identify an established manufacturer of pedestrian signal systems and secure their commitment in helping us to get one or more AAPS installed in a public intersection. The industry partner would help us to establish a set of specifications that are progressive in promoting public safety and accessibility through advanced features and enhanced reliability while keeping system costs for installation and maintenance at or below the costs of existing APS installations.

Our success in meeting these goals can be measured by the number of publications, patent applications, acquiring of additional external funding, students graduating with advanced degrees and the devices developed for installation on public streets. We are currently working with Campbell Company of Boise, ID, a well known manufacturer of pedestrian systems and APS stations. This company has supplemented our research effort with funding and employed a graduate student at their facility during the summer of 2009. Two patents have been applied for in the area of AAPS and APS based on Smart Signals technologies. Two graduate students, who worked on this project, received their Master of Science degrees in Computer Engineering in May of 2009. Their work is currently being continued by two graduate and two undergraduate Electrical Engineering students. Last year, we presented a paper at the 2009 Transportation Research Board (TRB) meeting that was accepted for the TRB record. Presentations have been made at regional workshops for industry practitioners and meetings for educators of the blind and disabled.

Finally, our research has resulted in the development of a new generation of Smart Signals pedestrian controls that meet the newest APS guidelines and have extensible capabilities for features not considered at this time. The system began beta production in October 2009 and is scheduled for beta site installation in February 2010. Based upon the reaction to previews of the

AAPS at industry trade shows and presentations at meetings for traffic professionals, the suggestions for enhancements seem endless. Our research for the next year is in the area of improved reliability to the extent that the Smart Signals research can begin to be applied to all traffic signal devices. The industry acceptance of this revolutionary technology has been slow and rightfully so because of the risk to life and property because of an undetected system failure.

The discussion of the development of the AAPS is presented in three areas: system operations and functionality, the communication approach to support the distributed control approach, and the electronic hardware needed to implement the control algorithms and communications. The AAPS description is designed to inform the reader of not only the present AAPS capabilities, but the kind of expansion capabilities possible in a software centric system. Although the detailed descriptions of computer code and algorithms are beyond the scope of this report, this information will be available in the form of theses for master’s degrees to be awarded in the summer of 2010.

Our future research will continue to look at new ways the Smart Signals technology can improve traffic safety, efficiency, and accessibility. But our main research will be to make certain that what we are doing now represents the lowest risk, the highest availability of service, and the greatest economic benefit. We will develop testing procedures and, if necessary, develop new hardware for testing Smart Signals to assure those responsible for installing, maintaining, and operating Smart Signals based traffic controls are of the highest reliability and dependability.

Table 1: Definitions of Acronyms

Acronym	Definition
APS	Accessible Pedestrian Signal
AAPS	Advanced Accessible Pedestrian Signal
APB	Advanced Pedestrian Button
APC	Advanced Pedestrian Controller
AAPMS	Advanced Pedestrian Management System
BPL	Broadband Power Line
CGI	Common Gateway Interface
CM	Conflict Monitor
dbeacon	Destination Beacon
DW	Don't walk
EoP	Ethernet over Power line
EP-APS	Extended press activated APS
FDW	Flashing Don't Walk
FTP	File Transfer Protocol
HMI	Human Machine Interface
HTML	Hypertext Markup Language
IETF	International Engineering Task Force
ibeacon	Initiation Beacon
IP	Internet Protocol
ITS	Intelligent Transportation Systems
LAN	Local Area Network
MIB	Management Information Base
MMU	Malfunction Management Unit
MUTCD	Manual for Uniform Traffic Controller Devices
NTCIP	National Transportation Communications for ITS Protocol
OID	Object Identifier
PCM	Pulse-Code Modulation
PDU	Protocol Data Unit
SDLC	Synchronous Data Link Control
SNMP	Simple Network Management Protocol
TCP	Transmission Control Protocol
UDP	User Data Protocol
W	Walk
WAN	Wide Area Network

DESCRIPTION OF PROBLEM

Initially, the Smart Signals research focused on traffic signal devices that used network based distributed control technology with plug and play capability. An advisory board was soon established consisting of traffic signal designers from industry, state and federal traffic engineers, academic researchers, and pedestrian advocacy groups including the Federation for the Blind. Their input was solicited to help guide and direct our research effort as the Smart Signals technology revolved and matured. As a result of the first advisory board meeting, the Smart Signals research directed its attention to the deficiencies in the pedestrian signal and operations. Three major areas for improvement were identified: The consistency and accuracy of countdown pedestrian timers; pedestrian button failure modes that cannot be detected by the traffic controller, MMU or CM; and the inability to adequately serve the visually impaired and mobility handicapped pedestrian community.

In 2006, a team of electrical and computer engineering graduate and undergraduate students successfully demonstrated that a countdown pedestrian timer based on Smart Signals technologies can effectively maintain an accurate time for a wide range of traffic signal operating conditions. These include emergency and transit vehicle preemption, as well as, different time-of-day traffic signal timing plans.

In 2007, based on the advice of our advisory board, the Smart Signals researchers developed a distributed control network based on the NTCIP. This research resulted in a new pedestrian signal distributed around an intersection that is a logical extension for the computer program running in the traffic controller on the street corner.

The traffic controller’s timing plans allow either exclusive pedestrian movements (no vehicle traffic is permitted to enter the intersection) or concurrent parallel pedestrian and vehicle movements. Historically, pedestrians indicate to traffic controllers that they are requesting a walk signal to cross at signalized intersections by activating a mechanical switch. The mechanical switch is commonly called a pedestrian button and usually completes an electrical circuit that connects the conductor wire to the designated pedestrian input of the traffic controller to the ground or common potential.

Conventional pedestrian signals have three states of operation, Don’t Walk (DW), Walk (W), and Flashing Don’t Walk (FDW). The normal sequence of events when a pedestrian activates the pedestrian button is as follows; the traffic controller indicates the start of the pedestrian phase by illuminating the Walk signal. The Walk interval is typically on the order of seven seconds and can be truncated or terminated by several processes such as a preemption condition. The Walk time is just enough to get the pedestrian started across the intersection.

After the Walk interval, the pedestrian signal flashes the Don’t Walk signal on and off during the pedestrian clearance or change interval. (Wording of Section 4E.05 of the 2009 MUTCD changed the FDW from “pedestrian clearance” to “pedestrian change” interval.) The Flashing Don’t Walk (FDW) interval is based upon the length of the cross walk and the assumed pedestrian walking speed. The FDW interval terminates with a solid Don’t Walk signal. The FDW and DW intervals are fixed unless manually changed in the timing database and are at this time never modified dynamically.

For exclusive pedestrian movement operations, the timed intervals of the W, FDW and DW intervals are fixed. For pedestrian movement schemes that allow parallel vehicle movement, the maximum time of the W plus FDW intervals must be no longer than the displayed vehicle green time. In the event that the minimum green time for the parallel traffic movement is shorter than the pedestrian times, the signal will simply rest in green following the termination of the minimum green interval until the pedestrian intervals time out. [1]

There are two types of audible indications for pedestrian signals: tones of a particular frequency and interval and speech messages. Although there are currently no specific audible tones or messages required for APS, Section 4E.06 of the Manual for Uniform Traffic Controller Devices (MUTCD) specifies that when accessible pedestrian signals have an audible tone(s), they shall have a tone for the walk interval. The content of the audible informational message can vary depending upon the needs of the location where the APS is installed. The audible message types and vibrotactile nonvisual indicators are identified in the Accessible Pedestrian Signals Guide for Best Practices. [2].

Modern APS systems have an extensive set of features to assist the pedestrian regardless of their visual acuity. Locator tones help pedestrians find the button. Information concerning the geometry of the intersection is available by pressing the pedestrian button for an extended period of time. Beaconing is possible to assist low-vision pedestrians to the destination sidewalk.

The state or condition of the pedestrian signals and the pedestrian button must be known for the APS to play the proper tone or speech message. Typically, some of electronics needed to implement an APS system is physically located in the pedestrian signal. From this location, the system derives its power from the voltage used to power the pedestrian displays. A conduit containing the necessary conductors must be routed from the pedestrian signal to where the button is located. Usually, the conductors for the pedestrian buttons are routed separately back to the controller.

As previously discussed, for a low-vision pedestrian, the audible messages have the same safety and traffic control authority as do lighted signals for pedestrians with adequate vision and vehicle operators. Traffic control systems incorporate a conflict monitor (CM) or malfunction management unit (MMU) that independently monitors all traffic controller signal outputs. If the CM or MMU detects that the signal outputs generate conflicting traffic movements, all traffic signals flash red and all pedestrian signals are turned off. The premise of the CM and MMU is that the state of all signals is determined by the outputs of the load switches controlled by the traffic controller. Possible failures are limited to conductors shorting to ground or to another conductor or becoming an open circuit. To the extent possible, the load switches are designed to detect these types of failures.

Today’s APS systems operate unsupervised. A review of manufacturers of APS systems shows that APS systems usually use a microprocessor to detect the state of the pedestrian signals and determine the appropriate audible message to play. Such decisions are beyond the observation coverage by the CM and MMU. Present APS systems operate in an open loop fashion. Once the signal control lines leave the controller cabinet, there is no feedback from the signal other than the amount of load current. Hence if the microprocessor malfunctions and plays the incorrect audible message that indicates a walk signal is on when, in reality, there exists a conflicting traffic movement thus resulting in a safety hazard.

The pedestrian button is also unobservable. There are two possible failure modes: permanently open and permanently shorted. The first case results in the pedestrians not being able to request service and for the second case, a permanent call is placed on the controller. In either event, the failure is only detectable by public complaint or intersection inspection by maintenance personnel.

APPROACH AND METHODOLOGY

An advanced APS (AAPS) was designed to address many of the issues uncovered in the paragraphs above by providing an extensible software and hardware platform using network-based distributed control technologies. The network approach makes use of the fact that microprocessors are already required to implement the complex control needed to play different audio messages depending upon pedestrian signal status and the operation of pedestrian buttons. Using distributed processing architecture, such as the one shown in **Figure 1** representing the AAPS, allows bidirectional communications to exchange information relating to operating controls and possible failure modes. Ethernet is chosen for the communications because of its high bandwidth, widespread use in industrial controls and the availability of low cost hardware.

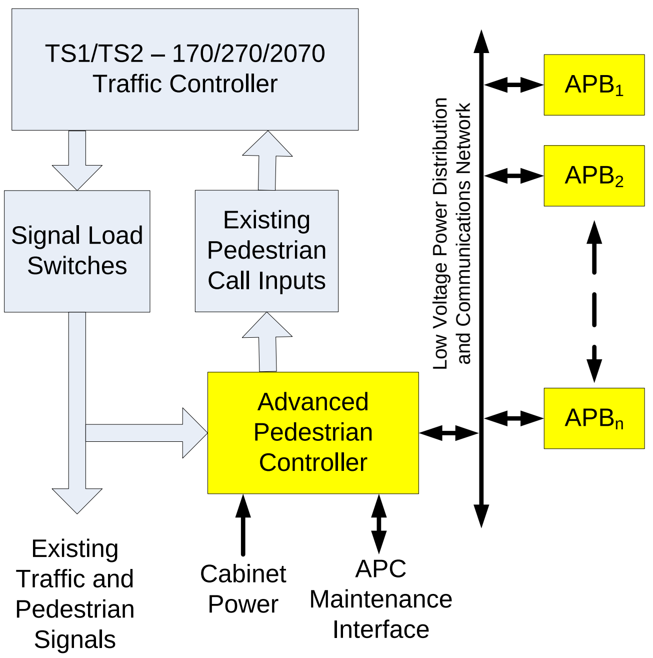


Figure 1: AAPS system block diagram.

The interface between the AAPS and the traffic controller cabinet is presently limited to detecting the pedestrian signal state and placing pedestrian calls by direct connection to the cabinet field terminals. Although this is not the most cost effective interface from an installation perspective, the direct wire interface does make the AAPS compatible with a vast majority of traffic control cabinet designs including NEMA TS1 and TS2 controllers and ATC model 170 and 2070 controllers.[3,4].

Although some of the operating features will be described in sections to follow, the hardware to support the AAPS is highly scalable in both number of pedestrian buttons and the modes of operation. The basic hardware and software are the result of research into application of distributed systems concepts at the University of Idaho that has been reported on starting in 2006 [5,6,7]. It is customary in present pedestrian controls to parallel the inputs that control a common set of pedestrian signals. Using a distributed approach, each pedestrian button is uniquely distinguishable enabling the use of beaconing on one side of an intersection only.

The AAPS will be presented by focusing on three areas: operations and capability, communications and information, and hardware design. The AAPS operations and capability is a snap shot at one point in the development as the features are added to accommodate the needs of specific traffic agencies. One of the significant qualities of the software centric distributed processing based architecture is the ability thus far to accommodate the numerous revisions we have been able to incorporate to date.

AAPS Operations

As previously described, there is a real-time control operations and near real-time supervisory operations. The supervisory operations dictates how the AAPS is to operate based upon the selection of options and configuration parameter values. Once the hardware has been installed, all setup or tuning operations are completed by the Ethernet interface with the APC. The real-time control operations will be discussed after the supervisory operations are described.

AAPS Supervisory Operations

All AAPS programmable configuration is completed using a web interface. The computer used for maintenance and servicing does not require proprietary software; only a standard web browser such as Internet Explorer®, Google Chrome®, or Mozilla Firefox®. The maintenance and setup of the system uses web based controls through a web page that is hosted by the APC single board computer.

The Advanced Accessible Pedestrian Management System (AAPMS) web page is organized into an upper frame with fixed content and a bottom frame with variable content. The web page organizes the data into three types: system operational status, configuration settings, and log files. Status information includes the state of APC inputs and outputs as well as the state of all

APBs. Configuration settings are organized into two types: system wide and APB specific settings. The contents of the various web pages will be discussed in detail to provide a systematic approach to describing the functionality and capability of the AAPS.

AAPS Supervisory Operations - Status and Real-Time Monitoring

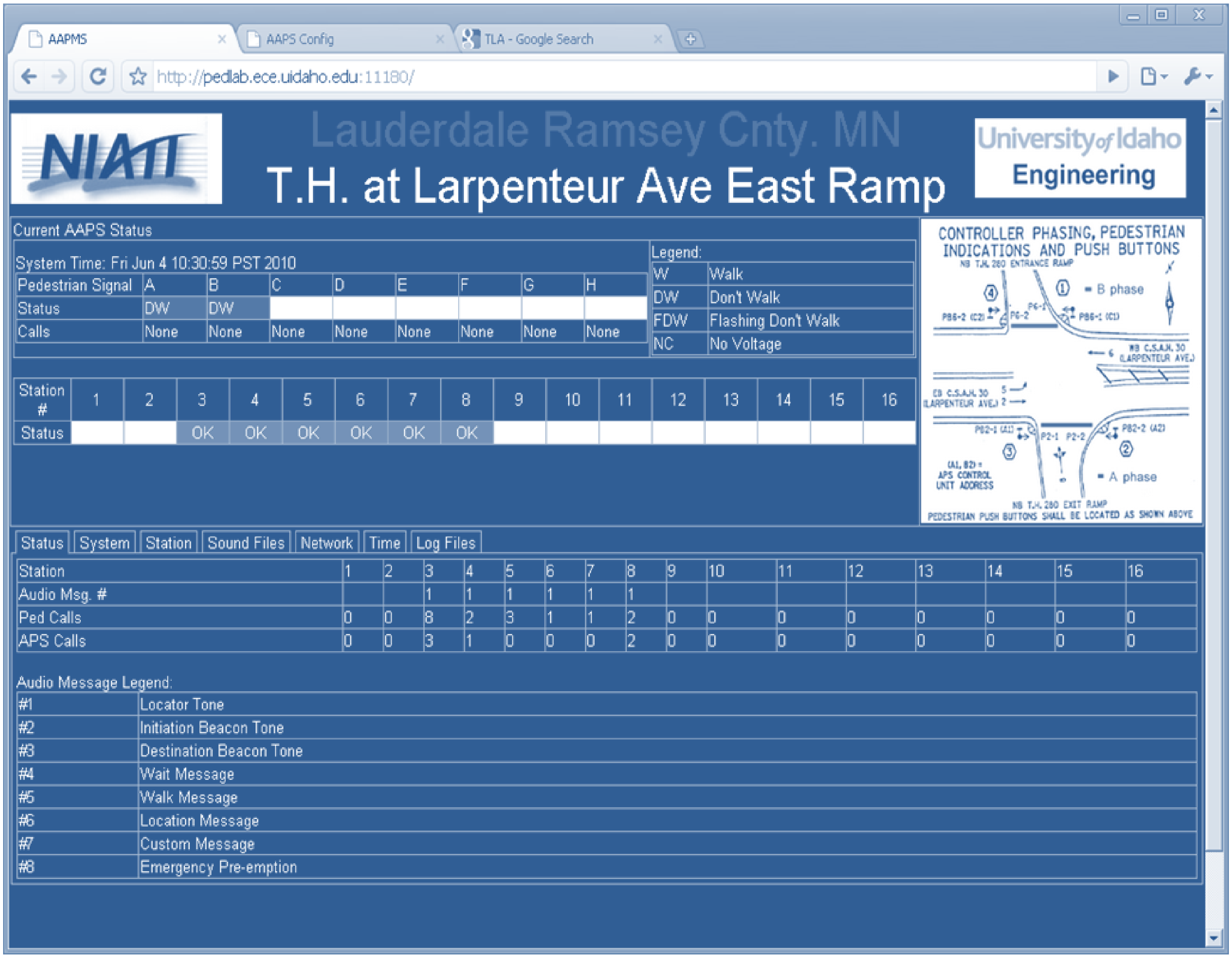
Figure 2 is a screen capture of the default web status page. The top frame of fixed content presents system real-time status information of the pedestrian signals and pending pedestrian calls waiting to be serviced. The pedestrian signal status line shows the state of the pedestrian signal phases that are labeled A through H. Lettering the pedestrian phases on the AAPMS web page eliminates confusion with the traffic controller phase assigned to the specific pedestrian signals. Correlating the AAPS pedestrian phases and the traffic controller phases is completed in software as well as wiring of the AAPS to the cabinet field terminals. For each AAPS phased A through H, there are two conductors that are used to sense the on/off state of the 120VAC load switches for the pedestrian signals associated with traffic phases.

Most traffic controller installations parallel the pedestrian button inputs such that multiple pedestrian stations place a call on a single pedestrian phase. AAPS pedestrian stations have unique network identification and the calls to the traffic controller must implement the parallel or logic *OR* operation in software. Configuring the system that associates groups of pedestrian buttons to a specific pedestrian call to the traffic controller is discussed below.

The status portion of the AAPMS also indicates what type of activation was used to generate the call that is awaiting service if any. To the right of the signal and pedestrian call status lines is a legend to explain the abbreviations used in the Signal Status boxes to help make the web page self-documenting. The graphical picture to the right of the legend boxes is a diagram of the intersection that illustrates the association of pedestrian stations number one through sixteen with the pedestrian signal phases lettered A through H. The procedure for changing this diagram will be discussed later in this document.

The real-time operating condition of each active button is established by communications between the APC and each APB at a rate of four times each second. The text in the fields associated with each pedestrian station will indicate “OK” if the station is functioning properly or “BAD” if there is no or incorrect communications with the station. Inactive stations are blank or shaded white and contain no text. **Figure 2** shows the case when only stations three through eight are configured to be part of the system for this application of the AAPS.

A constant call is asserted on the phase associated with pedestrian stations that are detected as nonfunctional. Calls on all phases are placed on the traffic controller should the APC become inoperative. APS that loose communications with the APC will reset to a benign non-functional state until communications are re-established with the APC.



Lauderdale Ramsey Cnty. MN

T.H. at Larpenteur Ave East Ramp

Current AAPS Status

System Time: Fri Jun 4 10:30:59 PST 2010

Pedestrian Signal	A	B	C	D	E	F	G	H
Status	DW	DW						
Calls	None	None	None	None	None	None	None	None

Legend:

W	Walk
DW	Don't Walk
FDW	Flashing Don't Walk
NC	No Voltage

Station #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Status			OK	OK	OK	OK	OK	OK								

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Audio Msg. #			1	1	1	1	1	1								
Ped Calls	0	0	8	2	3	1	1	2	0	0	0	0	0	0	0	0
APS Calls	0	0	3	1	0	0	0	2	0	0	0	0	0	0	0	0

Audio Message Legend:

#1	Locator Tone
#2	Initiation Beacon Tone
#3	Destination Beacon Tone
#4	Wait Message
#5	Walk Message
#6	Location Message
#7	Custom Message
#8	Emergency Pre-emption

Figure 2: AAPS system status web page.

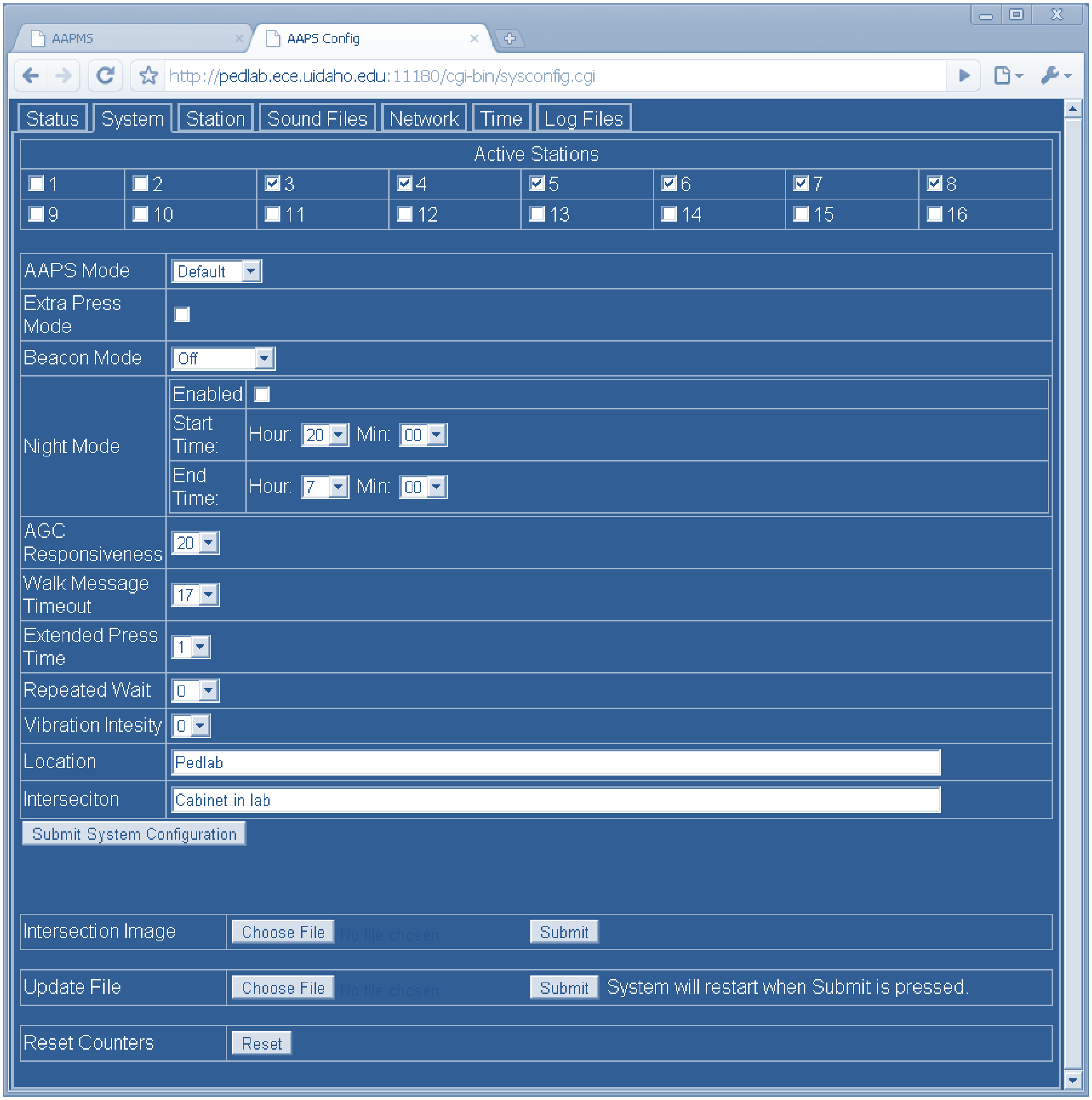
AAPS Operations – Pedestrian Station Operational Status

As stated above, the lower portion of the web page has variable content that is selected using the row of seven tabs. **Figure 2** shows the contents when the *Status* tab is selected displaying the operational status of the individual pedestrian stations showing the pedestrian station operational mode and activity history. The “Audio Message #” line displays a number associated with the audible message that is currently being played at each active pedestrian station. A legend that explains the audible message numbers is shown at the bottom of the screen.

The data shown on the Ped Calls and APS Calls line is a running count of the number of calls placed at the associated pedestrian stations. Although the AAPS can be programmed to do so, at the present, there is no difference in the output signal to the traffic controller between normal pedestrian calls and APS pedestrian calls produced by an extended press (EP-APS).

AAPS Operations – System Configuration

Besides the system *Status* frame, there are six other display options for the contents of the bottom variable content frame of the service page: *System* (configuration), *Station* (configuration), *Sound Files*, *Network* (properties), *Time* (configuration), and *Log Files*. Figure 3 shows the content of the system configuration. These settings are used to select the operating modes for the APC and those APB options that are common to all stations.



Active Stations

☐ 1	☐ 2	☑ 3	☑ 4	☑ 5	☑ 6	☑ 7	☑ 8
☐ 9	☐ 10	☐ 11	☐ 12	☐ 13	☐ 14	☐ 15	☐ 16

AAPS Mode	Default	
Extra Press Mode	☐	
Beacon Mode	Off	
Night Mode	Enabled	☐
	Start Time:	Hour: 20 Min: 00
	End Time:	Hour: 7 Min: 00
AGC Responsiveness	20	
Walk Message Timeout	17	
Extended Press Time	1	
Repeated Wait	0	
Vibration Intesity	0	
Location	Pedlab	
Interseciton	Cabinet in lab	

Intersection Image	
Update File	System will restart when Submit is pressed.
Reset Counters	

Figure 3: System configuration page.

Configuration settings of the AAPS on the AAPMS web page are submitted using URL encoded data. When the user submits configuration data via the AAPMS web page, a CGI scripts parses the URL encoded data and processes it accordingly. First, the APC parses the incoming data and saves it to non-volatile memory so that it will be retained during a power loss or system restart. Then, the configuration data is applied to the different parts of the AAPS. For APC specific configurations, the appropriate services are restarted, allowing them to re-read their specific configuration files.

The series of sixteen boxes is used to select the stations that will be active as indicated by a check in the box. Only the active stations can place a call and will play audible messages. Previously active stations can be made inactive by clearing the check box. Adding a new station to an AAPS requires the appropriate box to be first checked followed by a station configuration as described below.

The AAPS Mode drop down box configures the system to operate in one of four modes as described in Table 2. The *Ident* or identification mode is used for maintenance and installation only to help verify that the pedestrian stations are installed in the correct physical locations. If needed, the pedestrian stations can be configured differently after installation. The AAPS mode must be placed in one of the other three modes before calls can be placed to the traffic controller.

The Off mode causes the pedestrian stations to operate with no APS capability. For the default and EP APS modes, there are two optional features: extra press and beaconing. The extra press feature automatically places a second call after servicing the call just placed. This feature accommodates pedestrians who have difficulty getting into a position on the sidewalk to initiate their crossing during the first Walk interval. There are two different beaconing modes: target and ping-pong. Target beaconing plays a beacon tone at the destination end of the crosswalk. The ping-pong mode alternately plays a beacon at the destination and imitation ends of the crosswalks.

Table 2: AAPS Operation Modes

AAPS Mode	Description of Operation
Off	System function with no APS features
Default	System functions as a conventional APS: audible messages are confined to the locator tone as well as the wait, and walk messages
EP APS	Systems functions the same as the default mode except a location messages is played after an extended button press.
Ident	This is a maintenance mode only. The button LED repeatedly flashes the number of times associated with the station number that it has been assigned when configured.

In regards to noise pollution, the AAPS is capable of implementing a Night Mode operation where the audible volume of the locator tone and speech messages can be adjusted to accommodate both pedestrians and nearby residences and/or businesses. This option is enabled on the system configuration web page as well as the active hours for night time operation. Table 3 defines five additional operating parameters for the AAPS. The automatic gain control (AGC) responsiveness sets how quickly the volume is adjusted in response to a change in ambient audible noise or interference.

The Walk Message Timeout specifies the duration of the walk message regardless of how long the pedestrian walk signal is displayed. This setting is used for crosswalks that are served by a rest-in-walk intersection operation where the pedestrian signal normally displays a walk condition. The Walk Message Timeout terminates the audible walk message while the traffic system is in the resting walk state unless initiated by a pedestrian button press. The locator tone plays whenever the walk message is not playing.

The Repeated Wait setting indicates the delay time between wait messages that will be played after the button is pressed while waiting for the walk signal. A value of zero indicates that the wait audible message will be played only once each time the button is pressed.

Vibration Intensity allows the drive to the vibrotactile motor to be adjusted between zero which corresponds to off to full intensity. For some installations, the mechanical vibrations are amplified through resonance with the mounting structure and decreased motor drive is appropriate.

Table 3: System Operating Parameters

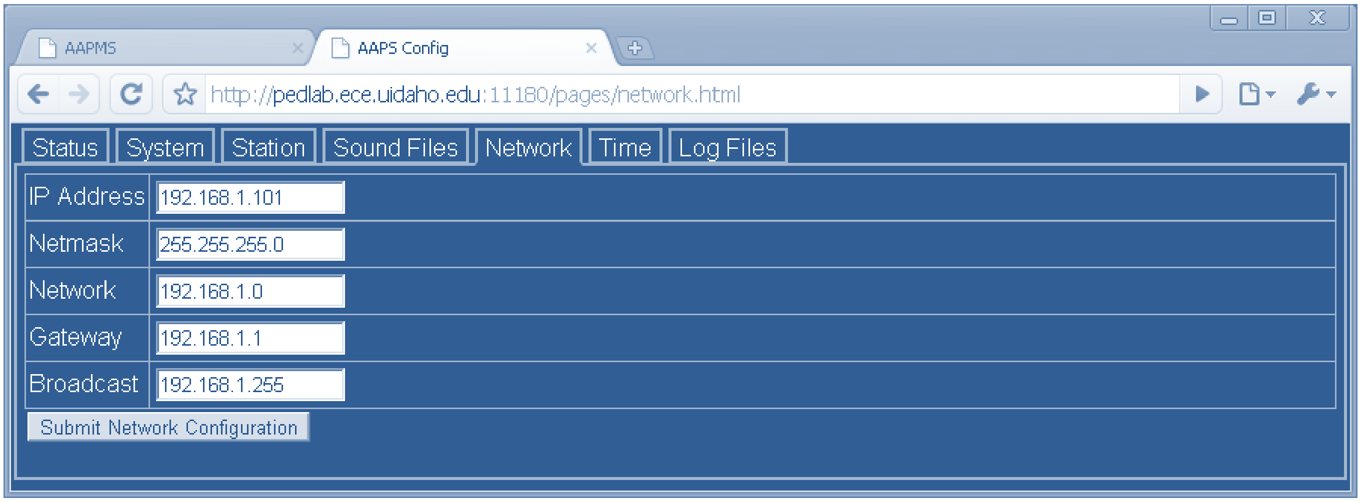
Configuration Parameter	Description
AGC Responsiveness	Set the speed of volume adjust for changes to ambient audio noise. The range is from 0.1 seconds to 2 seconds.
Walk Message Timeout	The length of time the walk message is played.
Extended Press Time	Time the button must be pressed to activate the EP APS mode.
Repeated Wait	The delay time in seconds between playing an audible wait message.
Vibration Intensity	The intensity of vibration of the vibrotactile pedestrian button.

The Location and Intersection text boxes allow one to change the text that is displayed in the upper fixed content web page. Any changes to the system configuration down to this point will not be recorded unless the Submit System Configuration button is clicked on.

The graphical image shown in the top right of the web page is downloaded from the computer viewing the web page to the AAPS server by first clicking on "Choose File" and navigating to the file location followed by clicking on the submit button.

Selecting the "Reset" button on the Reset Counters line causes all of the station call counters displayed on the Status web page to be reset to a count of zero.

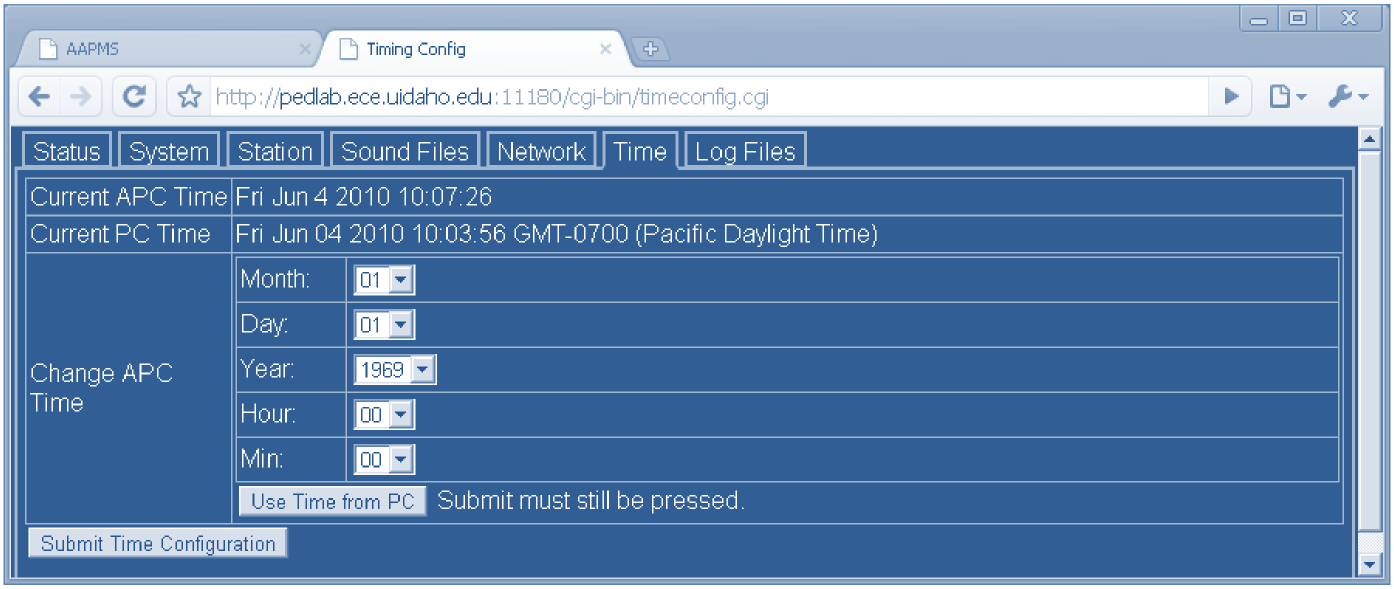
Figure 4 and Figure 5 show web pages that are also associated with the system configuration. If the AAPS is not connected to a WAN but directly to a PC or laptop computer, the default network settings need not be changed. Additionally, direct connection with the AAPS Maintenance port does not require a crossover Ethernet cable as the APC automatically makes the appropriate connection. When connecting to a WAN, some or all entries on the Networking page may require modification. These changes should only be completed by persons knowledgeable of the WAN requirements.



IP Address: 192.168.1.101
Netmask: 255.255.255.0
Network: 192.168.1.0
Gateway: 192.168.1.1
Broadcast: 192.168.1.255

Figure 4: System network properties page.

Figure 5 provides two methods for setting the real-time clock internal to the APC. The time can be specified by completing the text boxes or by clicking on the "Use Time from PC" box. The later method copies the PC time into the text boxes. Using either method, the "Submit Time Configuration" button must be selected before the changes are transferred to the APC.



Current APC Time	Fri Jun 4 2010 10:07:26
Current PC Time	Fri Jun 04 2010 10:03:56 GMT-0700 (Pacific Daylight Time)
Change APC Time	Month: 01 Day: 01 Year: 1969 Hour: 00 Min: 00 Use Time from PC Submit must still be pressed.

Figure 5: System time setup page.

AAPS Operations – Station Configuration

There are two web pages associated with configuring the individual pedestrian stations. The first web page configures the individual station to be integrated into the system. The second web page provides the capability for each individual pedestrian station to play up to eight unique audio files associated to specific pedestrian movements. These parameters contained in these two pages must be completed for every pedestrian station.

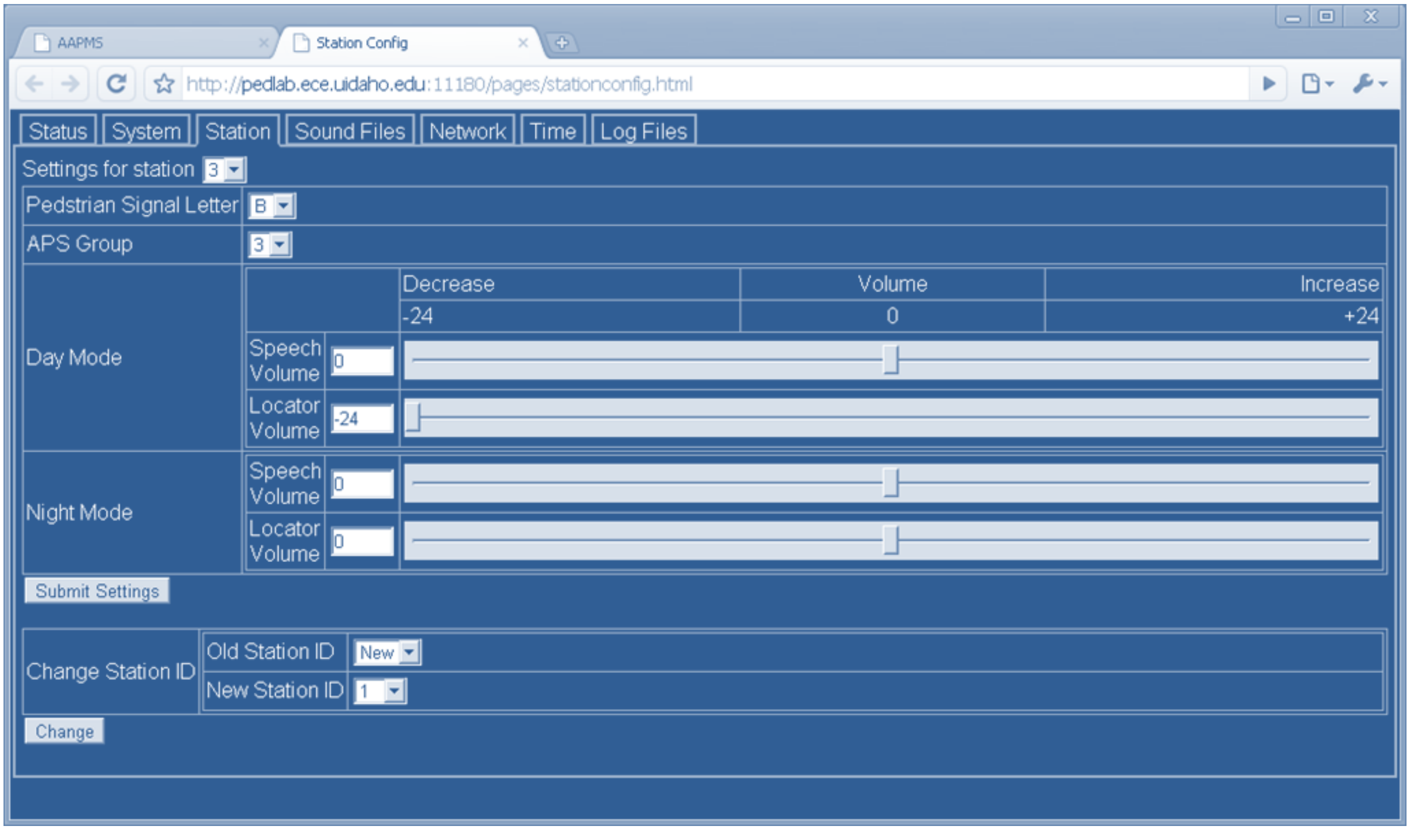
APB configuration options are handled much differently than system configurations. First, the APB's receiving new configurations are placed into a mode in which they are operable only at the basic level, i.e.as a plain button. This is done so that as new configurations are loaded, button operations are not affected. Next, the new configuration for that button is sent using the simple network management protocol (SNMP) that will be discussed later in this report. Upon a successful reconfiguration of the APB, it is placed into the received configuration.

AAPS Operations – Station Operating Parameters

Figure 6 provides the interface with the AAPS to configure an APB for a specific installation. Each station is assigned a unique identification number between one and sixteen and a signal phase that is used to determine the status of the pedestrian signals as well as the pedestrian call to activate whenever a button is pressed. The APS group parameter associates pedestrian stations that use common signal and call phases and must operate as pairs for beaconing.

The message and locator tone volumes of each station is set for both daytime and nighttime operation (if used). The setting of zero corresponds to an audio level of 5db above ambient noise level. Other values indicated on the volume scale are relative indications for reference only. The “Submit Settings” button must be selected before the configurations will be sent to the pedestrian station shown on the top line of this frame.

When changing the pedestrian station identification number or when first configuring a pedestrian station that has not been previously configured, the “Change Station ID” fields must be specified. If the station has never been configured, the “Old Station ID” defaults to a value that is identified by the text “New” that corresponds to a station ID of zero. Unless a pedestrian station has been configured for an ID value between one and sixteen, no other parameters will be accepted. Since all APBs have the same default identification number prior to configuration, only one new station can be connected to the system at a time.



Settings for station 3

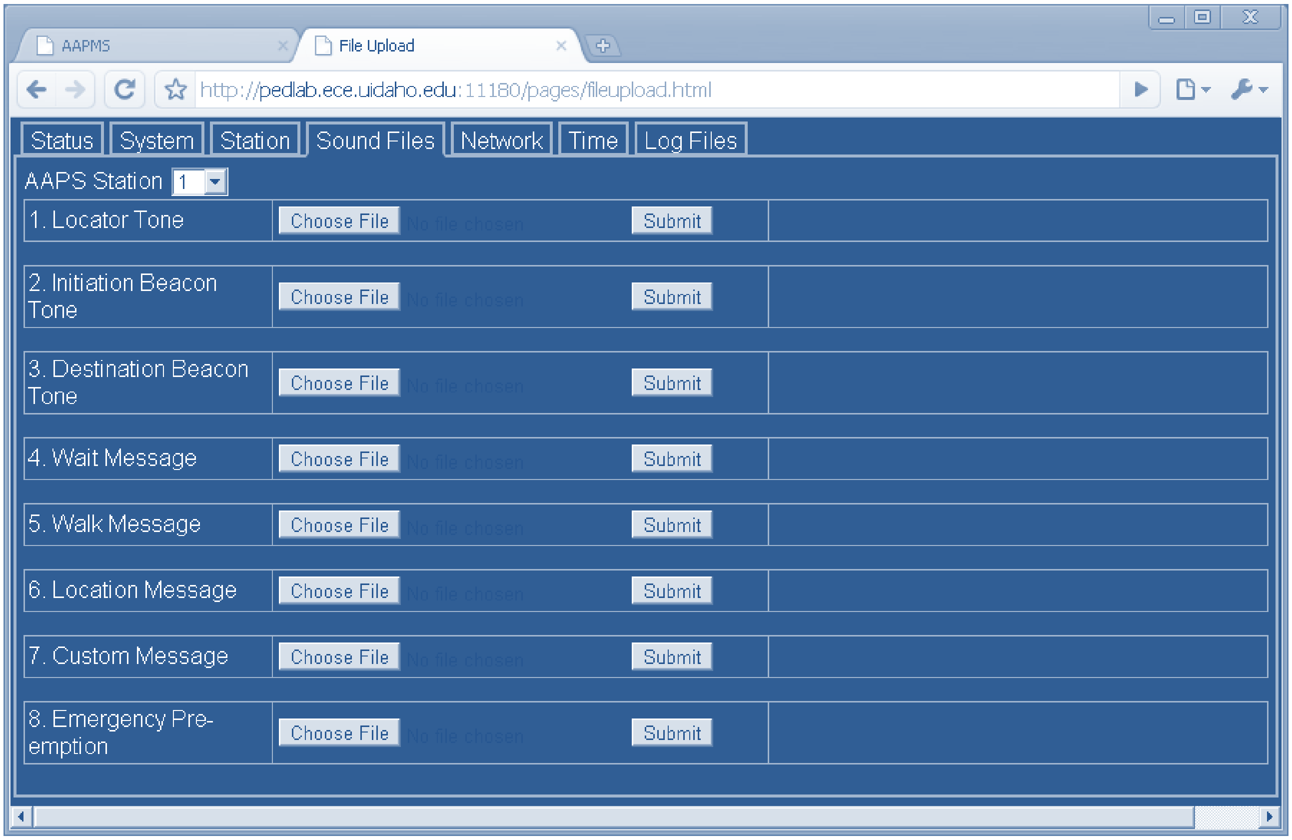
Pedstrian Signal Letter	B			
APS Group	3			
		Decrease -24	Volume 0	Increase +24
Day Mode	Speech Volume	0		
	Locator Volume	-24		
Night Mode	Speech Volume	0		
	Locator Volume	0		

Change Station ID	Old Station ID	New
	New Station ID	1

Figure 6: Station control page.

AAPS Operations – Audio File Management

Audio files are generated and stored on the service computer as “.wav” files. The files are transferred to the APC one at a time using the web link page shown in **Figure 7**. After receiving each audio file, it is passed on to the specified APB using the file transfer protocol (FTP). FTP uses the TCP/IP stack and creates a file system in the APB processor nonvolatile memory space. Each file has a unique name that must match for the file to be played. These file names correspond to the message that is being saved. The file names are wait, walk, location, locator, initiation beacon tone (*ibeacon*), and destination beacon tone (*dbeacon*). In addition, there are preempt and custom audio messages.



http://pedlab.ece.uidaho.edu:11180/pages/fileupload.html

AAPS Station 1

1. Locator Tone	Choose File No file chosen	Submit	
2. Initiation Beacon Tone	Choose File No file chosen	Submit	
3. Destination Beacon Tone	Choose File No file chosen	Submit	
4. Wait Message	Choose File No file chosen	Submit	
5. Walk Message	Choose File No file chosen	Submit	
6. Location Message	Choose File No file chosen	Submit	
7. Custom Message	Choose File No file chosen	Submit	
8. Emergency Pre-emption	Choose File No file chosen	Submit	

Figure 7: Sound file entry page.

The AAPS uses sound files in an 8bit 8 kHz pulse-code modulation (PCM) format. The sampling rate and data word size is chosen as a balance between sound quality and file size. The human voice contains frequencies that are primarily less than 4 kHz. Therefore, the 8 kHz sampling rate is fast enough to capture human speech according to the Nyquist-Shannon Sampling Theorem [8]. Eight data bits is the smallest word width in the PCM format but supplies enough resolution to reproduce recorded speech. PCM was chosen because it requires the least amount of processing by the device playing the sound. In PCM, the amplitude of the sound is recorded directly. Therefore, the only processing required for playback may be volume control. With 8 bit, 16 kHz PCM audio, it ultimately requires 16kB of nonvolatile memory on the APB to store one second of recorded audio.

Audio files are transferred to the APC using HTML multipart/form-data [9]. In this form, the sound file and other fields of the form are packaged and sent to the APC web host and processed by a common gateway interface (CGI) script. There are five fields sent to the APC web host: *stationid, fileid, resid,* the sound file, and the *submit* field. The *stationid* field is what APB the user selected to send the audio file to. *Fileid* is the number identifying which file is being sent. *Resid* is a text string used by the AAPMS web page to notify the user of the status of each file transfer. The *submit* field is the value of the parameter associated with the corresponding submit button that was pressed. In the multipart-form transfer, each field is separated by a field boundary. The boundary is browser and content specific and specified in the content header of the transfer.

When the APC receives the HTML form data transfer, the first step is separating each field along its boundary and storing the contents of each in the appropriate place. The AAPMS web page is then notified about the file transfer. If the audio file was not in the correct format or the file or station identification numbers are not valid, the web page notifies the user. Next, the sound file is processed. To prepare the sound files for transmission to the APBs, the APC strips all of the file information from the file to reduce the memory requirements. The resulting binary information is only the PCM binary data. This file is then sent to the APB specified by *stationid* as file *fileid.* At the beginning of the file transfer, the APB is placed into a silent mode so that no audio files are accessed during a file upload. Upon a successful transfer, the AAPMS web page displays a confirmation message to the user.

AAPS Operations – Fault Detection and Recovery

Fault detection for conventional pedestrian buttons is limited to “stuck-on” failures. “Stuck-off” failures are detectible only by monitoring the number of pedestrian calls to the traffic controller over a period of time. Failure detection for pedestrian controls is one of the major innovations of AAPS.

Being a distributed processing system, failures can occur at each of the APB installations and at the APC in the traffic controller cabinet. The distribution of information is critical to correct operation. Each APB expects a packet of information from the APC each 250ms. Any APB that miss two successive packets from the APC will go into fault operation where all audible messages are terminated and no calls are sent to the APC should the button be pressed while in this mode. An APB that is operating in the fault mode continues to listen for packets from the APC and if communications is restored, the APB resumes normal operation.

Each time the APC sends a packet to an APB, an immediate response is expected. The APB response packet contains information regarding the current activity of the APB including the number of the audible message being played. The organization of the audible messages is such that only certain audible messages are compatible with a given set of pedestrian signal states. The compatibility mapping illustrated in **Table 4** is checked in a manner similar to the programming card in a conventional MMU or CM. For each station, a parameter containing the message ID is sent to the APC. The current state of the pedestrian signal phase is logically tested using a logical AND operation in the computer program. If the result is zero or logical FALSE hence a system failure is detected. For example, the Wait message is only compatible with the FDW and DW pedestrian signal states as noted by the value of one in those columns.

Table 4: AAPS Malfunction Compatibility Table

ABP State		Pedestrian Signal State			
Message	ID	W	FDW	DW	PreEmpt
Locator	1	1	1	1	0
Ibeacon	2	0	1	0	0
Dbeacon	4	0	1	0	0
Wait	8	0	1	1	0
Walk	16	1	0	0	0
Location	32	0	1	1	0
Custom	64	0	0	0	0
Preempt	128	0	0	0	1

If this response is not received, the failure is logged and the web page updated to identify which APBs have failed to communicate. Additionally, a constant call is sent to the traffic controller on the phase that the particular APB has been configured. Should the APC loose power or fail to reset properly, constant calls are placed on all call output to the traffic controller. The APC and all APBs are programmed to fail in the safest output state and continually attempt to restore the system to full operation. There is no direct interface between the AAPS fault detection and the traffic controller CM or MMU.

NETWORK COMMUNICATIONS

The AAPS is designed around a distributed processing architecture and two independent Ethernet based networks: the real-time operations network and the supervisory network. The supervisory network uses a web based human-machine interface that operates in near real-time for indicating system status and supports making configuration changes to the AAPS. This network that is depicted as the *APC Maintenance Interface* in Figure 1 can connect directly to a PC or laptop, or it can connect remotely over a wide area network (WAN) infrastructure.

The real-time operation also uses Ethernet technology to implement a local area network (LAN). The LAN provides communications for sending the pedestrian signal status sensed by the APC to all active pedestrian stations, detecting failed pedestrian stations, and relaying pedestrian calls to the traffic controller whenever a pedestrian button is pressed. The real-time network uses a protocol that is structured following the NTCIP guidelines. The LAN is also used in a non-real-time mode for configuring individual pedestrian stations during setup and maintenance.

System Operations – Communications

Since the AAPS is a standalone system and operates on an isolated network, any network protocol could have been used. In order to allow future integration with NEMA TS2 traffic controllers, we chose to implement the AAPS using NTCIP. We recognized that many of the objects we needed are not included in the NTCIP 1202 guide, and hence we developed a specific set of objects which are described below [10,11,12]. A significant portion of the communications protocol used to implement the AAPS is based upon work reported on by Devoe, et.al. [13].

It is recognized that NTCIP was developed to provide supervisory level communications between a traffic control center and traffic controllers at the intersection. As noted by Paul Olson from FWHA in private communications, “NTCIP has not been defined or otherwise targeted to communications between the traffic signal controller and any devices within the cabinet and field devices. This has a significant impact on this paper as it is a totally new approach to the traffic signal controller/cabinet architecture.”

Ethernet Implementation to support NTCIP

The Ethernet stack is a software model provides the lower levels of the Ethernet protocol up to the transmission control protocol (TCP) and user data protocol (UDP) layers. The simple network management protocol (SNMP) layer will use this stack to access the UDP protocol. The SNMP objects provide a means to address and change objects that are used to control the operation of the system. **Figure 8** is a partially modified diagram of the NTCIP Standards Framework that the AAPS implements by adding EoP to the physical layer along with the twisted pair. The heavy solid lines represent the data path for the operational portion of the AAPS. The lighter solid line represents the data path used for transferring audio speech and tone files from the APC and the individual APBs.

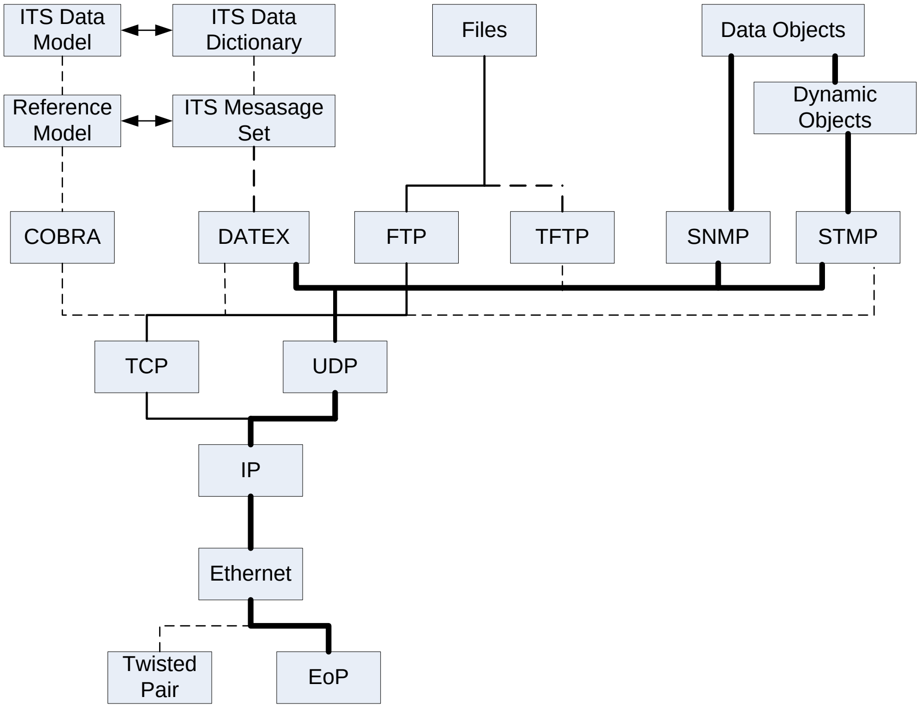


Figure 8: Partial NTCIP standards framework.

SNMPv1

SNMP was developed in the 1980's by the International Engineering Task Force (IETF) to provide standard extensible management of local area network based products [14]. Even though SNMP has been updated to version 3, our use is limited to operation of version 1. Version 1 provides the communication protocol necessary for the operation of the system.

For our system, all of the functions of the SNMP protocol are supported but not necessarily used. The SNMP messages enable the APC to validate this communication with each APB and that each APB is capable of verifying that a call has been placed to the APC. For normal operation, the APC periodically generates a *SetRequest* message that updates each system APB that in turn responds back to the APC a *GetResponse* message. This exchange of information provides verification to the APC that each APB is operational and has received the correct information.

When a user has pressed a pedestrian button, the station APB sends a *Trap* message to the APC. A *Trap* is an unsolicited message generated by the APB that the APC does not respond to. The Trap is verified received on the next received “SetRequest” message. If the next “SetRequest” message from the APC does not indicate that a call has been placed, the APB will generate another Trap.

The program, Wireshark [15] was instrumental as a development tool for designing the applications programs to build the SNMP frame. It displays individual packets in real time as they occur on the Ethernet physical layer. In its display, it breaks the packets down in user identifiable layers as well as the actual hexadecimal bytes in the packet.

SNMP OID’s

SNMP Protocol Data Unit’s (PDU) are used to manipulate values. These values are described by Object Identifiers (OID). An OID uniquely describe the value. NTCIP 1202[11] describes the OID’s that involve traffic controllers. NTCIP 1202 does not provide adequate objects to support the operation of the AAPS system hence we generated our own set of custom objects. For our research, the selection of the set of OIDs is of no consequence because there is no direct interaction between the AAPS network and any network that the traffic controller is connected to.

However, as an exercise, the root OID was defined following the guideline specified by NTCIP 8004 [12]. As shown in **Table 5**, the root OID is “1.3.1.4.1.1206.4.2.14”. **Figure 9** is helpful to understanding the architecture on Management Information Base (MIB) objects. The digits “1.3.1.4.1.1206” refer to all NTCIP SNMP MIB objects. The next digit, “4” was chosen because the pedestrian button is a transportation related device. For our implementation, it may be more appropriate to have specified a value of “2” indicating that AAPS is a NEMA experimental device. However, once the AAPS becomes a commercial product, the manufacturer can either apply for a private identifier, hence, the seventh digit would be a "3" or apply to NEMA to have pedestrian control devices assigned public device node value resulting in the value of "4". For our exercise, we chose to assume that the last scenario is the case.

The eight digit which has a value of "2" designated that the object refers to a device. The last digit in the root MIB OID has been specifically assigned to a value of "14" so not conflict with any of the 11 current device nodes registered under NEMA transportation devices.

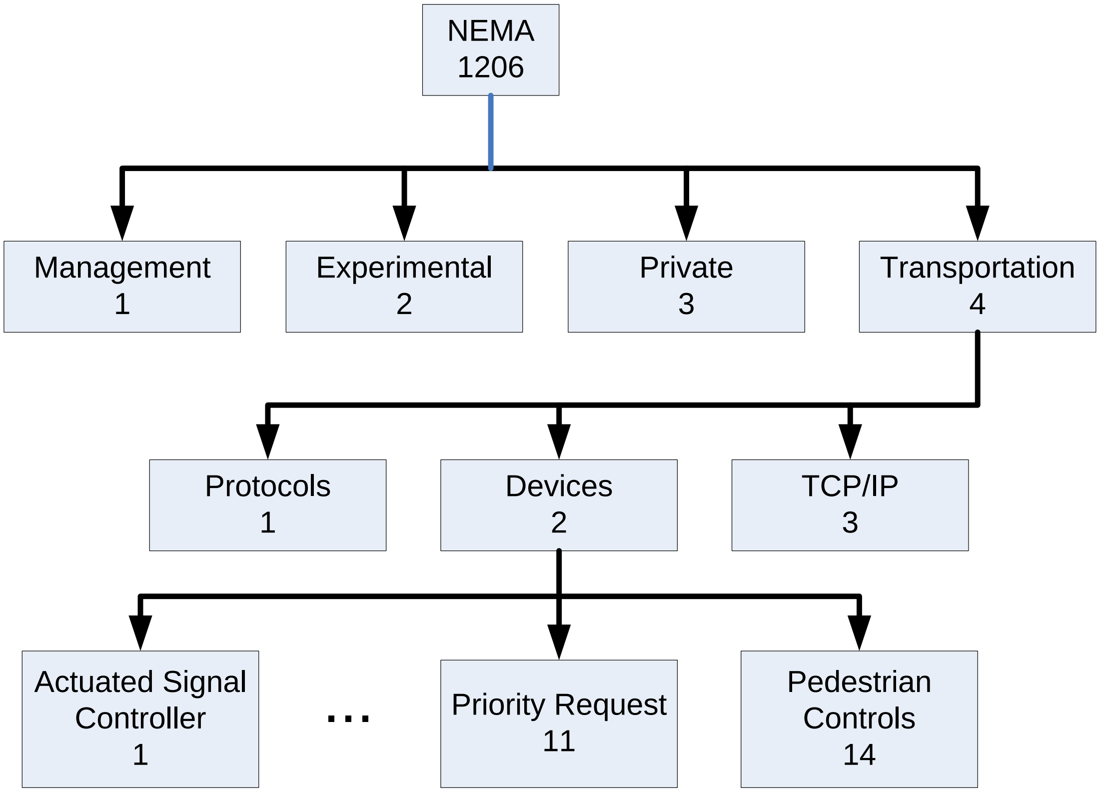


Figure 9: MIB tree for major NTCIP nodes.

The SNMP OID's that are needed for operation of the AAPS system are described in **Table 5** through **Table 7** below. The Status Node OID's are the objects that are sent from the APC to each APB at periodic intervals.

Table 5: Status OID Definitions

Node	OID	Type	Description
APB device ode	1.3.1.4.1.1206.4.2.14		Root node for APBS, 14 on end may change
Phase Status Node	APB.2	Bits	
Phase Status Don't Walks	APB.2.1	Bits	Bits. If set to 1 that phase is in the don't walk state
Phase status Ped Clears	APB.2.2	Bits	Bits. If set to 1 that phase is in the Ped clear state
Phase Status Walks	APB.2.3	Bits	Bits. If set to 1 that phase is in the Walk state
Phase Status Calls	APB.2.4	Bits	Bits. If set to 1 that phase has a call pending
Phase Status APS Calls	APB.2.5	Bits	Bits. If set to 1 that phase has an APS call pending
Phase Status Beacon Source	APB.2.6	Bits	The source of an APS call
Phase Status Beacon Destination	APB.2.7	Bits	The Destination of an APS call
Phase Status Block Object	APB.2.8	OS	Octet string containing all of the phase status objects
Station Status Node	APB.3		
Station Audio Message	APB.3.1	Int	Audio message currently being played

SNMP Trap

The SNMP trap PDU is required to contain two items: the system up time or time since its last reboot and the SNMP Trap OID. Any additional information can be added beyond the required OID’s. The APB will add either a Phase Status Calls or APS Calls OID depending on the type of input detected from the user of the button to the trap message. Each APB will use its preconfigured Station Phase OID value or Station Group OID value in the value field depending upon the type of trap that is generated. **Table 6** contains the list of objects that are sent when a SNMP trap is sent from the APB to the APC.

Table 6: Station Trap OID's Definitions for AAPS

Node	OID	Type	Description
Device OID	1.3.6.1.6.3.1.1.4.1	OID	SNMP Trap OID
System up time	1.3.6.1.2.1.3.0	OS	Octet string of system up time
SNMP Trap	1.3.6.1.6.3.1.1.4.1.0	Int	
Phase Status Calls	APB.2.4	Bits	Bits. If set to 1 that phase has a call pending
Phase Status APS Calls	APB.2.5	Bits	Bits. If set to 1 that phase has an APS call pending

APB Configuration Objects

The Configuration OID variables are also set using the SNMP protocol. These variables are configured once unlike the Status objects, therefore these objects are saved to nonvolatile memory. This allows for the system to recover from a power loss with no loss in service. **Table 7** describes the configuration information for each button. Each APB is initially programmed with default values for each OID. The default values allow a new button to be found when added to the network. This means that all buttons are programmed exactly alike and then configured to be unique in the system using the maintenance web interface.

Table 7: Configuration OID Definitions for AAPS

Node	OID	Type	Description
APB device node	1.3.1.4.1.1206.4.2.14		Root node for APBS, 14 on end may change
Station ID	APB.1.1	Int	Station ID number. Values 1-16 (0 for not configured)
Station Night Mode	APB.1.2	Int	1 If night mode is on
Station Day Locator Volume	APB.1.3	Int	Values 0-100
Station Day Speech Volume	APB.1.4	Int	Values 0-100
Station Night Locator Volume	APB.1.5	Int	Values 0-100
Station Night Speech Volume	APB.1.6	Int	Values 0-100
Station IP Address	APB.1.7	OS	4 byte octet string of the stations IP address
Station Mode	APB.1.8	Int	0-4 AAPS operation Mode
Station Identify	APB.1.9	Int	0 for identify off. 1 for LED blink/vib
Station Phase	APB.1.10	Bits	Bit corresponds to Station's phase
Station Group	APB.1.11	Bits	Bit corresponds to Station's Group
Station Beacon Mode	APB.1.12	Int	AAPS Beacon operational Mode

AAPS HARDWARE

Figure 1shows the system architecture for the AAPS system. The hardware consists of an advanced pedestrian controller (APC) and one or more advanced pedestrian buttons (APB) connected by a low voltage power conductor and a common ground or reference conductor. The APC interfaces with the traffic controller cabinet using existing field wiring terminals. The APC senses the pedestrian signal status by monitoring the 120 alternating current voltage (VAC) load switch outputs. Pedestrian calls are placed using the conventional terminals for pedestrian button inputs. Although not shown in **Figure 1**, it is possible to simultaneously operate both conventional APS and AAPS pedestrian stations provided the AAPS stations and conventional pedestrian stations use separate conductors.

The AAPS is powered from 120 VAC supplied to power the traffic controller cabinet. The 120 VAC is stepped down to a nominal 12 to 18 VAC to power the APC and all APB stations. The communications is implemented using Ethernet over power line (EoP) technology over the 12-18VAC conductors distributed to the APBs.

The APC maintenance interface is an independent Ethernet connection to a service computer for installation and maintenance. The function of this interface will be discussed later in this report.

Advance Pedestrian Controller

As shown in Figure 10, the APC consists of a commercial of-the-shelf Linux based single board computer with a 70 MHz ARM 7 microprocessor and a traffic cabinet interface board of proprietary design. All interfaces with the traffic controller cabinet use optical isolation and transient protection components. The system is capable of interfacing with eight pedestrian signal pairs to sense the 120 VAC W and DW load switch outputs.

An 18 LED array is the only local display that indicates APB failures. All other human-machine interface (HMI) is via the second Ethernet port connected to a service computer or laptop computer. The simple HMI on the APC eliminates the cost and space otherwise needed to support wide temperature range LCD displays and key panels. The Ethernet interface will be described later in this paper. A real-time clock with battery backup is provided to support an optional time of day operation.

The network interface uses a SM5560 EoP modem that supports the 85 Mbps Ethernet using the HomePlug ® 1.0 standard [16, 17]. Similar devices are commercially available that operate on 120 to 220 VAC and are not available to operate at low voltages. Our proprietary design is needed for the AAPS system to operate on the 12 to 24 VAC power that is used to power the pedestrian stations.

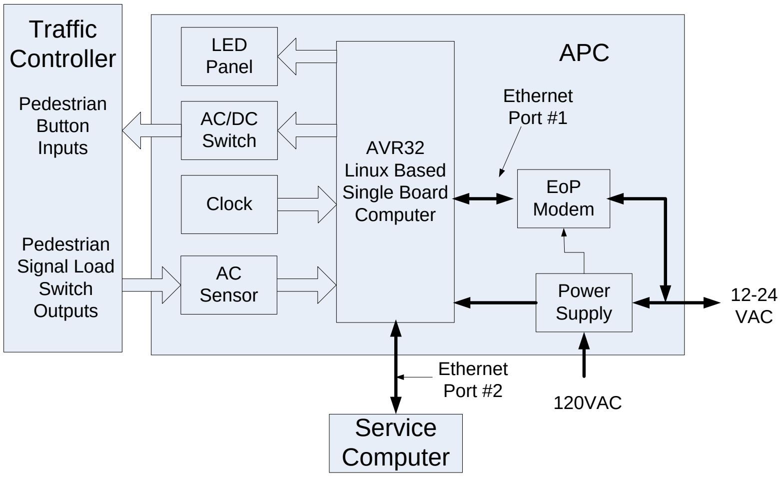


Figure 10: Block diagram of an advanced pedestrian controller.

Advanced Pedestrian Button

The block diagram for the proprietary APB electronics is shown in Figure 11. The APB uses a NXP LPC2468 processor based upon a 32 bit, 72 MHz ARM 7 processor architecture. This particular processor was chosen because it supported a media independent interface (MII) needed to communicate with the EoP modem and the 512 kB processor flash memory that can be used to store audio messages.

Apart from the communications, only six pins of the 208 processor pins are needed for input and output. Two inputs are for the audio microphone used for ambient noise compensation and the pedestrian pushbutton itself. The three outputs are used for a call acknowledge indication LED, the vibrotactile control output, the audio output for the speech messages, and a test output for remotely placing a pedestrian call. The MII interface for the EoP communications requires 18 processor pins.

On the surface, the processor chosen appears to be more than required for this application. However, the functionality designed into the NXP processor reduced system cost and physical size of the APB circuit board. The APB IO consists of two analog outputs, one digital output, one analog input, and one digital input. One analog output is used to drive the speaker for the audible messages. The second analog output is in the form of a pulse width modulation (PWM) control of the vibrotactile button plate for vibration intensity control. A digital output to an LED integrated in the pedestrian button indicates to the pedestrian that the APC has received the request for service and has placed a call to the traffic controller.

The analog input is connected to a microphone that is used for gain control of the audio output to compensate for ambient noise. The pedestrian button input used to place a request for service uses change of state detection. This means only the transition from the open to closed and closed to open states are detected. Once a call has been placed and acknowledged by the APC, no more requests are sent to the APC until the WALK interval has completed.

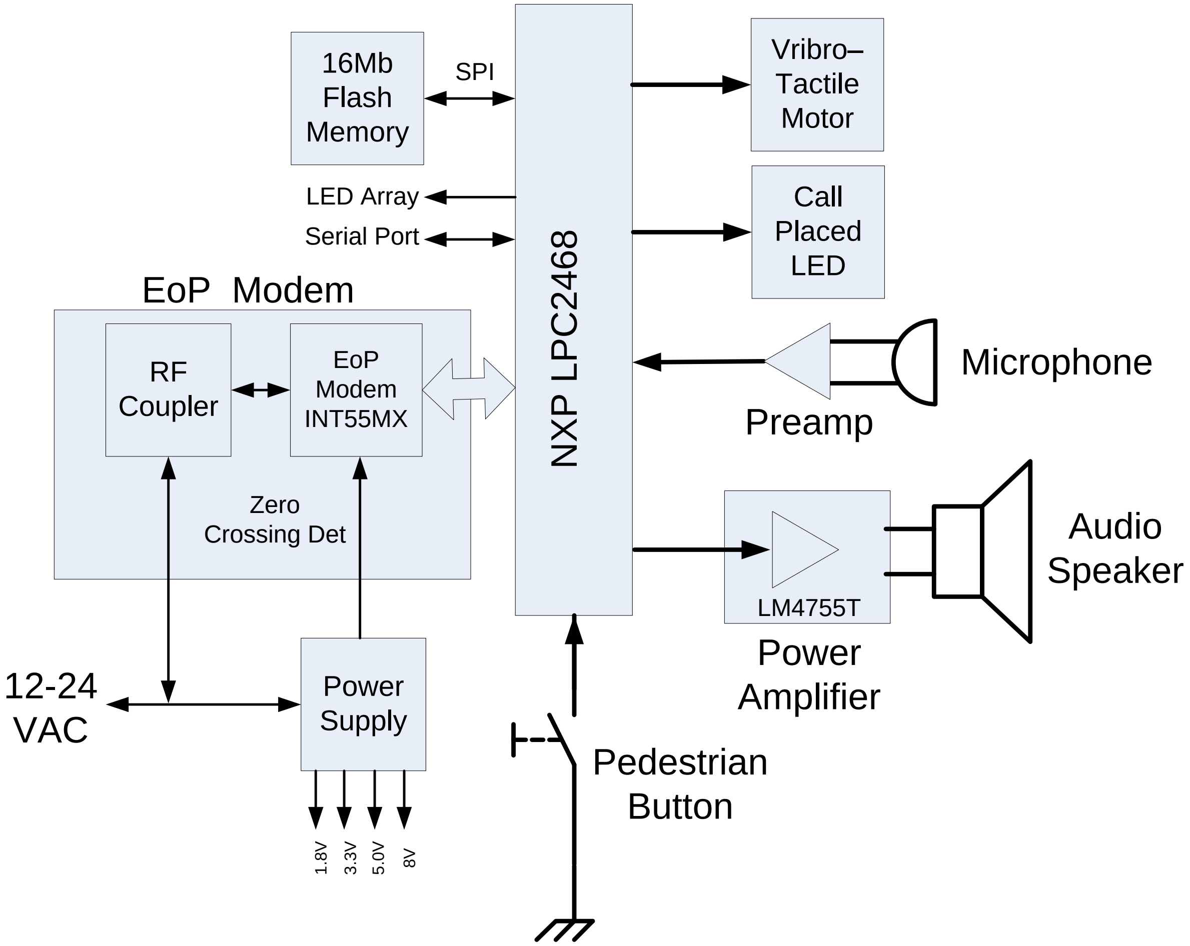


Figure 11: Block diagram of an advanced pedestrian button.

AAPS – Future Research

The AAPS was designed to provide infrastructure support for advanced features such as the ability to integrate remote pedestrian controls to enhance the accessibility for mobility and visually impaired pedestrians [18]. We have tested such a system that can place pedestrian calls, provide navigational aids to help pedestrians stay within the crosswalk, and allow the traffic controller to track the pedestrian’s progress across the intersection. New cell phone and personal communications technology devices that have become available even within the past year makes the remote operation more feasible by overcoming position accuracy and range short comings previously experienced.

Although the 2009 edition of the MUTCD allows, based on dialogs with human factors professors at the University of Idaho, we do not recommend operating with the beaconing feature active. The variability of the acoustical environment hinders the repeatability and reliability of the audible tones for navigation use. Presently, the orientation of the pedestrian button and the speakers are designed to guide low-vision pedestrian to locate the button; not the destination end of the crosswalk. To be effective, the volume of the beacon tone must project across the entire length of the crosswalk and must remain on the entire time of the walk and flashing don’t walk intervals. The later has a high potential for complaints of noise pollution. Certainly this is an area that requires additional study in order to be safe and effective.

As noted in the discussion of the AAPS fault detection and recovery, there is no direct interface between the AAPS and traffic cabinet MMU or CM. Current intersection operations specify that if a conflict is detected, all traffic signals will flash the red signal and all pedestrian signals will be turned off defaulting to an all-way stop with a pedestrian crosswalk. Prudence dictates that the pedestrian signals should be checked for conflicts along with the traffic signals. Since the audible messages serve the same function for controlling pedestrian movement as pedestrian signals do for sighted pedestrians, it is logical that the audible message compatibility should become part of the overall MMU operations. Research is needed to determine the most effective way to implement the fault detection.

Pedestrian button failures present potentially hazardous conditions that result from pedestrians deciding that he or she must take risks to make a street crossing in violation to the indication of the pedestrian signals. The lack of responsiveness to a pedestrian call is source of frustration and serves to undermine the confidence in even functional pedestrian call systems. The fault previous detection and recovery discussion addresses the operations of the electronic components and the software program code. However, the fault coverage as determined by the percentage of the system that is testable is limited to conditions that are observable on the inputs of the processors. Failure detection for mechanical inputs and outputs may require analysis of operating patterns. Regardless of the techniques used to detect and mitigate failures, they may require significant additional software and possibly additional hardware to achieve the desired system fault coverage which can ultimately reduce the overall system availability. There is also the issue of who is checking the checker that is not addressed. Although the following proposed fault detection schemes have not been implemented, the existing hardware can support most if not all of the approaches. The following discussion does not address the mitigation of detected failures but must also be considered when adding the detection capability. To quote an unknown source, “There is no use in taking a measurement that provides information that is not used.”

Electric signals are more easily monitored and allow the use of separate electronics for independent verification. NEMA TS2 type controllers have the ability to present the signal state in multiple formats: the AC voltage from the load switches, the messages on the Synchronous Data Link Control (SDLC) serial bus, and the NTCIP objects available over the Ethernet connection to the traffic controller. Using either the SDLC serial bus or Ethernet port, the APC can confirm that a pedestrian call output to the traffic controller has indeed been placed. Similarly, the pedestrian signal detection can be detected by comparing the inputs from the connections to the load switch outputs with the data available via the SDLC serial bus or Ethernet connection.

Inputs and outputs with which humans interact are inherently difficult to observe using automation and usually require special instrumentation. APS involve three of the five human senses to communicate the states of the pedestrian signals. The APB has three outputs for interface to pedestrians: the visual output in the form of an LED that indicates that a call has been place, a vibrotactile surface on the button that indicates that the WALK interval is in progress, and the audible output that indicates the pedestrian button location and the state of the pedestrian signals.

The LED indication that a call has been placed is provided to give user confidence that the system recognized the button press, and that he or she will be given service in due course of the operation of the intersection. LED devices have such a low failure rate and a minimal risk to human safety because of a burned out LED, that the added expense to confirm that the LED can emit light does not appear to be economically justifiable. However, identifying a low-cost detector and an efficient means of implementing the detection could have far reaching effects for LED traffic and pedestrian signals.

The mechanical vibrations from the vibrotactile button can be detected using an accelerometer. This solution requires additional electronics for the transducer and signal conditioning.

Certainly the audible output is the most critical output particularly for low vision pedestrians. A possible means of observing the audio output is to use the microphone that is used by the APB for volume compensation due to ambient noise. The audio feedback can be used to detect a volume level from the speaker or implement a pattern recognition algorithm to correlate the microphone feedback to the input to the analog signal that is sent to the power amplifier.

Testing the APB inputs can be accomplished using the latest hardware design. As discussed above, the microphone can be used to sense the output from the speaker. The only issue with this approach is differentiating between a failure in the audio output electronics and the audio input electronics. However, since the audio system relies on both operating correctly, the importance is in the detection of a failure in the audio system and not necessarily of failed component identification.

The latest version of the APB electronics circuit board has the capability of remotely activating the pedestrian button input. A transistor has been added that operates in parallel with the pedestrian button such that it can be controlled to short the pedestrian button input. This capability allows both remote and local automated pedestrian button operation. The remote pedestrian button activation appears to have some interest by traffic agency technicians and engineers. The remote button operation capability can detect buttons that fail in the pressed state and shorted button wires. A button that has failed in the open state is detectible by observing the use history as indicated by the APC call count registers. Another possible solution is to alter the mechanical design of the pedestrian button to operate as the classical form C contact where the button has two outputs: one for the pressed condition and one for the relaxed condition. Unfortunately, the mechanical integrity of the button itself remains outside the fault coverage for current button designs.

Future research is planned to identify remaining failure modes and the cost to implement the various detection schemes. Based on AAPS operating experience and advice from traffic operation practitioners, a priority list will be established and the additional fault coverage will be systematically expanded. Safety and expense are the top criteria when establishing a priority list.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

The additional requirements to accommodate pedestrians with a wide range of physical and visual disabilities results in a highly complex set of controls. The audible messages provided by APS have the same level of need for accuracy and consistence as do visual pedestrian signals. The numerous intricate traffic system operating modes must be precisely integrated with both visual and audible pedestrian signals resulting in multifaceted computer programs with many operating parameters.

The approach to the AAPS design was to provide an extensible architecture that allows for easy integration of enhanced features and operating modes. A web interface eliminates the need for application specific PC software for system maintenance and diagnostics. The system logs maintenance operations and system failures which can be archived for system documentation. The web interface allows one person to view the entire system operations from one location.

Using network communications enables observations of operations for microprocessors located outside the traffic controller cabinet. Audio files that are played at each pedestrian station are compared to be consistent with the pedestrian signal status. Each communications transaction is verified to detect equipment and wiring errors as well as communication errors. The constant communications allows the system to detect pedestrian station failures at the traffic controller cabinet even when there is no pedestrian button activity. Using an industry standard network protocol allows the interoperability with future and present traffic control devices.

The AAPS presented in this report uses a hardware architecture that has the capability to meet the expanding requirements of APS systems. A system that uniquely identifies each pedestrian station can now be programmed so that pairs of pedestrian stations can operate in concert to facilitate beaconing with no additional wiring. Time of day operation can be used to reduce volume depending upon local requirements.

It is apparent that the existing AAPS is capable of performing a higher level of self-testing than is currently implemented. The AAPS software, hardware, and method of communication are specifically designed with the capability to expand the functionality. There are numerous approaches that are considered for future research in improving the reliability and safety of accessible pedestrian systems by expanding the fault detection coverage.

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