Final Report

Interactive Signals for Able-Bodied and Disabled Pedestrians

University of Idaho
National Institute for Advanced Transportation Technology
October 5, 2009

Prepared By

<table>
<thead>
<tr>
<th>Document Owner(s)</th>
<th>Project/Organization Role</th>
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<tbody>
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</tbody>
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Project Closure Report Version Control

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<th>Author</th>
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<td>R.W. Wall</td>
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1 PROJECT CLOSURE REPORT PURPOSE

Project Closure Report Purpose

This report is the final document produced for the Idaho State Board of Education to assess the success of the project, identify best practices for future projects, resolve all open issues, and formally close the project.

2 PROJECT CLOSURE REPORT GOALS

Project Closure Report Goals

This Project Closure Report is created to accomplish the following goals:

- Review and validate the milestones and success of the project.
- Confirm outstanding issues, risks, and recommendations.
- Outline tasks and activities required to close the project.
- Identify project highlights and best practices for future projects.

3 PROJECT CLOSURE REPORT SUMMARY

3.1 Project Background Overview

Project Background Overview

Project Goals

- To develop the next generation of Accessible Pedestrian Signals (APS) devices that will improve safety and access for able-bodied and disabled pedestrians at signalized intersections.
- To work with industry partners to develop specifications for the AAPS technology.
- To apply the Spiral Development Cycle methodology for fast prototype development, testing, evaluation, and risk assessment.
- To identify an advisory board consisting of traffic industry practitioners, representatives of federal, state, and city traffic agencies, and pedestrian advocacy groups.
3.2 Project Highlights and Best Practices

**Project Highlights and Best Practices**

**Project Highlights:**
- A complete AAPS was designed, constructed, and tested within a laboratory.
- An established manufacturer of APS devices has funded this research and will oversee the beta field testing, manufacturing, and marketing of the AAPS.
- Two patent applications were filed based upon the design and testing of the AAPS.

**Best Practices:**
- Recommendations by the advisory board directed the development of a system with enhanced safety features for low vision and mobility impaired pedestrians.
- Applying the spiral design methodology, two iterations of hardware was designed with minimum risk of failure.

3.3 Project Closure Synopsis

**Project Closure Synopsis**

- This project is being closed because the project funding period has expired.

4 PROJECT METRICS PERFORMANCE

4.1 Goals and Objectives Performance

**Goals and Objectives Performance**

**Goal 1:** “Improve safety and access for able-bodied and disabled pedestrians at signalized intersections.”

**Goal 2:** “Work with industry partners to develop specifications for the technology.”

**Goal 3:** “Formation of a technical oversight committee to guide the development of a test plan.”

**Goal 4:** “Employ a spiral development cycle to rapidly prototype new devices and evaluate them in iterative developmental stage’s”

**Goal 5:** “Provide a unique educational opportunity for UI/NIATT’s undergraduate and graduate students to collaborate with faculty and professionals in state agencies and private industry by making an important contribution to pedestrian safety while developing essential technical skills.”
4.2 Success Criteria Performance

<table>
<thead>
<tr>
<th>Success Criteria Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Functional performance</strong></td>
</tr>
<tr>
<td>a. Measure the usefulness of technology for disabled pedestrians as determined by instructors for the vision impaired and representatives of the low vision population.</td>
</tr>
<tr>
<td>b. Measure the information reliability and probability of communications failure</td>
</tr>
<tr>
<td>c. Measure the impact on traffic flow.</td>
</tr>
<tr>
<td><strong>II. Cost effectiveness for integration to existing traffic controller installations</strong></td>
</tr>
<tr>
<td>a. Magnitude of modifications to TS1 and TS2 type traffic controllers</td>
</tr>
<tr>
<td>b. Cost of hardware that is required to be added to traffic controllers</td>
</tr>
<tr>
<td>c. Cost of installation and maintenance (labor and education for maintenance personnel).</td>
</tr>
<tr>
<td>d. Scalability for future development. Amend the Manual on Uniform Traffic Controller Devices (MUTCD), and promote national adoption</td>
</tr>
<tr>
<td><strong>III. Ease of Use</strong></td>
</tr>
<tr>
<td>a. Estimated cost of final product</td>
</tr>
<tr>
<td>b. Ease of maintenance</td>
</tr>
<tr>
<td>c. Ease of learning the system (according to age, learning ability, dexterity)</td>
</tr>
<tr>
<td>d. Operational requirements</td>
</tr>
<tr>
<td><strong>IV. Ease of Manufacture</strong></td>
</tr>
<tr>
<td>a. Direct cost of materials and fabrication</td>
</tr>
<tr>
<td>b. Maturity of technologies</td>
</tr>
<tr>
<td>c. Cost of marketing</td>
</tr>
</tbody>
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### 4.3 Milestone and Deliverables Performance

<table>
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<tr>
<th><strong>Milestone and Deliverables Performance</strong></th>
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</table>
| **Goal 1:** 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 report describes a distributed control system that uses Ethernet communications over power lines.  

The systems consist of a controller unit housed in the traffic controller cabinet and interfaces to existing National Electrical Manufacturers Association (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 used 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.  

Simple Network Management Protocol (SNMP) and Simple Transport Management Protocol (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 National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) custom objects. |

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| **Goal 2:** During the research period, we assembled a technical oversight advisory board consisting of representatives from industry, government, and advocacy groups for the disabled. Campbell Company of Boise, Idaho provided an additional $61,535 funding to develop the Advanced Accessible Pedestrian Signals (AAPS).  

During the summer of 2009, a University of Idaho Electrical Engineering graduate student worked in the Campbell Company manufacturing facility in Boise, ID to assist in the transfer of technology from the University of Idaho research laboratories to industry. Manufacturing of the AAPS was initiated in August 2009.  

Goal 3: Based upon the recommendation from three meetings of our advisory board that formed our technical oversight committee (ToC), we specified, developed, evaluated, and assessed two implementations for an AAPS.

<table>
<thead>
<tr>
<th>ToC Member</th>
<th>Affiliation</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carol Baron</td>
<td>Idaho School for the Deaf and Blind</td>
<td>Mobility and orientation needs for the visually impaired.</td>
</tr>
<tr>
<td>Gary Duncan</td>
<td>Econolite Control Products, Inc.</td>
<td>TS2 Controller Manufacturer. Controller design and operations from a manufacturer’s perspective.</td>
</tr>
<tr>
<td>Craig Gardner</td>
<td>Intelight, Inc.</td>
<td>TS2 Controller Manufacturer. Microprocessor use in traffic control.</td>
</tr>
<tr>
<td>Michael Graham</td>
<td>IDVR</td>
<td>Needs of pedestrians with disabilities.</td>
</tr>
<tr>
<td>Brent Jennings</td>
<td>ITD</td>
<td>Traffic administration. Traffic signal operations, installation and maintenance from a State perspective.</td>
</tr>
<tr>
<td>Lance Johnson</td>
<td>FHWA</td>
<td>Traffic administration. Traffic signal operations, installation, and maintenance from a Federal perspective.</td>
</tr>
<tr>
<td>Phil Tate</td>
<td>Campbell Company</td>
<td>Manufacture of APS devices. Specifications, development, and marketing of APS devices.</td>
</tr>
</tbody>
</table>

Goal 4: Working with Federal Highway Administration (FHWA) guidelines for APS and in cooperation with the Campbell Company, a set of initial specifications was established. Using the limited risk approach of the Spiral Design Cycle, a first generation pedestrian system was developed that utilized inexpensive, readily available, hardware that enable designers to use low cost hardware and software development tools. Due to prior experience and education, there was minimal learning effort for the selected components. A restricted capability AAPS was tested for compliance to the requirements of APS systems. This was followed by an assessment of the performance in regards to system responsiveness, failure rate, and resource utilization.

Goal 5: Four graduate and four undergraduate electrical and computer engineering students participated in this research project. They have provided the bulk of the technical effort in the design activities. One student completed an internship with our industry sponsor and another graduate student completed his Masters of Science degree. One student who started as an undergraduate is continuing to work on the project and is now a graduate student.
## 4.4 Schedule Performance

<table>
<thead>
<tr>
<th>Research Activity</th>
<th>Phase</th>
<th>Quarter 1</th>
<th>Quarter 2</th>
<th>Quarter 3</th>
<th>Quarter 4</th>
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<tr>
<td><strong>Initial Design:</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>- Meeting 1 with technical oversight committee (ToC) to prioritize functionality of design</td>
<td>#1</td>
<td>2/21/08</td>
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<td>- Design specification approval for stand-alone operation of devices</td>
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<td>- Test and performance review</td>
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<td><strong>Alpha Testing:</strong></td>
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<tr>
<td>- Meeting 2 with ToC for performance review and second level functionality selection</td>
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<td>4/20/08</td>
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<tr>
<td>- Design revision and testing with traffic controller integration</td>
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<td>4/20/08</td>
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<tr>
<td>- Testing and performance review by disabilities advisors</td>
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<td><strong>Beta Testing:</strong></td>
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<td>- Meeting 3 with ToC for performance review and final level functionality selection</td>
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<td>- Beta test of completed system (Deployment at test intersection)</td>
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<td>- Publish results</td>
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<td>- Next stage planning</td>
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<tr>
<td>- Marketing development plan</td>
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## 4.5 Budget Performance

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<td>03-Irregular Help</td>
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<td>$1,464.36</td>
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<td>04-Travel</td>
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<tr>
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<td>08-Reserve</td>
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<td>$ -</td>
<td>$ -</td>
<td>$-</td>
</tr>
<tr>
<td>09-Overhead</td>
<td>$-</td>
<td>$ -</td>
<td>$ -</td>
<td>$-</td>
</tr>
<tr>
<td>10-Tuition/Stipends</td>
<td>$2,606.00</td>
<td>$2,606.00</td>
<td>$ -</td>
<td>$-</td>
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<tr>
<td><strong>Total</strong></td>
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<td>$56,777.91</td>
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<td>$11,780.00</td>
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4.6 Metrics Performance Recommendations

Recommendation 1. Research by our team on the remote pedestrian assistant will be suspended at its present state of development.

Justifications:
   a. Inaccurate positioning information: Current GPS infrastructure does not have the required accuracy, availability, or coverage to provide an adequate degree of safety needed for pedestrian guidance in hazardous environments.
   b. Accurate directional information: Current electronic compass technology is susceptible to errors generated by local dynamic environment conditions.
   c. Insufficient range and availability of communication with the traffic control system: Bluetooth communications does not have sufficient range to support the necessary communications for real time control. Cell phone technology does not have the required reliability for real time safety-critical control.

Advantages:
   a. Research effort can be focused on developing infrastructure capability.
   b. Cost of cell phones will drop as the technology matures.
   c. The demonstration of need draws in additional researchers to address the current problems.
   d. New GPS technology is under development in the US and Europe that may soon resolve GPS accuracy issues.

Disadvantages:
   a. Loss of advanced navigational assistance.

Risk: The safety advantages associated with the tracking, orientation and guidance capabilities continue to put low vision pedestrians at risk but no more so than currently exists.

Action: New technology has been uncovered and is being investigated. The enabling infrastructure provided by the hardware platform for AAPS Rev 4 is capable of merging a diverse set of positioning technologies and communications schemes. (For additional information, see http://www.ti.com/corp/docs/landing/cc2431/index.htm)
Recommendation 2. Redesign the accessible pedestrian button based upon a more capable microprocessor.

Justifications:
a. The processor used in the first design has insufficient resources: Cypress design utilized all memory resources supporting minimum advanced features.
b. Savings in pedestrian button reduces system cost: More robust development tools inherently results in more reliable designs with less development effort.
c. Fewer electronic devices results in increased product reliability.
d. Fewer components reduce manufacturing and fabrication costs.
e. Additional system functionality is anticipated when the next version of the MUTCD is published.

Advantages:
a. The cost of the single high performance processor is less than the cost of the eight electronic devices replaced on the design based on the Cypress “programmable system on a chip” (PSoC) microprocessor.
b. A total system cost savings was possible by using a processor with more integrated resources. The new design results in a 60% reduction in component cost per pedestrian station. This savings has a multiplier of 2 to 16 depending on the intersection design.

Disadvantages:
a. Extends development time.
b. Higher cost for development software.

Risk: Increased development time and expense delays product introduction.

Action: Second design iteration of the Advanced Pedestrian Buttons (APB) has completed evaluation of three revisions. Revision 4 hardware is moving to manufacturing and field trials.
**Recommendation 3.** The AAPS will be designed only to interface with the National Electrical Manufacturers Association (NEMA) TS1 type traffic controllers.

**Justification:**

a. This interface is functional with all traffic controller systems in use today.
b. Only a fraction of all NEMA TS2 type traffic controllers fully support the National Transportation Communications for Intelligent Transportation Systems (ITS) Protocol (NTCIP) communications.
c. The traffic industry has not addressed security issues with the current version of the NTCIP.
d. Current traffic controllers have a constraint in the communications speed of the Ethernet based NTCIP interface.
e. No modifications are required to NEMA TS1 type controller devices.

**Advantages:**

a. Research effort is focused on TS1 interface design.

**Disadvantage:**

a. There is significant cost savings with the NEMA TS2 traffic controller interface.

**Risk:** Wiring errors in the TS1 interface that are introduced during installation can create hazardous operations.

**Action:** The industry seeks to move to the NTCIP Ethernet interface provided by the NEMA TS2 type controllers. The development of this feature is 90% complete at this time and will be introduced to the market as soon as beta testing of the TS1 interface is complete. Currently only the ASC3 traffic controller manufactured by Econolite Controls has been tested. An acceptance process will need to be established for RS2 controllers produced by other manufacturers.
**Recommendation 4.** Traffic agencies should be contacted to determine potential sites for field trials.

**Justification:**
a. The test and analysis of the first design clearly demonstrate the capability and advantages of the AAPS.

b. Much of the design knowledge associated with the Ethernet over power line technology is directly transferrable to the redesign equipment.

**Advantages:**
a. System weaknesses are identified prior to wide scale deployment making corrections and redesigns less costly.

b. A broader audience is allowed to review the functional capabilities and make suggestions as how to improve the systems features and usability.

c. A record of installation questions can be used to improve documentation.

**Disadvantages:**

a. Additional expense is incurred for travel.

b. The lack of proper test equipment can make field trouble shooting difficult.

**Risk:** Serious design flaws can undermine customer confidence.

**Action:** Minnesota Department of Transportation has agreed to install equipment at two intersections as soon as Campbell Company can manufacturer the equipment. Installation is scheduled for November 2009.

## 5 PROJECT CLOSURE TASKS

### 5.1 Resource Management

<table>
<thead>
<tr>
<th>Resource Management</th>
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<tbody>
<tr>
<td>• Funding is needed to provide manufacturing support. An educational plan is needed to train manufacturers, installers, the consumers, and the traffic agencies how to configure and maintain the new equipment.</td>
</tr>
</tbody>
</table>

| • Pursuant to efficient technology transfer, the following actions are planned: |
| o Engineering manual containing the hardware and software design plans. |
| o Support documentation to identify production steps for assembly and distribution of AAPS systems. |
| o Tutorial describing development environments used for software development. |
| o User's manual that describes the procedures for field installation and maintenance. |
Pursuant to further development, the following actions are planned:
  o Identification of advanced features.
  o Assessment of cost per proposed feature.
  o Formation of a new advisory board to guide further development.
  o Planned meetings to prioritize incorporation of new features
  o Additional funding contract with Campbell Company and agencies representing advocacy groups are planned.

Pursuant for further research funding, the following actions are planned:
  o $106,992 University Transportation Centers (UTC) funding was secured starting in August 2009.
  o Campbell Company will be approached to provide funding for at least one graduate student starting January 2010.

### 5.2 Issue Management

**Issue Management**

- Each item listed in Section 5.2 is being addressed under Campbell Company Contract.
- Professor Richard W. Wall will continue to be the lead investigator on this research effort.

### 5.3 Risk Management

**Risk Management**

See Section 4.0

### 5.4 Quality Management

**Quality Management**

Funding provided by current UTC, “Closed Loop Operation of Network Based Accessible Pedestrian Signals” grant addresses secure and dependable AAPS operation.
5.5 Communication Management

**Communication Management**

- Weekly research team meetings that include researchers and industry sponsors were scheduled. Email communication took place on an as-needed basis and, historically, resulted in turn-around resolution in less than 24 hours. This is supplemented with phone calls when required.
- During the course of the project, communications with Campbell increased significantly. During the summer 2009 while the UI graduate student worked at Campbell Company in Boise, the graduated students established a Skype connection which was in daily, almost hourly, use.
- Campbell Company was added to the SMART SIGNALS email distribution list so that company personnel could monitor daily progress.

5.6 Customer Expectation Management

**Customer Expectation Management**

- Campbell Company personnel were frequently asked for input and direction as the final phase of the system was in design. They also participated in systems tests that were conducted on September 10th and 24th of 2009.

5.7 Asset Management

**Asset Management**

- Systems built and tested during the prototyping phase will remain in the Department of Electrical and Computer Engineering Smart Signals research laboratory under the direction and control of Dr. Richard Wall.
- Development software and hardware tools will remain in the Department of Electrical and Computer Engineering Smart Signals research laboratory under the direction and control of Dr. Richard Wall.

5.8 Lessons Learned

**Lessons Learned**

- **Planning**
  - The Spiral Development Model is extremely effective resulting in a systematic process for specification, test and evaluation in minimum time with minimal risk.
  - Advisory board guidance resulted in a system that is capable of achieving the stated goals under this funding.
  - Frequent personal contacts form face to face meetings improve distance communications.
- **Development**
  - The cost of switching technologies midway through the design process is minimized by using the Spiral Development Model.
  - Frequent performance evaluation is critical to determining when such a technology shift is necessary.
  - It is important to develop a close relationship with industry early in the design cycle to ensure manufacturability.

- **Technology Transfer**
  - Projects involving significant technology advances require significant customer education.
  - Working on projects that have real social value motivate students.

### 5.9 Post-Project Tasks

<table>
<thead>
<tr>
<th>Post-Project Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field testing will commence as soon as production systems can be manufactured. It is proposed that the field testing will begin in late November 2009.</td>
</tr>
<tr>
<td>The system documentation will be completed during the interim when field testing.</td>
</tr>
<tr>
<td>Training requirements have not been established at this time.</td>
</tr>
<tr>
<td>Identification of future system developments, functionality enhancements, and new productions has not begun.</td>
</tr>
<tr>
<td>A fourth and final meeting is delayed until March 2010. This report will be distributed prior to that meeting.</td>
</tr>
</tbody>
</table>

### 5.10 Project Closure Recommendations

<table>
<thead>
<tr>
<th>Project Closure Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>This is the first field implementation of the Smart Signals Concept research that begun in 2005. It represents a significant step in the technology transfer to the public use. The fact that a state traffic agency is willing to install and test the system signifies an acceptance of technology that represents a paradigm shift in the way future traffic control systems will function.</td>
</tr>
</tbody>
</table>
6 PROJECT CLOSURE REPORT APPROVALS

Prepared By:

Richard W. Wall, Professor, Department of Electrical and Computer Engineering.

James Frenzel, Associate Professor, Department of Electrical and Computer Engineering.
7 APPENDICES

7.1 System Technical Description

Abstract: This report presents 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 report describes a distributed control system that uses Ethernet communications over power lines.

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 used 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.

7.2 Introduction

The U.S. Department of Transportation Federal Highway Administration’s Manual on Uniform Traffic Control Devices (MUTCD) defines a traffic control signal (traffic signal) as any highway traffic signal by which traffic is alternately directed to stop and permitted to proceed[1]. Furthermore, Section 4B of the MUTCD defines traffic as pedestrians, bicyclists, ridden or herded animals, vehicles, streetcars, and other conveyances either singularly or together while using any highway for purposes of travel.

Following the American Disability Act of 1990, Accessible Pedestrian Signals (APS) were introduced to help low vision pedestrians more safely cross streets at signalized intersections. Section 4A.01 of the MUTCD, defines an Accessible Pedestrian Signal (APS) as “a device that communicates information about pedestrian timing in nonvisual formats such as audible tones, verbal messages, and/or vibrating surfaces” [2]. Accessible pedestrian signals are fundamental in designing accessible rights-of-way. Traffic signals are designed and installed for the public safety and individuals disobeying the directions indicated by the signals are disobeying federal, state, and/or local laws. For low-vision individuals, the audible signals have the same safety and legal implications as do the illuminated traffic signals.

Section 4E.06 of the MUTCD contains the following statements: “The primary technique that pedestrians who have visual disabilities use to cross streets at signalized locations is to initiate their crossing when they hear the traffic in front of them stop and the traffic alongside them begin to move, corresponding to the onset of the green interval. This technique is effective at many signalized locations. The existing environment is often sufficient to provide the information those pedestrians who have visual disabilities need to operate reasonably safely at a signalized location. Therefore, many signalized locations will not require any accessible pedestrian signals.” These statements fail to recognize the lack of audio cues used by the visually impaired during evening hours when traffic volumes are low and vision for drivers is poor. The quietness of hybrid-electric vehicles has created serious challenges for low-vision pedestrians.
who customarily utilize the “sound surge” for cues when to enter the crosswalk and navigational aids while crossing.

7.3 Background

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. After a predetermined time that is based upon the length of the cross walk and the assumed pedestrian walking speed, the pedestrian signal flashes the Don’t Walk signal on and off. The FDW interval terminates with a solid Don’t Walk signal. For exclusive pedestrian movement operations, the time 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 minimum vehicle green time.

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 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 manufactures 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 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.

7.4 AAPS - A Networked Based APS System

An advanced APS (AAPS) system was designed to address many of the issues addressed
in the paragraphs above. 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 technologies 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, wide spread use in industrial controls and the
availability of low cost hardware.

Although some of the operating features will be described below, 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 starting in 2006 [3,4,5]. 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.

7.5 AAPS Hardware

Figure 1 shows 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 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 used to power the traffic controller cabinet. The 120 VAC is stepped down to 12 VAC to power the APC and all APB stations. The communications is implemented using Ethernet over power line (EoP) technology over the 12VAC 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.

### 7.6 Advance Pedestrian Controller

As shown in Figure 2, the APC consists of a commercial off-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.

A 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 MX5500 EoP modem that supports the 85 Mbps Ethernet using the HomePlug ® 1.0 standard [6, 7]. Similar devices are commercially available that operate on 120 to 220 VAC. Our proprietary design is needed for the AAPS system to operate on the 12 VAC power used to power the pedestrian stations.
7.7 Advanced Pedestrian Button

The block diagram for the proprietary APB electronics is shown in Figure 3. 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 five 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 button itself. The three outputs are used for a call acknowledge indication LED, the vibrotactile control output, and the audio output for the speech messages. 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.
7.8 AAPS Communications

Network communications is our approach to address safety concerns raised in the introduction of this paper. The APC constantly exchanges information with each APB on the system. The APC continually sends a data messages containing the status of the pedestrian signals to each individual APB in a round robin fashion. Each APB responses back to the APC indicating the reception of the data. Any APB not responding in a preset time is identified on the APC’s LEDs as well as the maintenance web page. The data in the APB response message includes the current audio tone or message being played. This is checked against the status of the signals to verify that there is not a conflict in pedestrian and vehicle movements. The APB also sends an unsolicited message whenever a pedestrian has activates its button input.

Network communications to support APS maintenance or installation activities does not interfere with the real time operations. The sections that follow in this paper describe the implemented network protocols.

7.9 Network Communications

7.10 Ethernet layers

The Ethernet stack is a software model that provides the lower levels of the Ethernet protocol up to the TCP and UDP layers. The 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 4 is a partially modified diagram of the NTCIP Standards Framework that the AAPS implements. 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 4 is modified in that the EoP is added at the physical layer along with the twisted pair.

Figure 4. Partial NTCIP Standards Framework

7.11 Communications – Service and Maintenance

The computer used for maintenance and servicing does not require proprietary software; only a standard web browser such as Internet Explorer® or Mozilla Firefox®. The maintenance and setup of the system uses web based controls through a webpage that is hosted by the APC single board computer. The Advanced Accessible Pedestrian Management System (AAPMS) web page is organized into an upper static frame and a bottom variable frame.

The top frame presents system real-time status information of the pedestrian signals and pending pedestrian calls waiting to be serviced. Figure 5 is an example of the web service page displaying the system configuration frame. These settings are used to select the operating modes for the APC and those options that are common to all APB stations.

There are six display options for the contents of the bottom frame of the service page: System Status, System Configuration, Time Configuration, Station Settings, File Upload, and View Log Files. 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.
7.12 Audio File Management

Audio files are generated and stored on the service computer as "wav" file. The files are transferred to the APC one at a time. After receiving each audio file, it is passed on to the specified APB using the FTP protocol. The FTP protocol 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 saved. These file names correspond to the message that is being saved. The file names are wait, walk, location, locator, initiation beacon tone, and target beacon tone. In addition, there are preempt and custom audio messages.

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. 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, 8 kHz PCM audio, it ultimately requires 8KB 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 [8]. 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 webpage to notify the user of the status of each file transfer. The submit field is the value of the 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 webpage 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 webpage 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 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 to the user.

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. APB configuration options are handled much differently. 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 via SNMP. Upon a successful reconfiguration of the APB, it is placed back into the mode it was configured.

7.13 Communications – System Operations

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 [9]. A significant portion of the communications protocol used to implement on the AAPS is based upon work reported on by Devoe, et. al. [10].

7.14 SNMPv2

The simple network management protocol (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 [11]. Even though SNMP has been updated to version 3, our use is
limited to operation of version 2. Version 2 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. 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 [13] 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.

### 7.15 SNMP OID’s

SNMP PDU’s are used to manipulate values. These values are described by Object Identifiers (OID). An OID uniquely describe the value. NTCIP 1202 [9] 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. The SNMP OID’s that are needed for operation of the AAPS system are described in Table I through III below. The Status Node OID’s are the objects that are sent from the APC to each APB at periodic intervals.

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

### 7.16 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 in the value field of this OID. Table II contains the list of objects that are sent when a SNMP trap is sent from the APB to the APC.

Table II: Station Trap OID’s Definitions

<table>
<thead>
<tr>
<th>Node</th>
<th>OID</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device OID</td>
<td>1.3.6.1.6.3.1.1.4.1</td>
<td>OID</td>
<td>SNMP Trap OID</td>
</tr>
<tr>
<td>System up time</td>
<td>1.3.6.1.2.1.3.0</td>
<td>OS</td>
<td>Octet string of system up time</td>
</tr>
<tr>
<td>SNMP Trap</td>
<td>1.3.6.1.6.3.1.1.4.1.0</td>
<td>Int</td>
<td></td>
</tr>
<tr>
<td>Phase Status Calls</td>
<td>apb.2.4</td>
<td>Bits</td>
<td>Bits. If set to 1 that phase has a call pending</td>
</tr>
<tr>
<td>Phase Status APS Calls</td>
<td>apb.2.5</td>
<td>Bits</td>
<td>Bits. If set to 1 that phase has an APS call pending</td>
</tr>
</tbody>
</table>

7.17 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 III 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 III: Configuration OID definitions

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

The AAPS presented uses as 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 pair 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.

Using network communication 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 communication transaction is verified to detect equipment and wiring errors, as well as, communication errors. The constant communication allows the system to detect pedestrian station failures at the traffic controller cabinet even when there is no pedestrian button activity.

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 systems documentation. The web interface allows one person to view the entire system operations from one location.

7.19 ACKNOWLEDGMENT

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7.20 REFERENCES


[8] URL-encoded and multipart forms http://www.w3.org/TR/html4/interact/forms.html#h-17.13.4.1, last viewed on July 20, 2009


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