Design and Evaluation of Hybrid Wired and Wireless Sensor Networks with Cloud Services for Monitoring of Early-Stage Environmental Corrosion

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By

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Topics of Discussion

1. Introduction to Army CERL Sponsored "Micro/Nano Technology Sol-Gel Corrosion Sensor System – Corrosion Monitoring"
2. Sol-gel and Cylindrical Corrosion Sensors
3. Sensor Networks Technology: Wired and Wireless
4. The Corrosion Monitoring System with Wired Sensor Nodes
5. Experimental Testing of Second Generation CMS with Hybrid Wired and Wireless Sensor Nodes
6. Summary and Future Work

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Introduction

- The project: “Micro-Nano Technology Sol-Gel Corrosion Monitoring System,” 2011-2014
  - Project sponsor: Army Construction Engineering Research Laboratory, IL: Richard Lampo and Michael McInerney, and Jerry Ryan
  - Project Team:
    - **Max S. Yen, Paul I-Hai Lin and Dong Chen**
    - **Graduate Students: MengWei Li, Robert Tilbury, Muhammad Shoaib Mansur**
    - **Undergraduate EE Student: Steve Groff**

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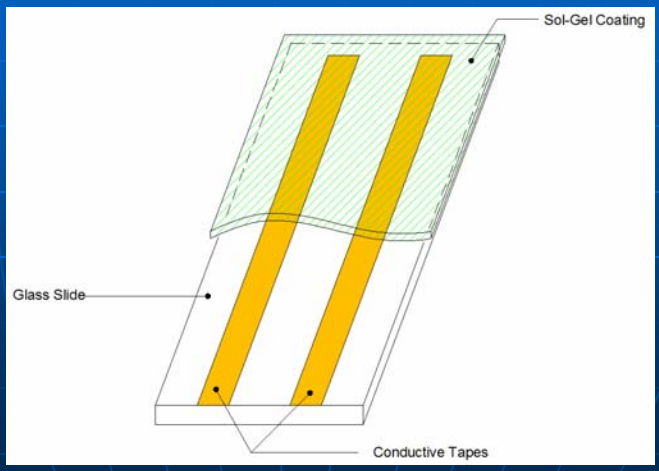
2. Sol-Gel and Cylindrical Corrosion Sensors
Cylindrical Corrosion Sensor:
A Sol-Gel Corrosion Sensor (Capacitive Type)



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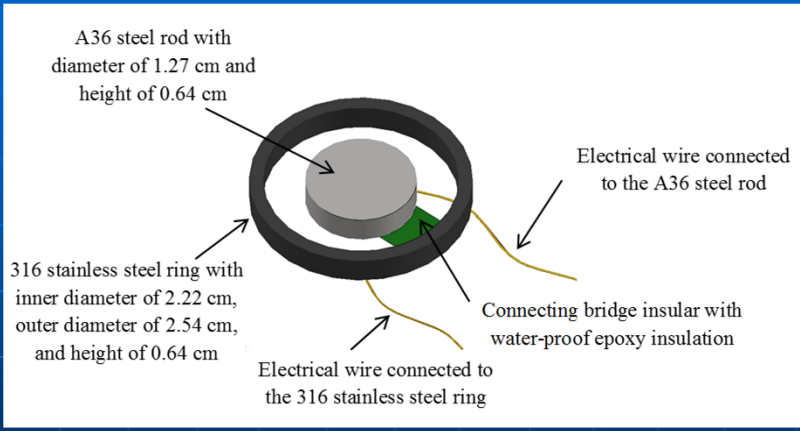
2. Sol-Gel and Cylindrical Corrosion Sensors: Cylindrical Corrosion Sensor (Capacitive Type)



$$C = 2\pi\varepsilon_0 h \frac{\varepsilon_1\ \varepsilon_2}{\varepsilon_1 \ln\left(\frac{b}{a+\delta}\right) + \varepsilon_2 \ln\left(\frac{a+\delta}{a-\delta(1-\varphi)}\right)}$$

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3. Sensor Network Technology: Wired and Wireless

- Definition of Sensor Network
  - An infrastructure includes sensing, computing, and communication elements to provide the ability to instrument, observe and react to events and phenomena in a specific environment [1].
  - Communication Element: Wired/Wireless
- Physical Signal Sources
  - Electromagnetic radiation signals: radio and light
  - Optical, acoustic , seismic, acceleration, strain, vibration signals
  - Chemical and biochemical signals
  - Environmental signals: light, temperature, humidity, barometric

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3. Sensor Network: Wired and Wireless

- Wireless Sensor Network (WSN) Applications
  - Industrial Monitoring, Control, Automation;
  - Building Automation
  - Home Automation and Consumer Electronics
  - Security and Military Sensing
  - Asset Tracking and Supply Chain Management
  - Intelligent Agriculture and Environmental Sensing
  - Health and Medical Monitoring
  - Critical Infrastructure Monitoring, Protection and Security

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3. Sensor Network: Wired and Wireless

- **Wireless Sensor Network (WSN) Architecture**
  - Application Dependent: network sensor nodes, gateway node, data sources and sinks
  - Network Topologies and Routing Algorithms
    - Single-hop vs. multi-hop networks
    - Mobility consideration
    - Network lifetime
    - Scalability
    - Protocols
  - Energy Efficiency and Management
  - Network Management
  - Data Management
  - Security and Data Integrity

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3. Sensor Network: Wired and Wireless

- **Wireless Sensor Network (WSN) Architecture**
  - Network Topologies and Routing
    - **Star Network**: One master node, multiple slave nodes
      - One master node- synchronization and channel access
      - Multiple slave sensor nodes
      - Examples: Bluetooth, 802.11b “WiFi”
    - **Ring and Tree Network**
      - Cellular and paging system
      - Base stations are connected using wired network
    - **Ad Hoc Networks**
      - Multiple-hops path relaying data from user-to-user to reach data receiver
      - May form clustered and overlay network
    - **Mesh Network**: Multi-hop, multi-path

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3. Sensor Network: Wired and Wireless

- Sensor Node Platform Selection Criteria
  - Hardware:
  - Software:
  - Programming Language Tools
  - Industrial Standard
  - Protocols
  - Other Features

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3. Sensor Network: Wired and Wireless

- **Sensor Node Platforms**
  - **Microcontroller**: TI MSP430-based, Atmel ATmega, IntelPXA255, etc
  - **Memory**: Program and Data
  - **Interface** (USB/Serial/WiFi/Ethernet)
  - **ADC and Digital I/O**
  - **Transceiver** (802.15.4-compliant, others)
    - XBee
    - TI CC2420
  - **Wireless Communication**
    - License-free frequencies
    - 433, 868-915 MHz, and2.4 GHz

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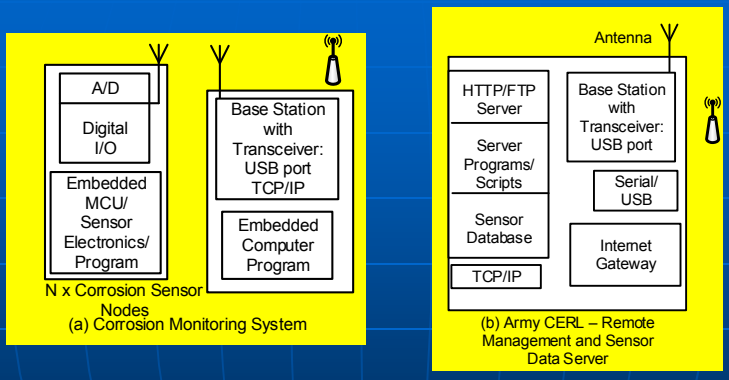
4. Corrosion Monitoring Sensor System:
System Architecture I with Wireless Sensor Node



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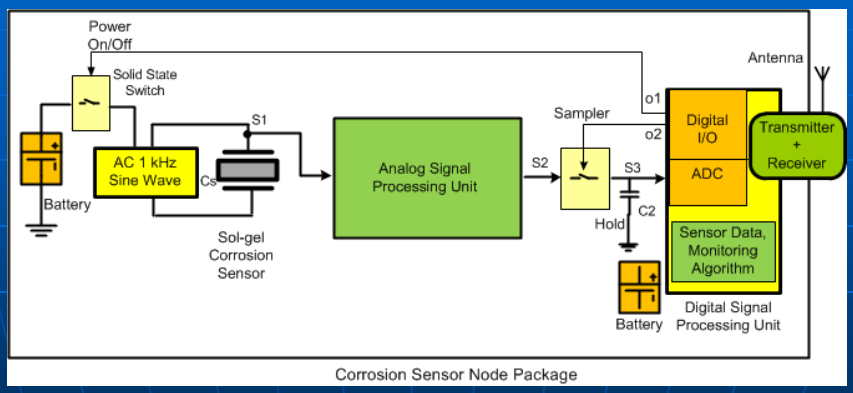
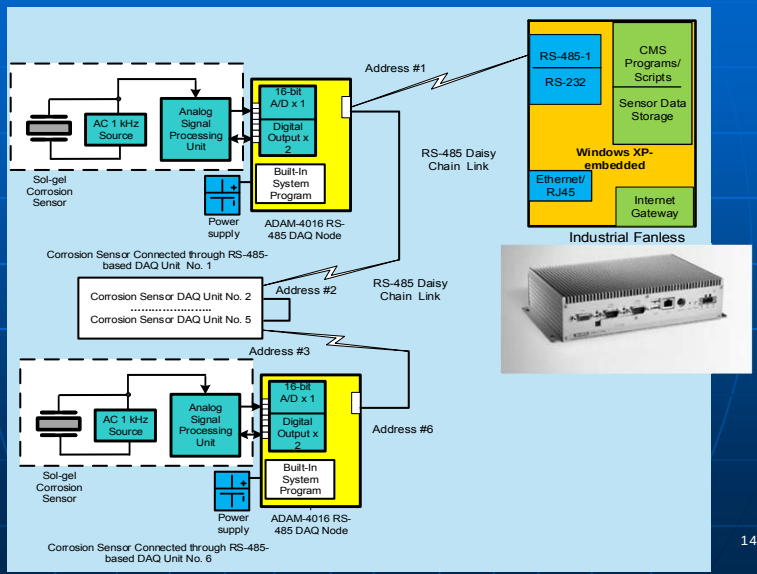
4.1 Remote Corrosion Sensor Node Design



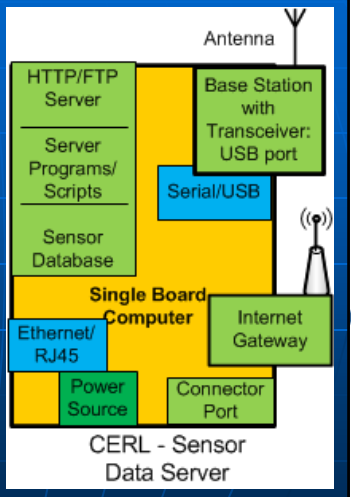
4.2 Corrosion Monitoring Sensor System:

System Architecture II with Wired Star Topology using RS 485 Serial Communication



4.3 Corrosion Monitoring System – Base Station

- Faneless Industrial Computer
  - HTTP Web server
  - FTP file server
  - Sensor data storage
  - Server scripts/programs
  - Data manipulation programs
- Internet Gateway
  - Remote system
  - Web client
- USB – WiFi wireless adapter
- RS 485, 232 Serial interface



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4.4 Corrosion Monitoring Sensor System (continue)

Corrosion Monitoring Sensor System (CMS)

a) Power supply system
b) The Central Monitoring Computer (CMC)
   - Fanless Embedded Computer, Windows XP OS setup and networking option configuration
   - RS485 serial communication: CMS to Sensor Nodes
   - Ethernet Ports for Internet communication
c) Thermal Electric Cooler: mounted on the front-side of the CMC
d) Six RS485-based Sensor Nodes with 16-bit ADC
e) Packaging and Cabling
f) Software for Polling Sensor Data Processing and Storage

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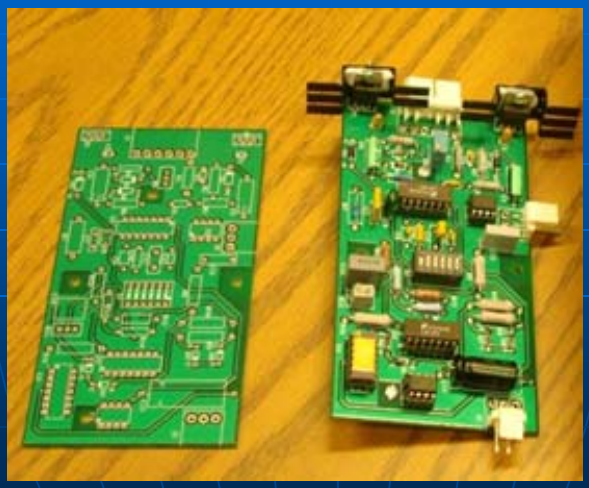
4.5 Analog Signal Processing Circuit and Fabrication of Printed Circuit Boards

Fabricated PCB Boards and ADMA 4016 ADC



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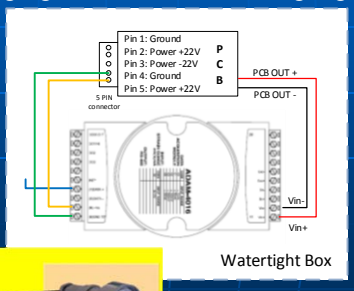
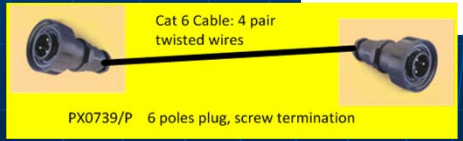
4.6 Corrosion Sensor Modules (Boxes)

Corrosion Sensor Modules (Boxes):

a) Power supply
b) RS-485 communication
c) Microcomputer with 16-bit ADC (analog-to-digital conversion)
d) Sensor Box Packaging with Sensor's analog signal processing PCB
e) Cabling



Watertight Box



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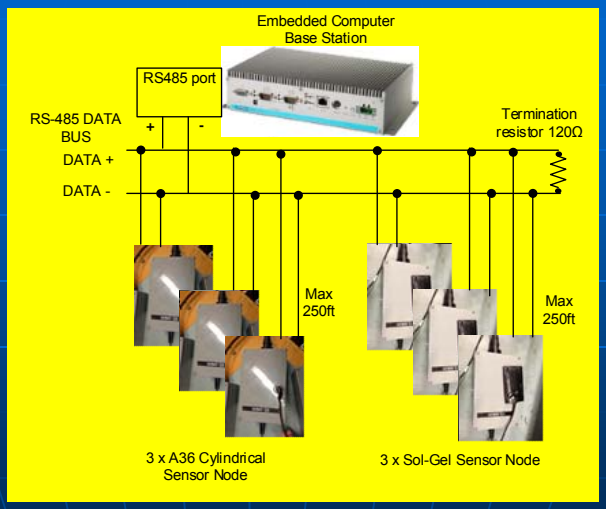
4.7 Corrosion Monitoring Sensor System
RS-485-based Wired Sensor Network



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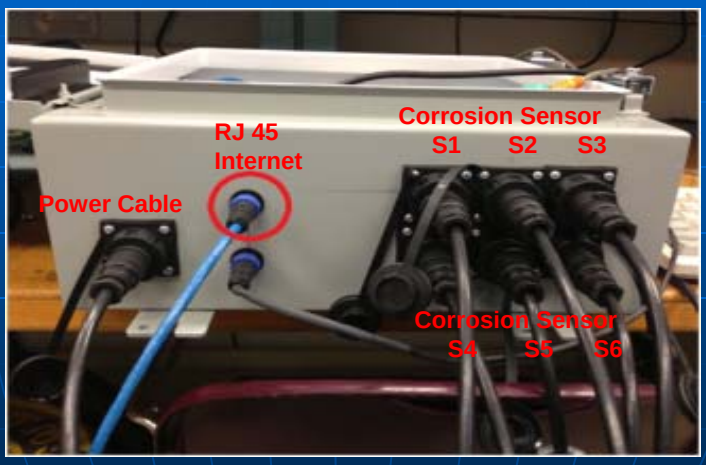
4.7 Corrosion Monitoring Sensor System

Packaging and Cabling



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4.8 Corrosion Monitoring Sensor System – Installation (May 2013)

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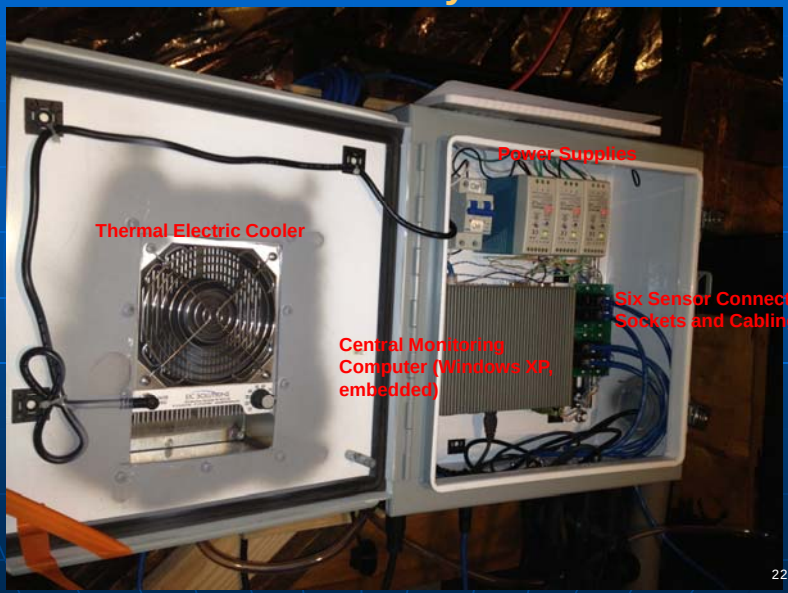
4.8 Corrosion Monitoring Sensor System Installation – May 2013



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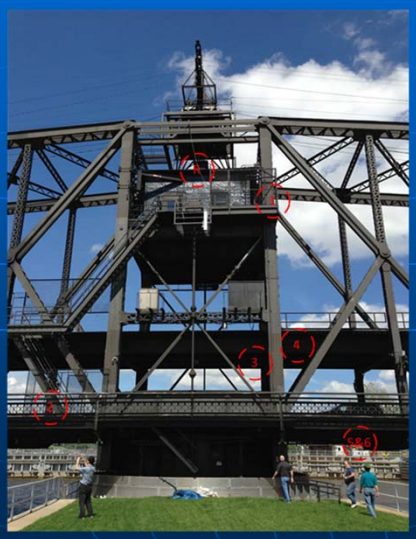
4.9 Deployment and Testing: Corrosion Sensors and Wired Sensor Network at RIA Bridge, IL



- Sensor #1 (coal tar epoxy coated sol-gel sensor)
- Sensor # 2 (coal tar epoxy coated sol-gel sensor)
- Sensor #3 (sol-gel sensor)
- Sensor #4 (sol-gel sensor)
- Sensor #5 (stainless steel cylindrical sensor, coal-tar epoxy coated) Sensor #6 (A36 cylindrical sensor, coal-tar epoxy coated)

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4.9 Deployment and Testing: Corrosion Sensors at RIA Bridge, IL

- **Sensor #1** (coal tar epoxy coated sol-gel sensor) at the lower car deck (31 inches above the deck, 2 ft above the car deck level, on the west side of the bridge)

Sensor #1

Sensor DAQ Box #1

Box#1 (before installation)

- **Sensor # 2** (coal tar epoxy coated sol-gel sensor) at the top of bridge control room (mounted on the vertically – south side)

Sensor #2

Sensor DAQ Box#2

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4.9 Deployment and Testing:
Corrosion Sensors at RIA Bridge, IL

- **Sensor #3** (sol-gel sensor) on the ceiling of the car deck, or below train deck (west side)

Sensor #3 and Sensor DAQ Box#3

- **Sensor #4** (sol-gel sensor) on the ceiling of the car deck, or below train deck (east side)

Sensor #4 and Sensor DAQ Box#4

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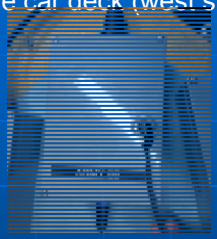
4.9 Deployment and Testing:
Corrosion Sensors at RIA Bridge, IL

- **Sensor #5** Cylindrical Sensor (316 stainless steel cylindrical rod and ring, coal-tar epoxy coated) under the car deck (west side)



Sensor #5 and Sensor DAQ Box#5

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4.9 Deployment and Testing:

Corrosion Sensors at RIA Bridge, IL

- **Sensor #6** Cylindrical Sensor (A36 cylindrical rod sensor, stainless steel outer ring, coal-tar epoxy coated) under the car deck (east side).

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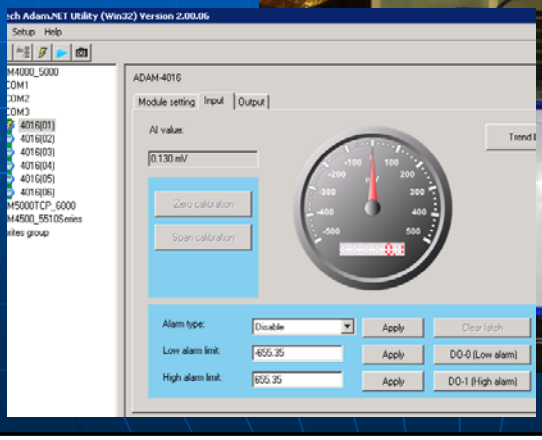
4.10 Testing of CMS with Sensor Nodes and Wired Sensor Network, RIA Bridge, IL

Initial Testing of Deployed Sensors using ADAM Utility & Spraying Water on Sensors



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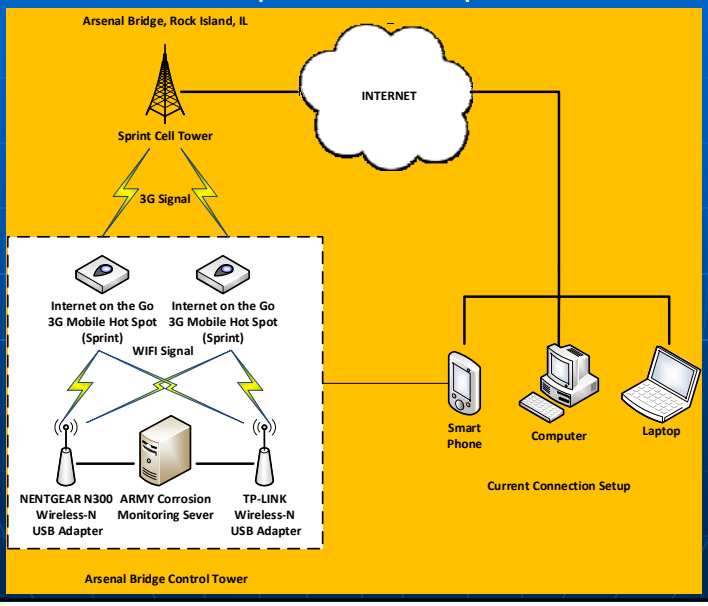
4.11 CMS Networking and Communication Subsystem

Redundant WiFi Hotspots and LAN Adapters



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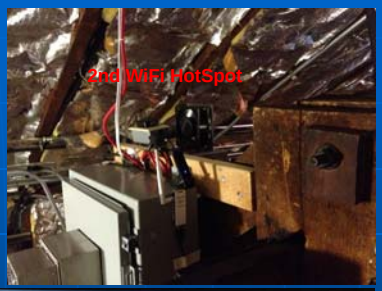
4.12 Redundant WiFi Hotspots and USB LAN Adapter



4.13 Corrosion Monitoring Sensor System

Server Scripts / Programs

- **CMS sensor data polling program**
  - Every 30 minute, read sensors capacitance/voltage value: S1,… S6
  - Add time stamps
  - Store sensor data S1, … S6
- **Sensor node control, data access**
- **Remote access to the CMS through a secured web client**
  - **Cloud storage service: DropBox**
  - **Cloud-based remote access - LogMeIn**

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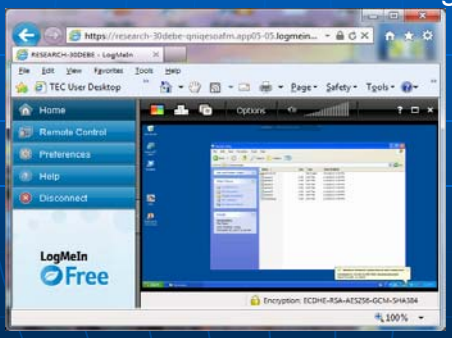
4.14 Sensor Data and Remote Data Collection

a) Data Collection and Storage
   - Data saved (every 30 minutes) at the CMS system located at RIA bridge

b) Cloud-based Remote Access: LogMeIn



c) Move data to Cloud-based Data Store: Drop Box

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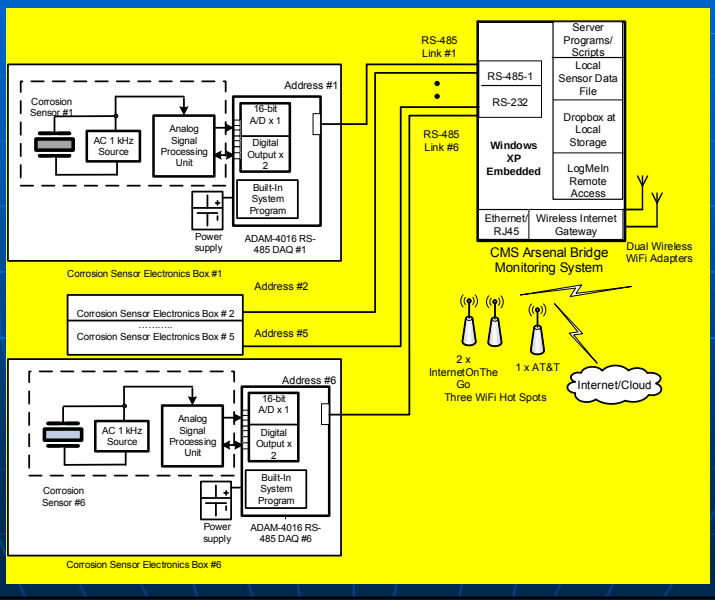
4.15 The Corrosion Monitoring System – Oct. 31, 2014



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5. The Second Generation CMS System:

Wired & Wireless Sensor Nodes and Networks

- Improved Internet and remote CMS system accessibility with at least one dedicated static IP address to provide better remote system access and maintenance support.
- Addition of Wireless Sensor Nodes and Networks to enhance the system reliability
- Additional local temperature and humidity data collection

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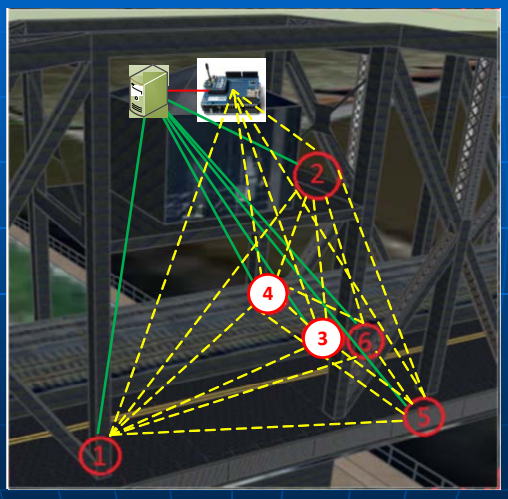
5. Second Generation CMS System:
Wired & Wireless Sensor Nodes and Network

- Wired Star Network: RS-485, Wireless Mesh Network



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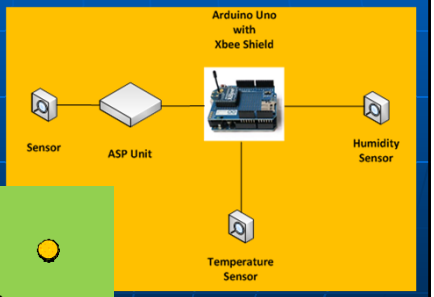
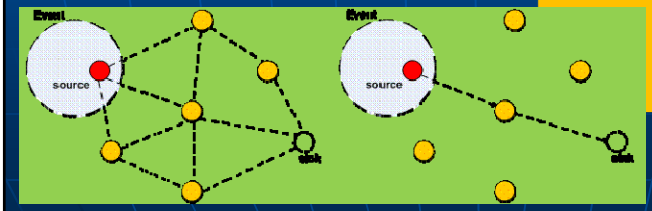
5. Second Generation CMS System:
Wired & Wireless Sensor Nodes and Networks

- Wireless Sensor Nodes and Network to enhance the system reliability
  - Redundant measurement using an extra wireless sensor node running ZigBee-based (XBee) sensor network protocol
  - Mesh sensor network to provide maximum reachability and data routing for each sensor





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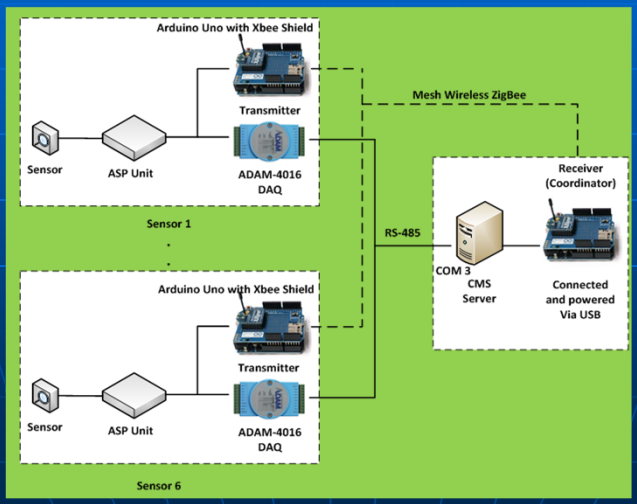
5. Second Generation CMS System:
Wired & Wireless Sensor Nodes and Networks

- Wireless Sensor Nodes and Networks to enhance the system reliability



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5. Second Generation CMS System:
Wired & Wireless Sensor Nodes and Networks

- Experimental Testing of Wireless Sensor Nodes and Networks in M.S. Tech Graduate Research Lab

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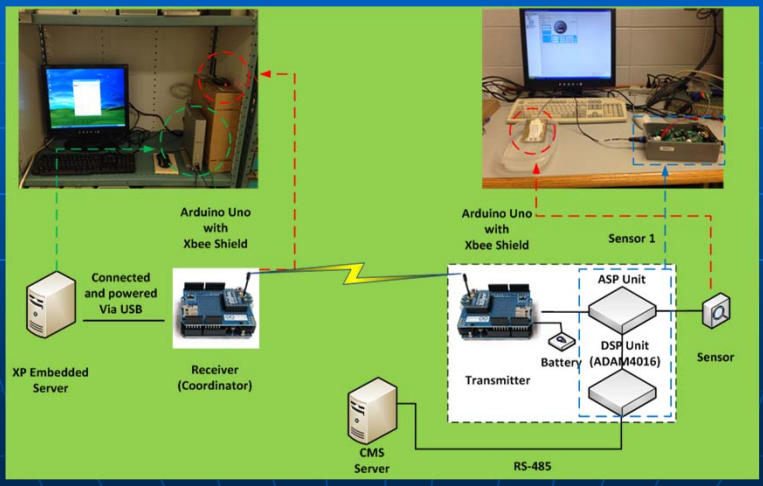
5. Second Generation CMS System:
Wired & Wireless Sensor Nodes

- Experimental Testing of Wireless Sensor Nodes and Network



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5. Second Generation CMS System:
Wired & Wireless Sensor Nodes and Networks

- Experimental Testing of Wireless Sensor Nodes and Networks (at Purdue U. Fort Wayne)

Table 1. Routing Table for the 2nd Generation CMS

	S1	S2	S3	S4	S5	S6
S1	0	3	2	2	4	4
S2	3	0	1	1	2	2
S3	2	1	0	1	2	2
S4	2	1	1	0	2	2
S5	4	2	2	2	0	1
S6	4	2	2	2	1	0

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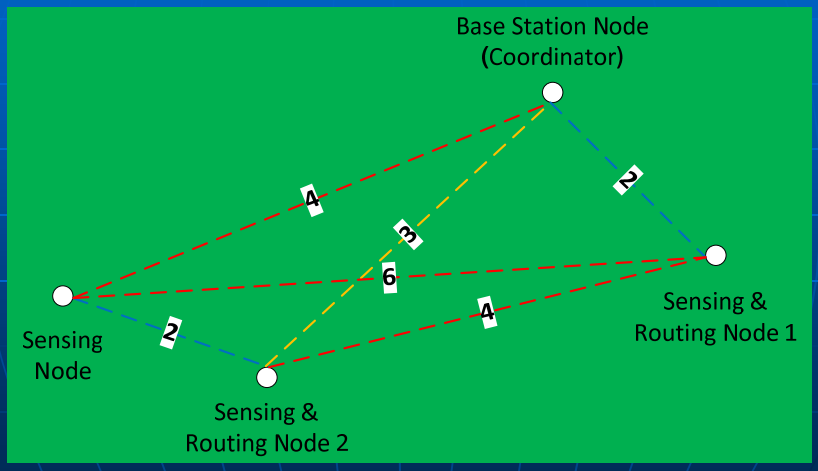
5. Second Generation CMS System:

Wired & Wireless Sensor Nodes and Networks

- Experimental Testing of Wireless Sensor Nodes and Networks to enhance the system reliability (4 nodes)



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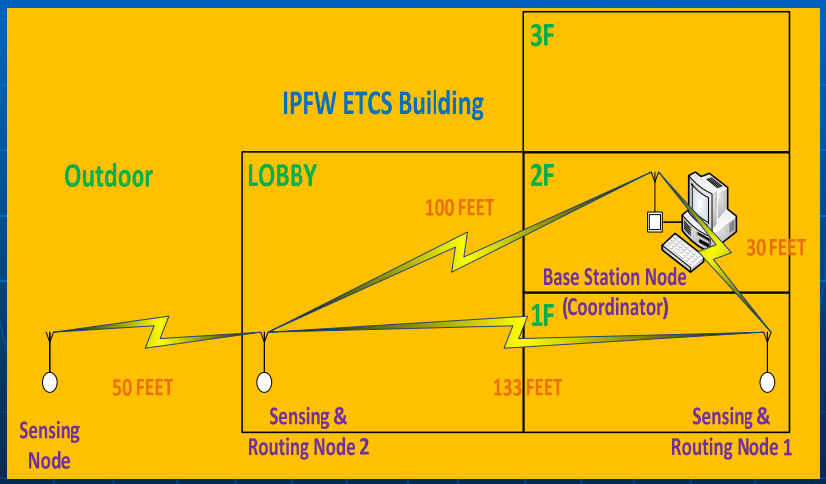
5. Second Generation CMS System:

Wired & Wireless Sensor Nodes and Networks

- Experimental Testing of Wireless Sensor Nodes and Networks to enhance the system reliability (4 nodes)



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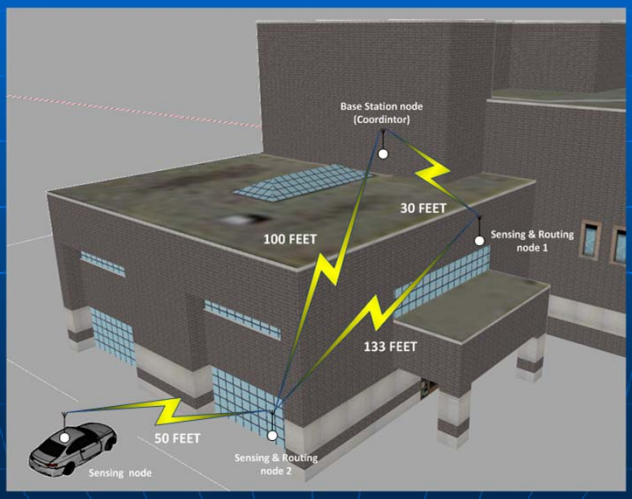
5. Second Generation CMS System:

Wired & Wireless Sensor Nodes and Networks

- Experimental Testing of Four Wireless Sensor Nodes and Network



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6. Summary and Future Work

- The star-based wired sensor network for Army Bridge's Corrosion Monitoring System deployed at RIA, IL has been running since May 2013
- Wires and wireless sensors version of the CMS has been discussed at CERL, IL on April 14, 2014
- Redesign new wireless sensor node which integrates the following modules and features (Luis Morale's Master of Science Directed Project, Spring 2014)
  - A new PCB board (surface mount)
  - Analog Signal Processing Subsystem – corrosion sensing
  - Xbee (Zigbee based transceiver with antenna)
  - Temperature, humidity, and barometric pressure sensing
  - Adurino Fio versions 2 and 3

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Conclusion

Any Questions?

Thank you!!!

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