Wireless Sensor Nodes for Corrosion Monitoring System

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Abstract/Executive Summary

- Over the last three (3) years Indiana-University Purdue-University Fort Wayne (IPFW) has been engaged in the development of a corrosion monitoring system using state-of-the-art sol-gel sensors and cylindrical sensors. This activity is a joint venture with the Army Construction Engineering Research Laboratory (CERL) and is focused at establishing a system that is capable of monitoring the level/degree of corrosion of steel and steel structures. The project in itself has seen many design stages, each of which has improved the sensing capabilities, ranges and overall robustness of the system.
- The author was involved in implementing design techniques which would significantly reduce the physical size, and improve the capabilities of the system. The design scope also required an analysis into various sensors and wireless communication techniques available for consumer and industrial applications.
- Research was conducted in order to properly incorporate a new generation of an Arduino product, which would enable a modular and versatile wireless sensor node. Additional sensing capacity such as; temperature, humidity and barometric pressure were incorporated. The additional data captured is critical in order to properly analyze and predict the main factors attributed to the corrosion of steel and a steel structure.

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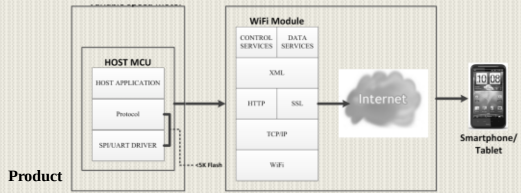
Introduction

- Consumer and Industrial products are expanded through wireless connectivity
  - Features include:
    - Remote Control, Monitoring, Diagnostics, & Troubleshooting
- Basic Sensors measure
  - Temperature, Humidity, Pressure, & Motion
- Fundamental Connectivity include
  - Product w/ Host Microcontroller, Sensors, Connectivity Module, Cloud Service and User Interface



Statement of the Problem

- A Sensor Network has been developed by IPFW and the Army as a joint project with the objective to provide an integrated system that is capable monitoring and predict corrosion on a steel surface or infrastructure.
- The initial design required extensive wiring and various power levels, which affected the overall reliability and robustness of the system.
- The second phase of the project investigated the feasibility of a potential open-source wireless solution. Reliable communication was established and long range testing surpassed expectations. The system was not optimized for packaging, as an off-the-shelf solution was implemented with the existing ASP (Analog Signal Processing Unit).

Significance of the Problem

- The development and integration of a wireless sensor network is the ideal solution for a system that requires multiple sense locations and data being transmitted (wired or wirelessly) to a central control hub.
- Phase 0 and Phase 1 of the Corrosion Monitoring System (CMS) provided the building blocks and fundamental understanding of the main problem and potential solutions.
- This exercise will expand on the knowledge that was obtained, and will expand system packaging and functionality.
- The fundamental design remained in-tact, as its basic functionality has been proven.

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Statement of the Purpose

- The Wireless Sensor Network - Corrosion Monitoring System will need to be redesigned with the goal of providing a smaller profile, more reliable solution.
- Components will be cross referenced, newer, more precise and lower cost components are implemented into the design.
- The ASP (Analog Processing Unit) must be an integrated solution with the Host MCU and Wireless Transceiver modules.
- Additional sensors will be integrated to further understand a larger scope of the environment to which the system and infrastructure is exposed to.

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Review of Literature/Background

- Wireless communication has been implemented in:
  - Healthcare, Military, Consumer Electronics, Home Automation,
  - Security and Sensor Networks
- Sensor Lead Time and Costs have decreased
- Commercialized communication protocols include:
  - Bluetooth, Zigbee, Wi-Fi

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Review of Literature/Background Cont.

- Bluetooth
  - Operates in the 2.4GHz - 2.4835GHz, Up to 1Mbps data rate
  - Mostly used in the Cell Phones, Keyboards, Mice, Printers
  - Challenges include:
    - Application Topology Flexibility, Auto Configurability, Power Consumption
  - Network Topologies:
    - Piconet (adHoc) - Master w/ Seven (7) Slaves
    - Scatter (Two (2) or more Piconets

Type	Power	Max Power Level	Designed Operating Range	Sample Devices
Class 1	High	100mW (20dBm)	Up to 100 meters (328 Feet)	USB Adapters, Access Points
Class 2	Medium	2.5mW (4dBm)	Up to 10 meters (33 Feet)	Mobile Devices, Bluetooth Adapters, Smart Card Readers
Class 3	Low	1.0mW (0 dBm)	Up to 1 meter (3 Feet)	Bluetooth Adapters

Bluetooth Class Definitions

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Review of Literature/Background Cont.

- Zigbee
  - Designed for Low Cost, Long Battery Life and Flexibility
  - IEEE 802.15.4 Standard
  - Frequencies include: 868MHz, 902-928MHz & 2.4GHz
  - Zigbee Alliance:
    - Focused on establishing standards across products and a support network
    - 200+ participants, across various levels of involvement
  - Topologies:
    - Star, Peer-to-Peer, and Mesh Networks

Frequency Band (MHz)	Data Rate (kb/s)	Channel Numbers	Geographical Area
868.3	20	1	Europe
902-928	40	1-10	America, Australia
2405-2480	250	11-26	Worldwide

Frequency Bands Based on Location

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Review of Literature/Background Cont.

- Wi-Fi
  - Revolutionized LAN's (Local Area Networks)
  - IEEE 802.11 Standard
    - 802.11b – capability of data rates up to 11Mbps @ 2.4GHz
    - 802.11a – capability of data rates up to 54Mbps @ 5.0GHz
    - 802.11g – capability of data rates up to 22Mbps
    - 802.11e - is being developed for higher operation standards
  - Topologies
    - STA's – Wireless Client Radios (Stations)
    - AP's – Bridge between Wired and Wireless LAN's (Access Point)

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Review of Literature/Background Cont.

- "Drop-In" Modules have been released for commercial and industrial development
- Basic RF Terms:
  - Reflection – Radio waves can be reflected by other materials
  - Absorption – Radio waves can be absorb by other materials
  - Geometric Spreading Loss – The radio waves loose power as the expand and get further away from their source
  - Path Loss – Weakening of the signals due to distance, similar to above

	ZigBee & 802.15.4	**GSM/GPRS/CDMA**	**802.11**	**Bluetooth**
Focus Applications	Monitoring & Control	Wide Area Voice & Data	High Speed Internet	Device Connectivity
Battery Life	Years	1 Week	1 Week	1 Week
Bandwidth	250Kbps	Up to 2Mbps	Up to 54Mbps	720 Kbps
Typical Range	100+ Meters	Several Kilometers	50-100 Meters	10-100 Meters
Advantages	Lower Power, Cost	Existing Infrastructure	Speed, Ubiquity	Convenience

Wireless Technologies Comparison

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IoT - Definition

"A scenario in which objects… are provided with unique identifiers and the ability to automatically transfer data over a network without requiring human-to-human or human-to-computer interaction." [24]

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IoT - Services

- IoT Services improve:
  - Reliability, Facilitate Forecasting, Reduce Waste, Prevention and Prediction of conditions
- Services include:
  - Remote Access (Lighting & Security), Diagnostics, Warranty Verification, Firmware/Software Update
- Applications include:
  - Medical – Patient Monitoring,
  - Farming – Animal with a biochip transponder
  - Automotive – Tire Pressure Sensors, Proximity Sensors
  - Industrial – Equipment Fault Alert System
  - Commercial – Smart Appliances (Refrigerators, Washers, Dryers, Television, Garage Door Openers, Outlets)

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IoT – Services Cont.

- Information/Analysis Scenarios
  - Enhanced Tracking Behavior – Embedded sensors can provide the location of products or services. In a rental car, location awareness can assist with locating services such as; gas stations, hotels and restaurants
  - Enhanced Situational Awareness – Infrastructure deployed sensors can provide an outlook on road condition, traffic patterns, environmental conditions, and crime reduction through the use of video, audio and vibration detection.
  - Sensor-Driven Decision Analytics – Retail chains can deploy sensors through the store and measure which displays or in store advertisement catch an individual's attention as well as the duration of the attention. This would assist in improving advertisement techniques to better attract customers [23]

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IoT – Services Cont.

- Automation/Control Services
  - Process Optimization – RFID sensor based design can improve a manufacturing facility, by capturing key pieces of information, process flow improvements can be made, and bottleneck processes can be eliminated or reduced
  - Optimized Resource Consumption – the incorporation of a "smart home" could improve power consumption by remotely reducing the power consumed by larger appliances during peak demand times
  - Complex Autonomous Systems – this includes systems that are aware of their surroundings and are able to make decisions based on a change in the environment. One key example is an autonomous automobile. Sensors would be responsible for maintaining safe drive speeds and distances, and would be responsible for proper responses or corrections in the event of an external trigger [23]

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IoT – Development Trends

- Corporations are looking to expand WSN, in order to:
  - Improve Reliability of products or goods
  - Predict premature failure of products or good
  - Provide targeted information to consumers
  - Expand access to products or goods
- Next Generation Integration include:
  - Home Automation
  - Smart Energy
  - WBAN (Wide Body Area Networks)

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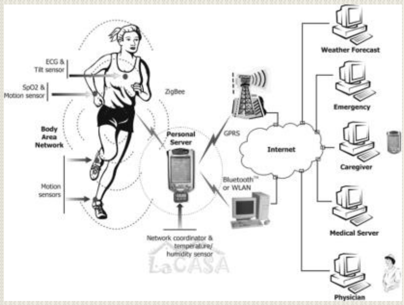
IoT – Development Trends Cont.

- Wide Body Area Networks (WBAN)
  - Wearable Sensors strategically placed
  - Used for Patient and Athletes Monitoring
    - Rehabilitation, Workout Analysis
    - Improves Rehabilitation Time, Optimized Workout Routines
    - Limiting the Risk of additional injury



Wireless Body Area Network for Health Monitoring [27]

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IoT - Technologies

- Home Automation has been developed using a number of protocols
  - X10 – “granddaddy” of home automation,
    - Initially PLC (power line communication) based
    - Operates in the 310MHz and 433MHz
  - Z-Wave – Proprietary owned by Sigma Designs, 900MHz
  - Insteon – Mesh Topology, Backwards compatible with X10
  - Zigbee –
  - Wi-Fi –

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IoT – Reported Projects

- Lowe's Iris:
  - Developed through AlertMe in the UK.
  - Comprised of a number of motion, proximity and activity sensors
  - Communicate to a central hub, through Z-Wave ad Zigbee.
  - The central hub communicates to home router using Wi-Fi.
  - Cost ranges from $129 for a wireless video camera, to $299 kits
- Vivint:
  - Packaged home automation, smart energy management, home security and solar energy.
  - Centralized the Go!Control
  - Costs around $699
- JDS Technologies:
  - Complete home automation system.
  - Compatible with Insteon, X10, IR and RS232.
  - Costs around $499

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IoT – Reported Projects Cont.

- SmartThings:
  - Home automation features key tracking & window open/door sensors.
  - Compatible with Zigbee and Z-Wave
  - Costs for 2 hubs and 6 sensors is about $323.
  - Additional outlets - $35 & additional motion/open-close sensors $25
- HomeSeer:
  - Features climate control, security, lighting, audio/video control
  - Utilizes X10, Insteon and Z-Wave.
  - Costs around $499.95
- mControl:
  - Features an integrated HD-DVR for security cameras, data logging, energy management, media control, and professional system connectivity.
  - Compatible with X-10, Insteon, Z-Wave, and Zigbee.
  - Costs around $370

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IoT – Reported Projects Cont.

- Additional Top Home Automation Systems
  - ADT Pulse
  - Revolv Smart Home Automation Solution
  - AT& T Digital Life
  - TaHoma by Somfy
  - Savant SmartSystems

- Commercialized Stand-Alone Products
  - SmartHome Brand – (motion sensors, thermostats, IP Security Cameras),
  - Belkin WeMo – (home light switch, motion sensors, Wi-Fi Based Baby monitors)
  - Nest Learning Thermostat – Wi-Fi based self-learning thermostat
  - Nest Protect - Smoke and Carbon Monoxide Detector

	X10	Z-Wave	Insteon	Zigbee	WiFi	Cost
Lowe's Iris		x		x	x	$299.00
Vivint		x				$699.00
JDS Tech.	x		x		x	$499.00
SmartThings		x		x	x	$323.00
HomeSeer	x	x	x		x	$499.95
mControl	x	x		x	x	$370.00
ADT Pulse		x			x	$99.00
Revolv		x	x		x	$299.00
AT&T Digital Life		x				$149.00
TaHoma		x			x	$2,500.00
Savant		x	x		x	Customizable

Home Automation Systems Matrix

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Backbone of IoT/Home Automation

- Corporations leverage on Cloud Service Providers
  - IaaS – Infrastructure (Servers, Storage, Networks)
  - PaaS – Platform (databases, web server)
  - SaaS – Application (communication, virtual desktops)

- Research was conducted on three Cloud Service Providers
  - Provide end-to-end platform for IoT designs
  - Facilitate Connectivity to the Cloud Target OEM's with easy, secure, and cost effective internet connected devices
  - Provide a drop-in platform solution

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Backbone of IoT/Home Automation Cont.

- Cloud Service Providers assist in:
  - Hardware:
    - Wi-Fi Chip/Module Selection
    - Controllable Power Supply
    - Antennas
    - Certifications
    - I/O Signal Compatibility
  - Software:
    - IP Stacks
    - SSL/Security/Certificates
    - Wi-Fi Network Connectivity
    - Firewall Management
    - Communications Protocols: Email, SMS, Twitter, Facebook, etc…
    - Micro Processor Drivers
    - Flexible API (Application Programming Interface)
  - Cloud Services:
    - Security & Certificate Management
    - Redundant Scalable Server Architecture
    - Scalable and Robust Databases
    - API for iPhone, Android and HTML
    - Connectivity to other web services
    - Data Analytics

Backbone of IoT/Home Automation Cont.

- Cost Analysis was conducted, with a quote being provided for the requested services
  - Monthly Service Fee: $1.10 per 50k EAU

Cloud Connectivity Solutions

	Description	Lead Time	Cost
Phase 0	Device Platform and Board Development	2 weeks	$ 8,500.00
	- Protocol Setup		
	- Data Simulation Setup		
	- Basic Data Visualization		
Phase 1	Mobile APP Development	6-8 weeks	$ 5,500.00
	- IOS Application (ON/OFF/Rx/Tx/Log)		
Phase 2	Production Development	16 weeks	$ 135,300.00
	- Application Architecture		
	- Project Management		
	- UI Designer		
	- Software Leader		
	- Software Developer - Mobile		
	- Software Quality Assurance		
		Total:	$ 149,300.00

Cloud Connectivity Solution Development Costs

Backbone of IoT/Home Automation Cont.

- Examples:
  - Craftsman AssureLink Garage Door Opener
  - Retrofit Unit Available for $129.99 (Sears)
    - Setup: Connect Gateway, Add Devices (Garage Door Opener)
  - Belkin WeMo Switch
    - Available for $49.99

Belkin Wi-Fi Enabled Switch

AssureLink Retrofit Kit

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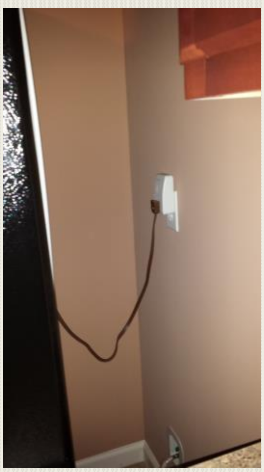
Backbone of IoT/Home Automation Cont.

- Examples:
  - Craftsman AssureLink Garage Door Opener – Home Installation
  - Wi-Fi Outlet – Power Management (Refrigerator)



Wi-Fi Enabled Outlet

AssureLink

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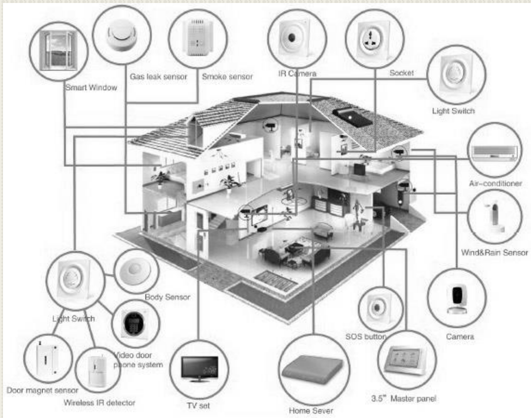
IoT – Smart Appliances

- "A smart space environment is characterized by the presence of intelligence in the presence of everyday objects." [5]



Smart Home Appliances Overview [6]

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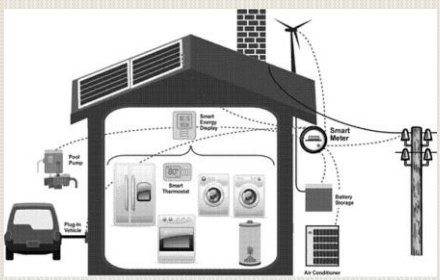
IoT – Smart Grid App

- Wireless Sensor Networks, Smart Appliances and Home Automation would tie into a Smart Grid Infrastructure
  - HAN (Home Area Network) w/ centralized EMS (Energy Management System)
  - Components will include: dishwasher, washer, dryer, refrigerator, televisions, water heaters, HVAC systems, etc…
  - Pro's: Demand Levelling, Green Incentives, Latest Tech.
  - Con's: Privacy Concerns



Smart Home Integration [9]

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Home Automation with Arduino

- Arduino – User friendly development environment
  - Phase 1 – Developed with the Arduino UNO
  - Phase 2 – Developed with the Arduino FIO

Name	Processor	Operating Voltage	CPU Speed	Analog I/O	Digital I/O PWM	EEPROM [KB]	SRAM [KB]	Flash [KB]	USB	UART
Uno	ATmega328	5 V/7-12 V	16 Mhz	6/0	14/6	1	2	32	Regular	1
Due	AT91SAM3X8E	3.3 V/7-12 V	84 Mhz	12/2	54/12	-	96	512	2 Micro	4
Leonardo	ATmega32u4	5 V/7-12 V	16 Mhz	12/0	20/7	1	2.5	32	Micro	1
Mega 2560	ATmega2560	5 V/7-12 V	16 Mhz	16/0	54/15	4	8	256	Regular	4
Mega ADK	ATmega2560	5 V/7-12 V	16 Mhz	16/0	54/15	4	8	256	Regular	4
Micro	ATmega32u4	5 V/7-12 V	16 Mhz	12/0	20/7	1	2.5	32	Micro	1
Mini	ATmega328	5 V/7-9 V	16 Mhz	8/0	14/6	1	2	32	-	-
Nano	ATmega168 ATmega328	5 V/7-9 V	16 Mhz	8/0	14/6	0.512 1	1 2	16 32	Mini-B	1
Ethernet	ATmega328	5 V/7-12 V	16 Mhz	6/0	14/4	1	2	32	Regular	-
Esplora	ATmega32u4	5 V/7-12 V	16 Mhz	-	-	1	2.5	32	Micro	-
ArduinoBT	ATmega328	5 V/2.5-12 V	16 Mhz	6/0	14/6	1	2	32	-	1
Fio	ATmega328P	3.3 V/3.7-7 V	8 Mhz	8/0	14/6	1	2	32	Mini	1
				6/0						
Pro (168)	ATmega168	3.3 V/3.35-12 V	8 Mhz	6/0	14/6	0.512	1	16	-	1
Pro (328)	ATmega328	5 V/5-12 V	16 Mhz	6/0	14/6	1	2	32	-	1
Pro Mini	ATmega168	3.3 V/3.35-12 V 5 V/5-12 V	8 Mhz 16Mhz	6/0	14/6	0.512	1	16	-	1
LilyPad	ATmega168V ATmega328V	2.7-5.5 V/2.7-5.5 V	8 Mhz	4/0	14/6	0.512	1	16	-	-
LilyPad USB	ATmega32u4	3.3 V/3.8-5V	8 Mhz	4/0	9/4	1	2.5	32	Micro	-
LilyPad Simple	ATmega328	2.7-5.5 V/2.7-5.5 V	8 Mhz	4/0	9/4	1	2	32	-	-
LilyPad SimpleSnap	ATmega328	2.7-5.5 V/2.7-5.5 V	8 Mhz	4/0	9/4	1	2	32	-	-

Arduino Product Line [Source: Arduino.cc]

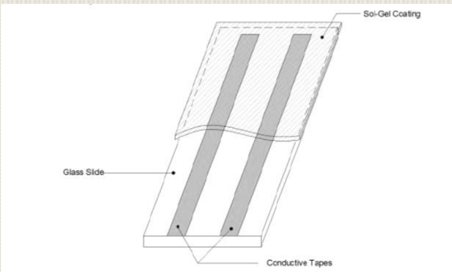
Home Automation with Arduino Cont.

- Easy integration with Digi XBee RF Modules
  - XBee Shields (Adapter Modules) available for easy integration
  - Arduino FIO contains on-board header for XBee
    - Various signal strengths 0dBm (300ft) to +25dBm (25 miles)
    - Protocols include: IEEE 802.15.4 or IEEE 802.11 (Wi-Fi), Proprietary, Mesh and Smart Energy Public Profiles

- Example Projects include:
  - Doorbells, Window and Door Sensors
  - Water Level Sensors
  - Security Alert System
  - Bird Feeder Sensor – Utilizing a capacitive based sensor
  - Weight Sensor
  - Wi-Fi Enabled Light Switch
  - Remote Control Curtain Actuator

Phase 0

- Corrosion Monitoring through Sol-Gel capacitive sensor
  - Two aluminum conductive plates, adhered to a glass plate
  - Coated with $SnCl_4$ (Tin Tetra Chloride) and/or $InCl_3$ (Indium Tri Chloride)
  - 5V/1.5V 1kHz signal placed across the plates
  - Created a capacitive sensor



Sol-Gel Sensor [10]

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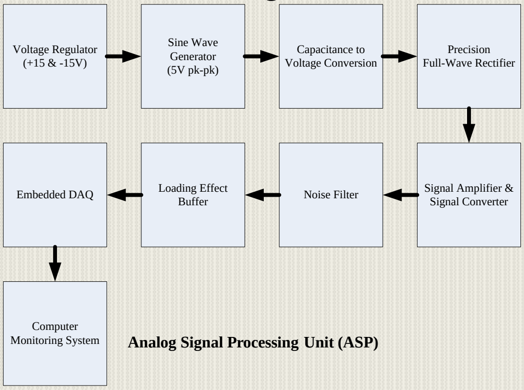
Phase 0 Cont.

- Capacitance measure and converted to voltage using an ASP
- ADAM-4016 A/D, RS485 serial based for data capturing
- Required +/- 22Vdc
- Deployed at the Arsenal Bridge - Rock Island, IL. 5/2013



Analog Signal Processing Unit (ASP)

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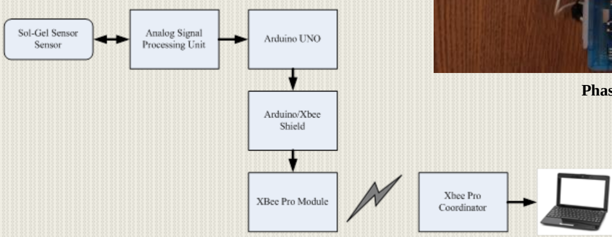
Phase 1 – Arduino UNO

- An attempt to increase flexibility and reliability
- Arduino UNO, XBee Shield, XBee Module + ASP selected as the next step solution
- Not an integrated solution

Phase 1 Solution



Phase 1 Solution Block Diagram

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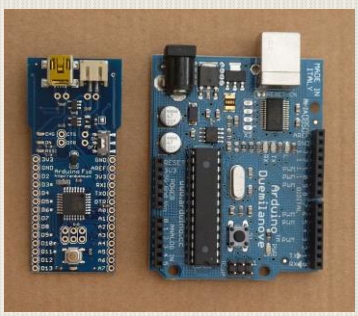
Phase 2 – Arduino FIO

- Arduino FIO V2.3:
  - ATmega328P, 14 Digital I/O, 8 Analog Inputs, UART
  - 3.3Vdc Working Voltage
  - Lithium Ion Battery Connector
  - USB Charge Connector
  - XBee On-Board Header



Arduino FIO vs Arduino UNO

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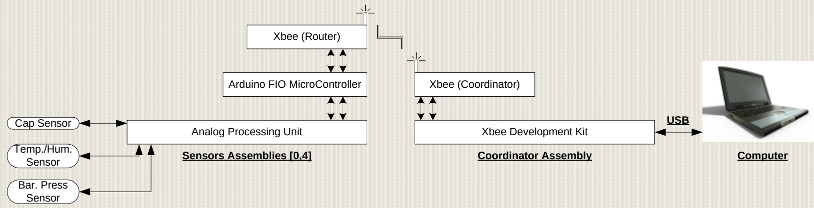
Network Node & Network Architecture

- Sensor Network comprised of:
  - 3 Sensor Nodes
  - 1 Network Coordinator
  - Capacitive, Temperature, Humidity & Pressure Sensors
  - 9600 bps at 2.4GHz
- Coordinator/Router Configured in AT Mode
  - AT Mode: Transparent with Single Coordinator
  - Data is automatically received, packaged & transmitted
  - API Mode: Destination address can be dynamically changed



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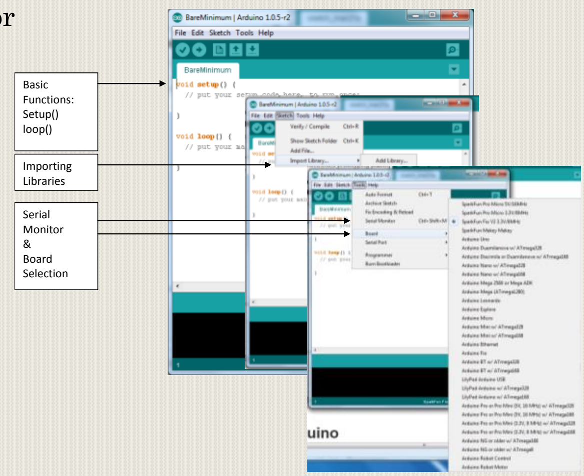
XBee Sensor Node & Coordinator

Arduino & Digi XBee IDE

- Arduino: Arduino IDE 1.0.5-r2
  - Single Page Compiler, Downloader, Data Monitor, Fault Indicator



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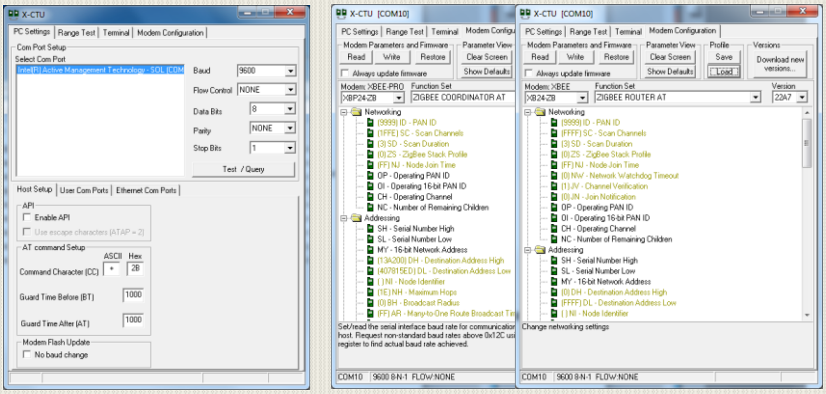
Major Functions of the Arduino IDE

Arduino & Digi XBee IDE Cont.

- Digi XBee: X-CTU, ver. 5.2.8.6
  - Utilizes the XBIB-U-DEV,
  - Drivers must be downloaded from www.digi.com
  - Settings: 9600 baud rate, 8 data bits, 1 stop bit



XBee Coordinator & XBee Router Properties Windows

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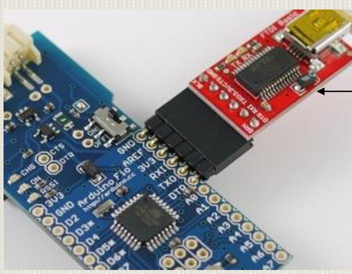
Programming Breakout Board (FIO V2.3)

- Arduino FIO V2.3 is pre-burned with a bootloader,
- USB port is strictly +5V Charge
  - D+ and D- are non-connect on the circuit board
- Purchase of an FTDI Programming Board Required
- Cost is: $14.95



FTDI Breakout Board

FTDI 3.3V Breakout Board

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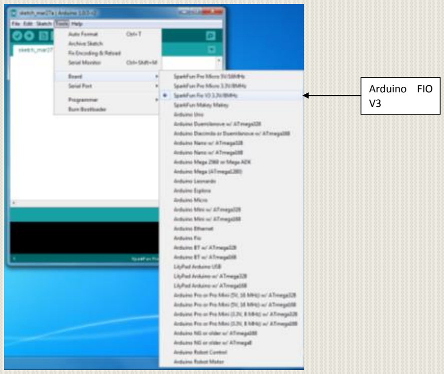
Programming Add-On (FIO V3.0)

- ADD-ON Files are required for Arduino FIO V3.0
  - Drivers and Arduino IDE Upgrade
  - Configures the IDE compatibility with FIO V3.0
  - Downloadable from sparkfun.com, must be placed within the "Hardware" folder of the IDE sketchbook



Additional Board Capabilities

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Design Considerations and Req.

- Development of Integrated Wireless Sensor Network with expanded sensing capabilities
- Explore Development with the recently released FIO V3.0
- Plan:
  - Step 1: Analyze the existing Arduino Uno conceptual design
  - Step 2: Analyze the software architecture
  - Step 3: Port the Software into the Arduino FIO V2.3/3.0
- Initial Design Utilized port, A0 – Capacitive Sensor Input
- Utilized functions (Arduino):
  - digitalWrite() – Turn On LED D13
  - delay() – LED ON/OFF Delay Time
  - analogread() - Read Analog Port (A0)

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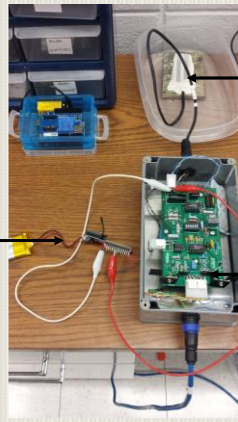
Sensor Node w/ FIO V2.3

- Utilized Function (FIO V2.3):
  - serial.print() – data out function
  - Utilizes Arduino FIO header and UART for communication to XBee Module
  - Initial Testing:
    - Connected Arduino A0,
    - Developed 3 total prototypes using solder-less breadboards



Initial Arduino FIO V2.3 Prototype Testing

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Sensor Node w/ FIO V3.0

- Arduino FIO V2.3 utilizes ATmega328P
- Arduino FIO V3.0 utilizes ATmega32u4

- Challenges:
  - Different Pin Locations
  - FIO V3.0 serial1.print() rather than serial.print() for UART Output
  - Different pins_arduino.h required to run FIO V3.0
  - Different software files and programming process was required for FIO V3.0

- Benefits:
    - On Board programmability (USB)
      Breakout board not required

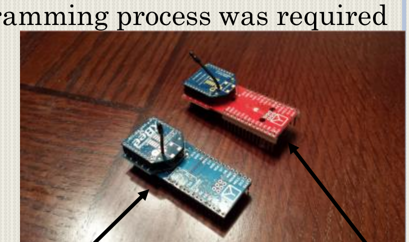

Figure 1: Arduino Fio V2.3 and V3.0

SENSOR NODE ROUTER & COORDINATOR

- Digi XBee modules were configured through these four main parameters
  - PAN ID: (Personal Area Network) Set as '9999'All XBee modules must have the identical PAN ID for proper communication.
  - Node Addressing: (Destination Address Low) Set as 'FFFF' for full broadcasting
  - Channel Verification: Set as '1' on all Routers to ensure the verification of the PAN ID
  - Serial Interface Data Rate: Set as '9600' for all nodes on the network

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SENSOR FUNCTIONALITY – DHT22

- Low Cost, Robust, Highly Accurate Component
- Four Pins: Vcc, Data (PWM), Ground
- Serial Data:
  - **Data**:
    - 8bit integral RH data + 8 bit decimal RH data + 8 bit integral Temp. data + 8 bit decimal Temp. data + 8 bit check-sum
  - **Checksum**:
    - 8bit integral RH data + 8 bit decimal RH data + 8 bit integral Temp. data + 8 bit decimal Temp. data
      - **RH**: (0000 0010 1000 1100)/10 = 65.2% RH
      - **Temp.**: (0000 0001 0101 1111)/10 = 35.1°C
      - **Check Sum**: (0000 0010 + 1000 1100 + 0000 0001 + 0101 1111) = **1110 1110**

	Humidity Range	Humidity Accuracy	Temp. Range	Temp. Accuracy	Sampling Rate
DHT11	20-80%	5%	0-50C	+/- 2C	1Hz
DHT22	0-100%	2-5%	-40-125C	+/- 0.5C	0.5Hz

Humidity Sensor Comparison Matrix

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Sensor Functionality – BMP180

- BOSCH - Low Cost, I^2C (Inter-Integrated Circuit) Serial Device
- Pins Required: Vcc, Ground, SCL, SDA
- Utilizes Arduino FIO SCL and SDA pins
  - FIO V2.3: SDA 27 (A4), SCL 28 (A5)
  - FIO V3.0: SDA 19 (D2), SCL 18 (D3)
- Data:
  - At start condition, the SCL is in a High ‘1’ state and the SDA is in a falling edge
  - 7-Bit register address is sent along with the R/W direction bit
  - ACK is sent on the 9th SCL cycle, by pulling SDA low ‘0’
  - Stop state, SCL is High ‘1’ state, and SDA is on a rising edge

	Temperature Range	Temperature Accuracy	Press. Range	Press. Accuracy
BMP180	0C-65C	0.1C	300-1100hPa	1Pa/0.01hPa/0.01mbar

Barometric Pressure Sensor Range

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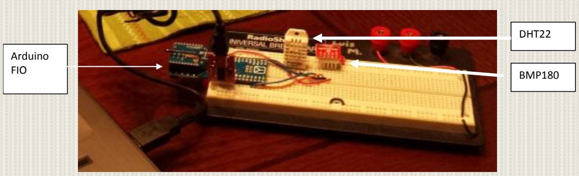
Prototype Assembly

- Arduino FIO contains 0.100” (2.54mm) pin spacing
  - Assembled in standard solder-less breadboard
  - 1 prototype used for initial development/testing unit built
  - 2 subsequent prototypes built



Initial Complete Prototype

Network Coordinator + 3 Prototype Sensor Nodes

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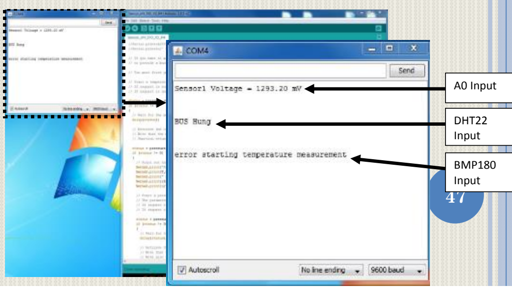
Prototype Software Development

- Software Development Steps:
  - a) Software Porting (A0 Read Functionality)
  - b) DHT22 and BMP180 libraries were imported and configured
  - c) DHT22 Sensor sample code was imported/modified/tested
  - d) BMP180 Sensor sample code was imported/modified/tested

  - Hardware purchase lead-time allowed for the development of the software basic functionalities



Software Testing

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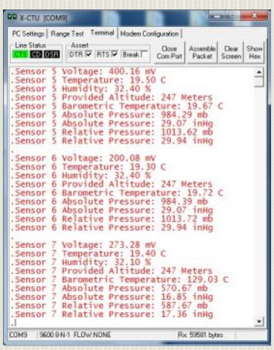
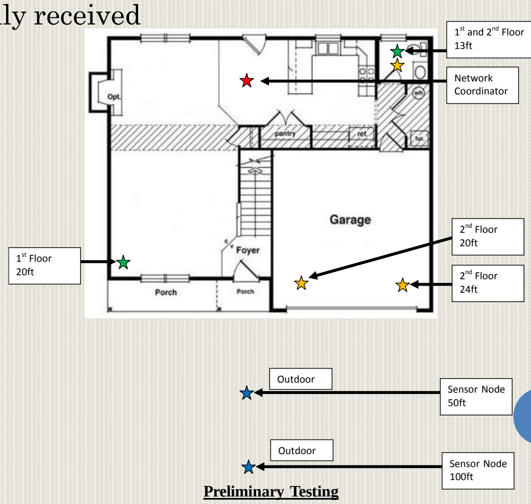
Prototype Testing

- Prototypes were placed at various locations/distances
  - Indoor and Outdoor Environment
  - Data was successfully received



Sample Data Received



Preliminary Testing

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WSN – Design Requirements

- Design of the next generation Corrosion Monitoring Sensor Network.
- Existing Design:
  - +/- 22Vdc supply
  - Leaded/Through-Hole components
  - Non-Direct Mounting of Arduino Development Boards
  - Single Senor Unit (Capacitance Meter)
- Next Generation:
  - Single Input Voltage
  - Surface Mount (SMD) Technology devices
  - Direct Mounting of Arduino FIO development board
  - Addition of the following sensors
    - Temperature
    - Humidity
    - Pressure

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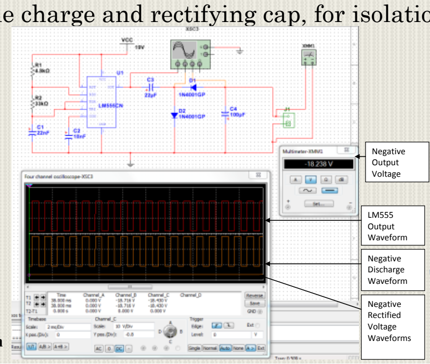
WSN - Power Supply Design

- Key CTQ (Critical to Quality) - Single Voltage Power Source
  - LM555 in Astable Mode – Continuous Square Wave Oscillation
  - The capacitor at the output of the IC (Pin 3) is charged through a forward biased diode during the positive pulse of the square wave
  - The output capacitor is discharged through the rectifying capacitor at the zero crossing (0 volt) of the waveform
  - A diode is placed between the charge and rectifying cap, for isolation



Negative Supply Output Simulation

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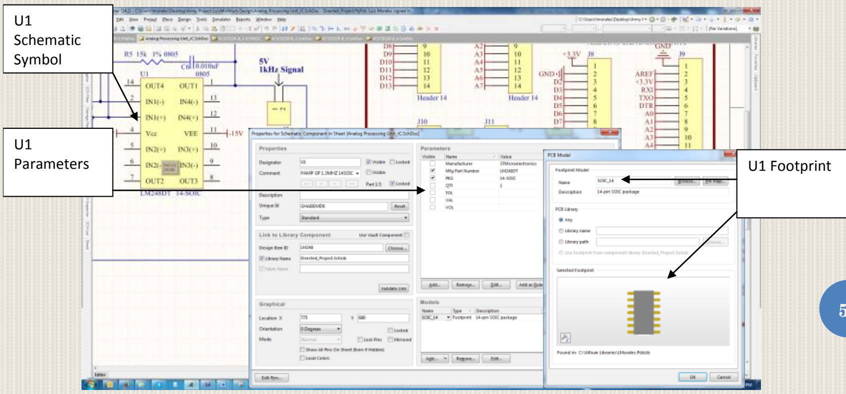
WSN – Schematic Capture

- Initial Design Captured in NI Multisim as
  - 5 Separate Sheets
- Recaptured in Altium Designer 14
  - Schematic Symbols
  - Parameters (QTY, Manufacturer, Part Number)



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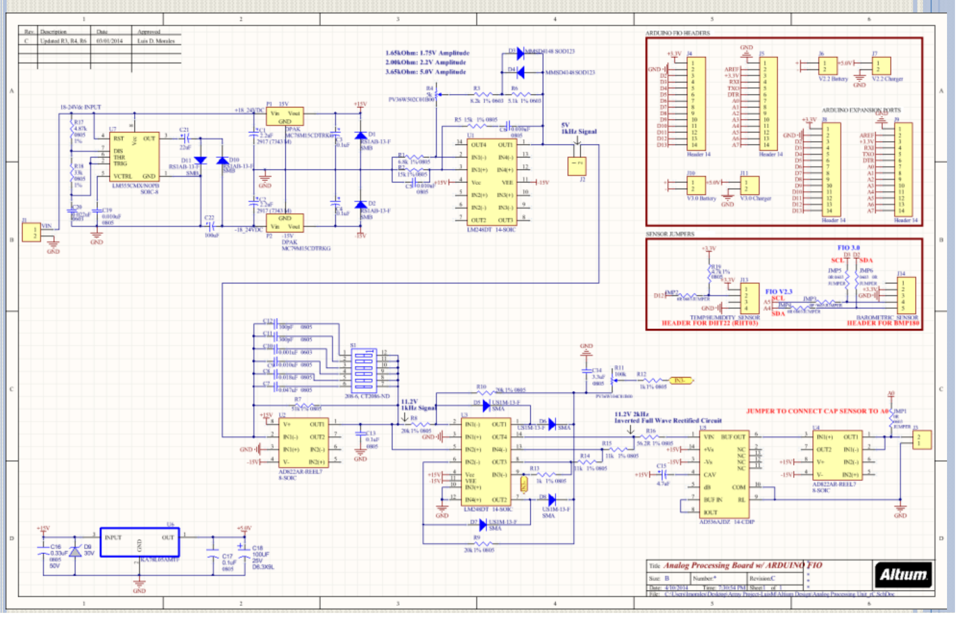
WSN – Schematic Capture Cont.



WSN – PCB Circuit Design

- Initial Design Captured in NI Ultiboard
  - Original Design – ASP Only 4” x 6”
- Recaptured in Altium Designer 14
  - PCB Footprint Generated
  - New Condensed Version with Direct Arduino FIO interconnects
  - Additional Prototyping Pads/Area
  - Final ASP dimensions: 1.67” x 2.87”
    - Overall size: 2.79” x 3.50”
  - Gerber Files Generated
  - Boards Quoted and Built through Advanced Circuits
- Altium Capabilities
  - 3D modelling capabilities for form-and-fit analysis
  - Separate Layer View for Analysis

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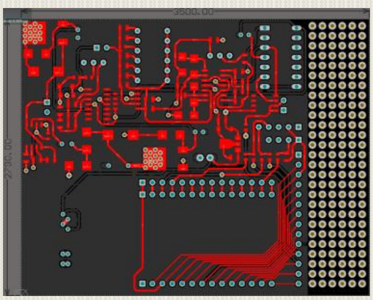
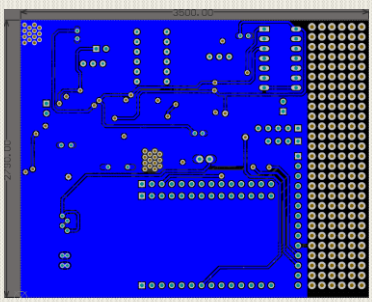
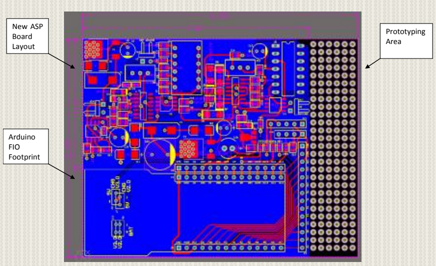
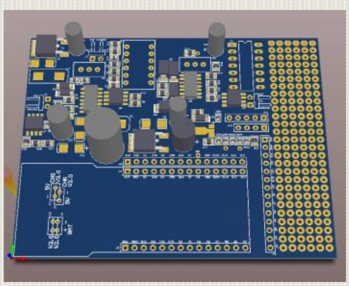
WSN – PCB Circuit Design Cont.


Top Layer View


Bottom Layer View



Combined Layer View


3DView

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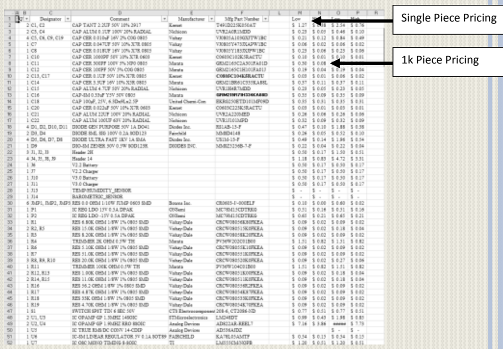
WSN – Cost Analysis

- WSN Cost analysis was conducted with
  - Single piece costs
  - 1k piece costs
  - 54% Reduction

	Low Volume	High Volume
Component Cost	$ 44.59	$ 19.95
DHT22	$ 9.95	$ 7.96
BMP180	$ 9.95	$ 7.96
Circuit Boards	$ 37.95	$ 2.22
Arduino Fio	$ 24.95	$ 19.96
Xbee 2	$ 22.95	$ 18.36
1000mAh Batt.	$ 11.95	$ 11.95
Total	$ 162.29	$ 88.36

Sensor Node Costs Analysis *



Component Cost Analysis Spreadsheet

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* Prices are based on Distribution Pricing, Direct Manufacturer Pricing was not obtained

Overall Cost Analysis

- Overall Project Cost Analysis was conducted
  - Design/Labor Costs & Material Costs

Project Time (1 Semester)			
16	Weeks		
8	Hrs/Week		
128	Total Hours		
35	% Engineering Time	44.8	Hours
65	% Research/Technician Time	83.2	Hours
$ 30.00	Engineering Rate	$ 1,344.00	Total
$ 14.00	Technician Rate	$ 1,164.80	Total

Engineering/Technician Cost Analysis

Total Project Costs	
Advanced Circuits	$ 218.45
Arduino Boards	$ 144.75
Sparkfun Order #905073	$ 63.89
Sparkfun Order #912168	$ 71.84
Digikey	$ 124.62
Engineering Time	$ 1,344.00
Technician Time	$ 1,164.80
Total Project Costs:	$ 3,132.35

Project Costs Analysis

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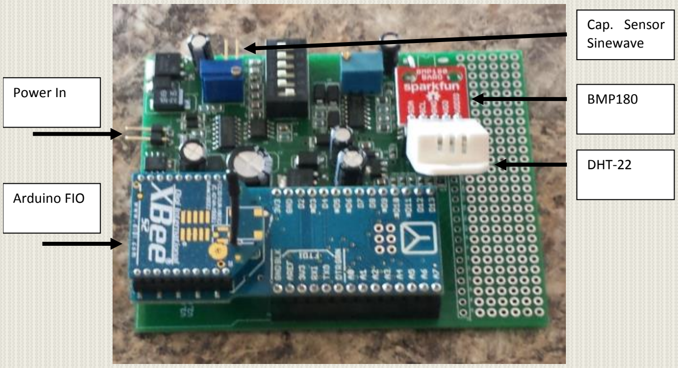
Formal Prototype Build

- Components were purchased for 5 total prototypes
- Three (3) prototypes were built
  - Component footprints were validated
  - Arduino FIO adapter/header footprint was validated



Wireless Sensor Node (Arduino FIO, XBee Transceiver & ASP)

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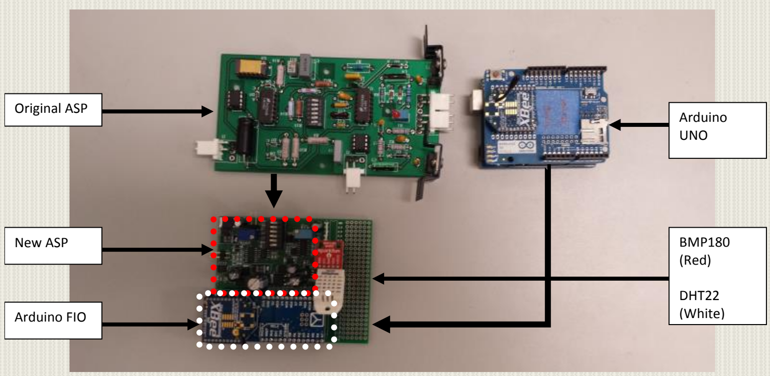
Formal Prototype Build Cont.

- Key CTQ (Critical to Quality) – Decrease Sensor Size
  - Surface Mount Components
  - Embedded Arduino Control Board
  - Additional Sensor Functionality



Wireless Sensor Node (Arduino FIO, XBee Transceiver & ASP)

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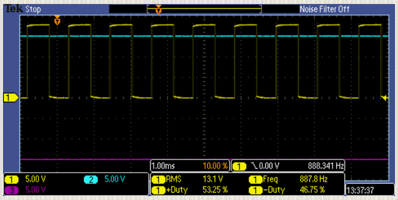
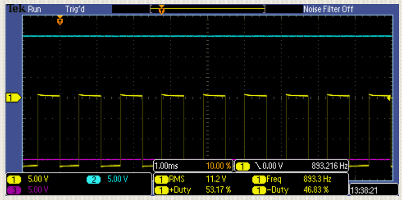
Power Supply Verification

- Dual Voltage Power Supply using LM555 in Astable Mode
  - 50% Duty Cycle
  - 1kHz Square Wave
  - +/- 15Vdc & 5Vdc (Battery Charge) Generated



Generated Square Wave - Positive



Generated Square Wave - Negative

	Arduino FIO 2.3			Arduino FIO 3.0		
	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)
ASP Only	19	0.038	0.722	19	0.119	2.261
ASP + Arduino	19	0.088	1.672	19	0.119	2.261
ASP + Arduino + Battery	19	0.15	2.85	19	0.18	3.42
Signal Power Measurement		.683mW/m^2	3.56mW/m^2		1.127mW/m^2	3.33mW/m^2

Power Consumption Matrix

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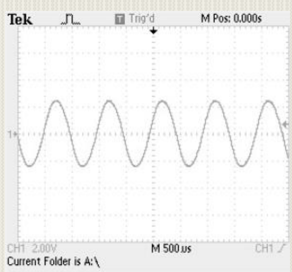
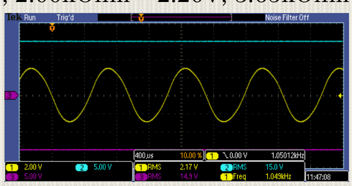
Testing and Implementation

- Sol-Gel Waveform Verification
  - Original Schematic called out a 5V 1kHz waveform
  - Previous reports specified a 1.5V 1kHz waveform
  - Testing demonstrated that with a 2kOhm potentiometer:

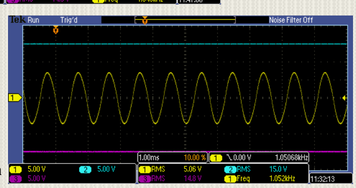
    1.7V & 2.2V were generated on existing boards
  - A 5kOhm potentiometer would generate the following voltages:
    - 1.65kOhm – 1.75V, 2.00kOhm – 2.20V, 3.65kOhm – 5.00V



Original Waveform



2.2V Waveform



5V Waveform

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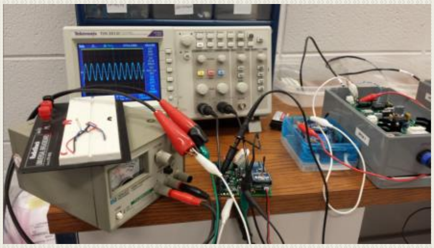
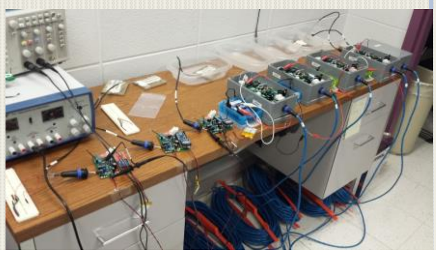
Testing and Implementation Cont.

- Sol-Gel Sensor Data Verified
- Temperature/Humidity Sensor Data Verified
- Barometric Sensor Data Verified



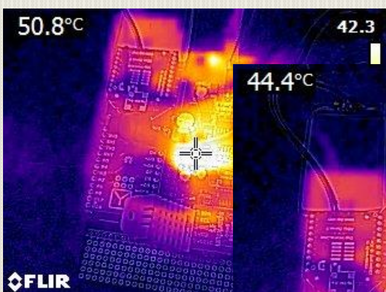
WSN Performance Verification



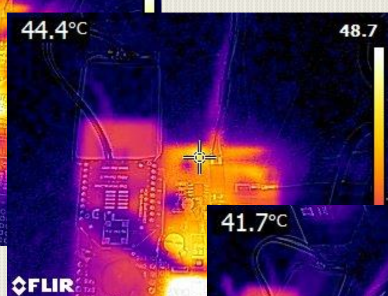
System Data Analysis

Testing and Implementation Cont.

- Thermal Analysis – 25C Ambient



-15V Regulator



LM555

+15V Regulator

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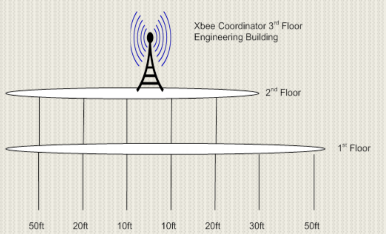
Testing and Implementation

- Range Testing:
  - Indoor:
    - Coordinator placed in ET305, Sensor Node was moved on 1st and 2nd floor. Within a 25ft radius, data was captured in its entirety
  - Outdoor:
    - Coordinator was placed in 1st floor Lobby, Sensor was moved (line of sight) through various outdoor locations.
    - Outdoor Range was greater



WSN Performance Verification

System Data Analysis

Next Generation Recommendations

- Solar Panel Charge System:
  - Tycon Power Systems TPSHP-12-120: 120W, 17.2V
  - 30W Continuous Power: 10 Sensor Nodes/Panel

Maximum Power (+/- 5%)	120W
Voltage at Pmax	17.2V
Current at Pmax	6.98A
Open Circuit Voltage	21.6V
Short Circuit Current	7.72A
Continuous Power	30W
Operating Temperature	-40 to +85C
Size	59x26x1.4"
Weight	23 lbs

TPSHP-12-120 Specifications

  - XBee Wi-Fi Module + Online Data Storage
    - XBee Wi-Fi (S6B)
    - Device Cloud $6/year service charge or
    - MS Dropbox Online Storage

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CONCLUSION

- The joint venture between Indiana-University Purdue-University Fort Wayne (IPFW) and the Army Construction Engineering Research Laboratory (CERL) has presented the opportunity to develop a corrosion monitoring system using state-of-the-art sol-gel sensors and cylindrical sensors. The Corrosion Monitoring System is capable of monitoring the level/degree of corrosion of steel and steel structures. The project in itself had seen two previous design stages, each of which has improved the sensing capabilities, ranges and overall robustness of the system. The development that has occurred over the last three (3) months has yielded promising results. Key activities have included;
  - 75% reduction of the physical size of each sensor ASP unit,
  - Single Voltage Power Supply
  - Modular design (ASP, Arduino FIO and XBee Wireless Transceiver)
  - Additional sensor capabilities such as; temperature, humidity and barometric pressure
  - On-Board Lithium-Ion Battery charging system

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- Demonstration

- Q&A Session

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