



Setting the Standard for Automation™

Low Cost Wireless Sensor Network Research at Oak Ridge National Laboratory (ORNL)

Wayne W. Manges

Peter L. Fuhr

T. Kuruganti

T.J. McIntyre

Standards

Certification

Education & Training

Publishing

Conferences & Exhibits

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ORNL is DOE's largest science and energy laboratory



- \$1.4B budget
- 4,550 employees
- 4,000 research guests annually
- \$500M invested in modernization
- World's most powerful open scientific computer
- Operating the world's most intense pulsed neutron source and a world-class research reactor
- Nation's most diverse energy portfolio
- Nation's largest concentration of open source materials research
- Managing the billion-dollar U.S. ITER project

ORNL Vision for Ubiquitous Sensor Networks

- The sensors are the network
- Ultra-integration is needed at the chip level – micro-controller, memory, IO, radio, battery or power harvester and sensors

OR

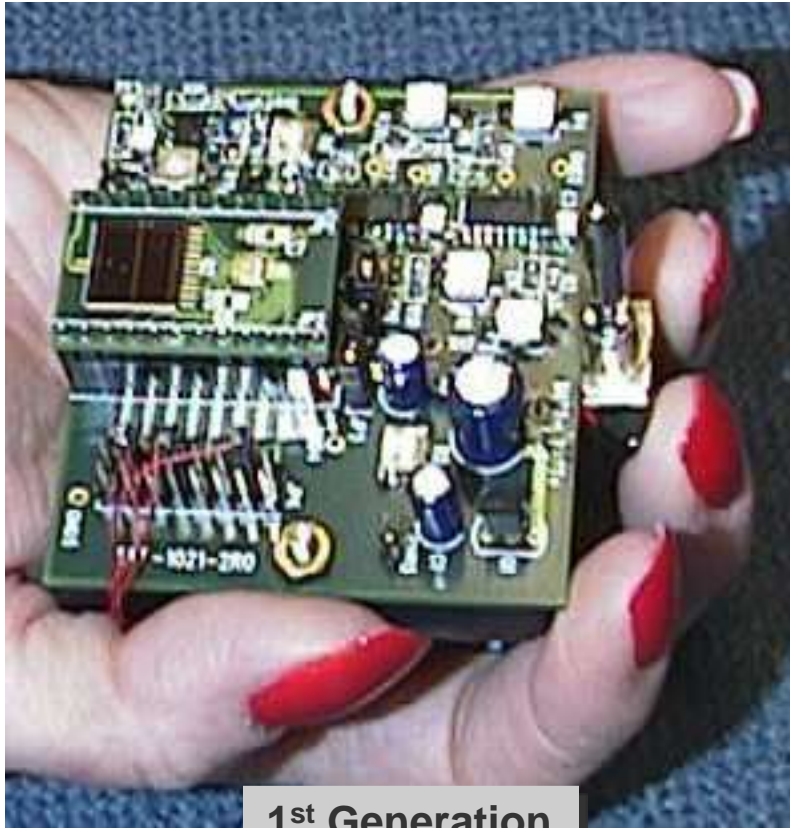
- New paradigm that changes the game – DISPOSABLE?
- Standard communication protocols and data formats

What are the market prospects?

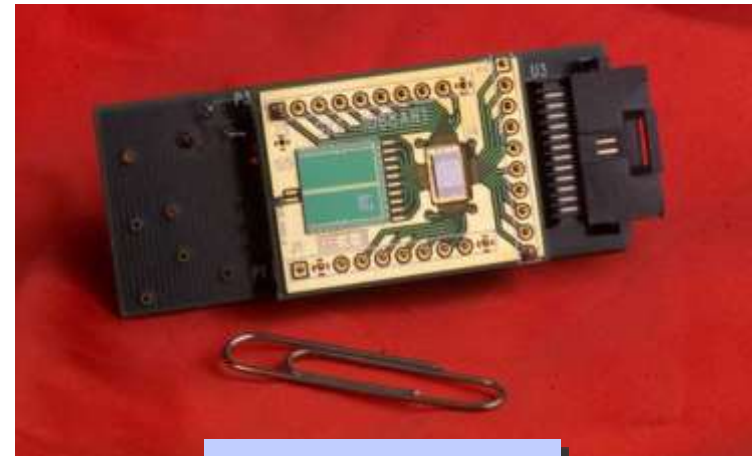
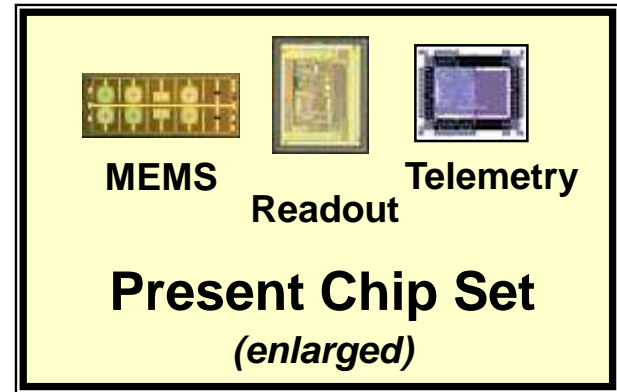
- **Commercial and residential buildings, There are over 300,000 buildings with little or no automation, >10million sensors**
- **Biomedical implants, >millions**
- **Smart vehicles and transportation systems, 10s of millions**
- **Smart grid diagnostics and load monitoring, 10s of millions**
- **Industrial control and smart parts, >10million – renewable!**
- **Infrastructure monitoring, situational awareness, ???**

For some applications the sensors will become disposal or be consumed with the product (e.g., smart oil filters that tell you when to change the oil instead of relying on a schedule).

ORNL has developed a custom chip set that includes sensors, electronic readout, and telemetry



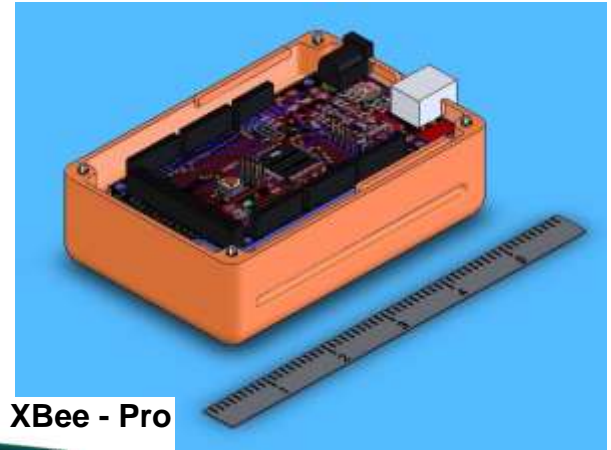
1st Generation



2nd Generation

Toward the Development of Ultra-low Cost Wireless Sensor Networks for Building Energy Efficiency

- The goal is a sensor platform that costs <\$5/mote
- The system must be easy to install and maintain – wireless
- The system need also be cyber secure
- Utilizing COTS initially, demonstrate a best-in-class sensor network for building controls
- Benchmark the possible – how much energy savings is possible from retro-commissioning a building with a wireless BAS.

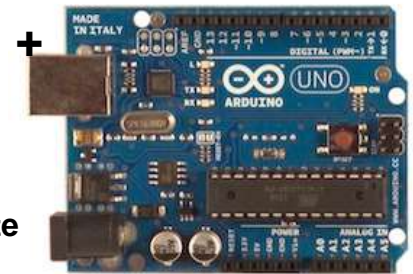


Arduino XBee - Pro



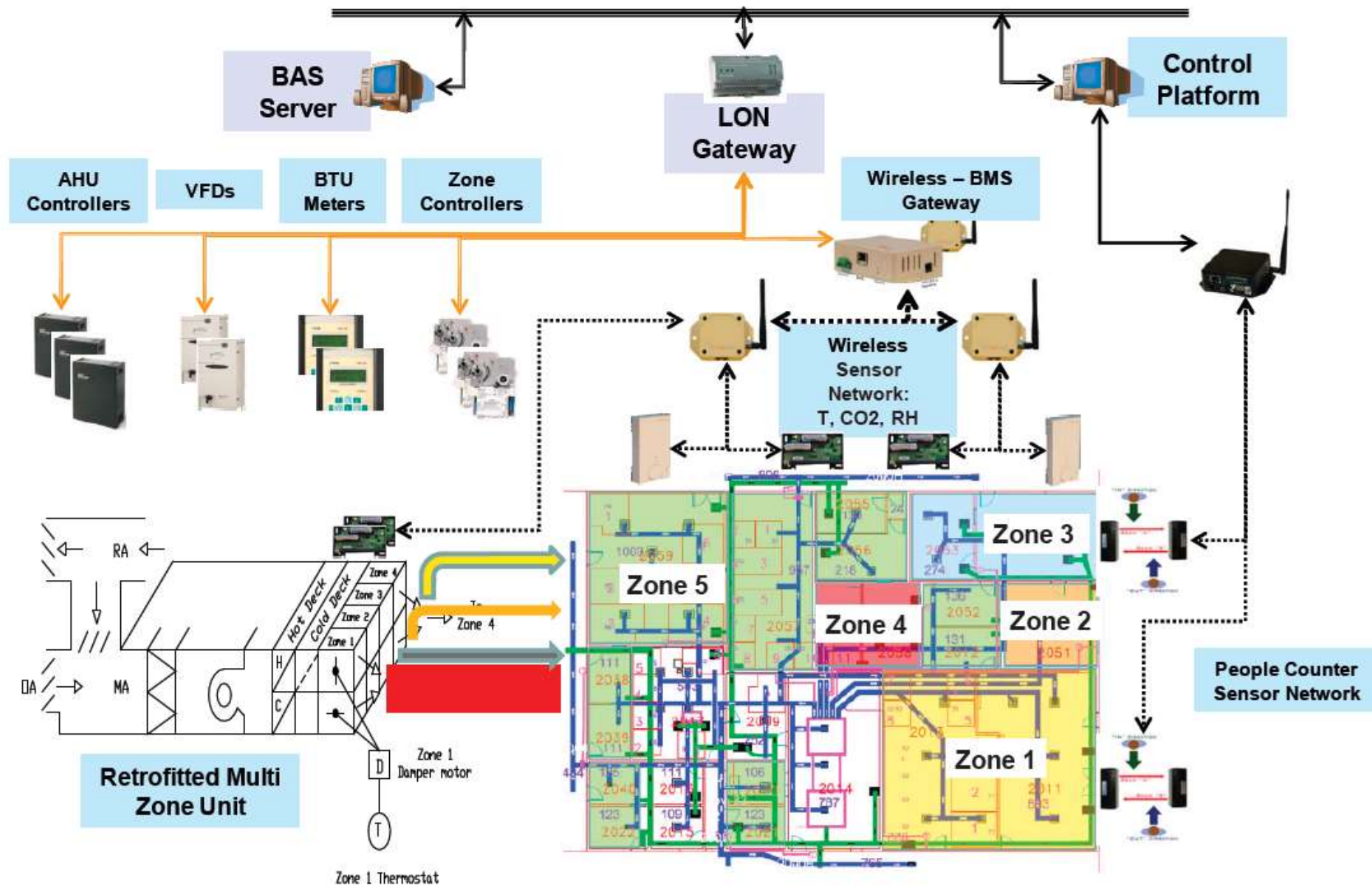
SensorMote \approx \$30/Mote

Arduino Uno

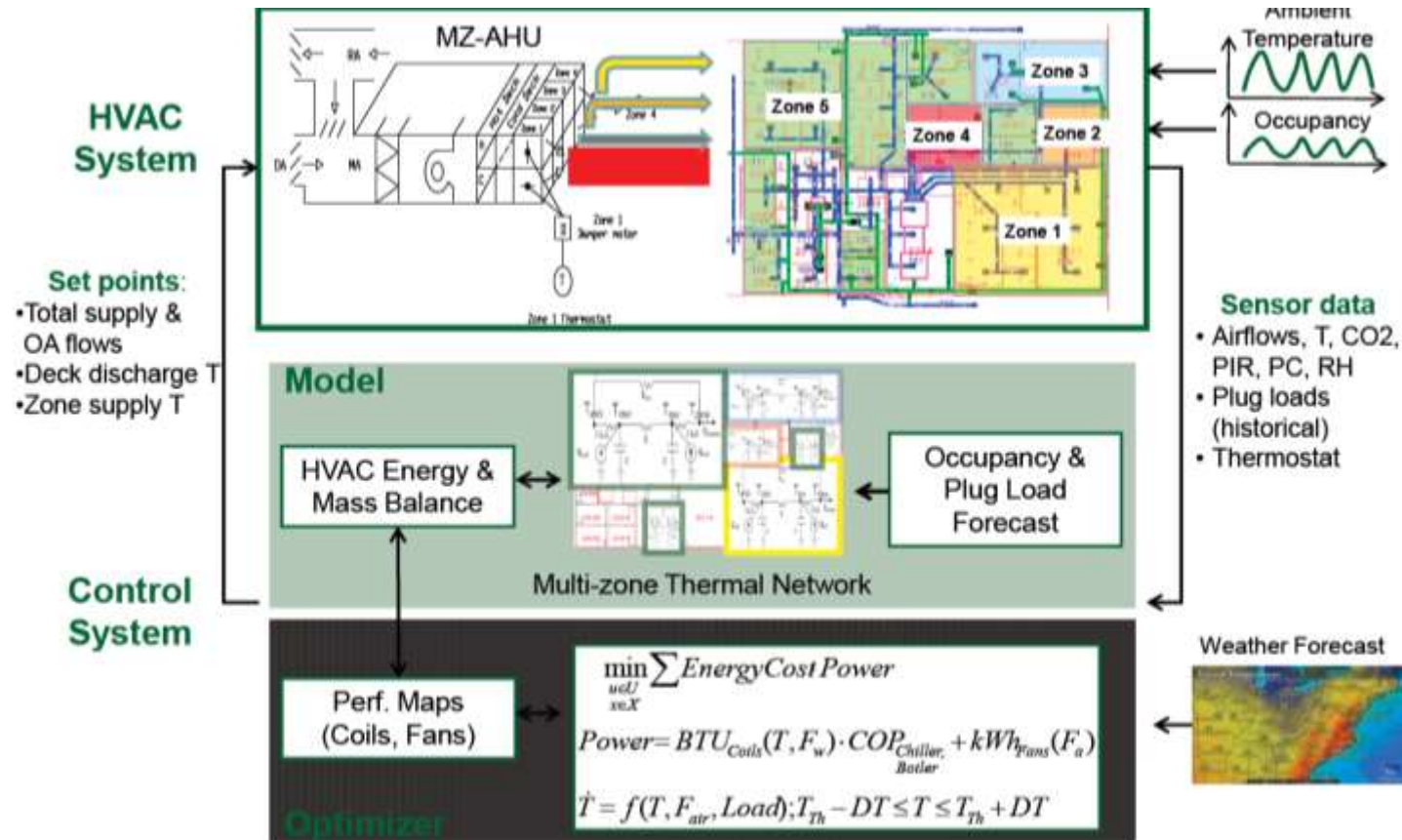


ORNL Next Gen Suitcase. Devices <\$43

Developing an Integration Architecture for Sensors, Controls and Building Automation Systems Implemented at CERL



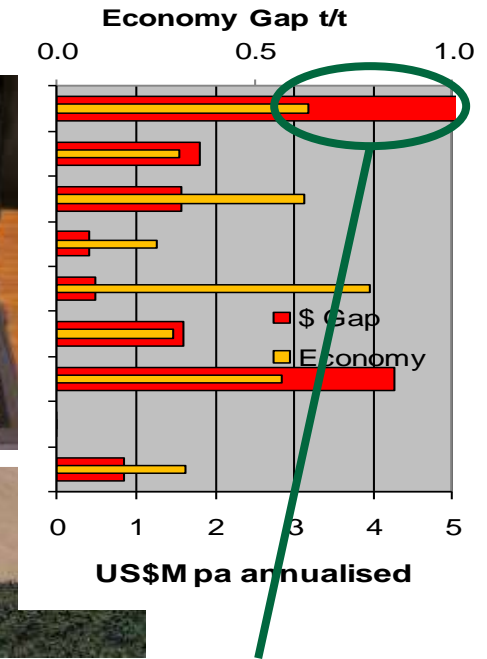
Supervisory Model Predictive Control Integrates Sensor Data, Control Set Points, Weather Conditions and Occupancy Profiles



RESULTS: 63% Reduction in Energy Consumption from the HVAC System

Low-cost Wireless Sensor Networks Impacting Industry

- ORNL deploys wireless suitcase at Alcoa

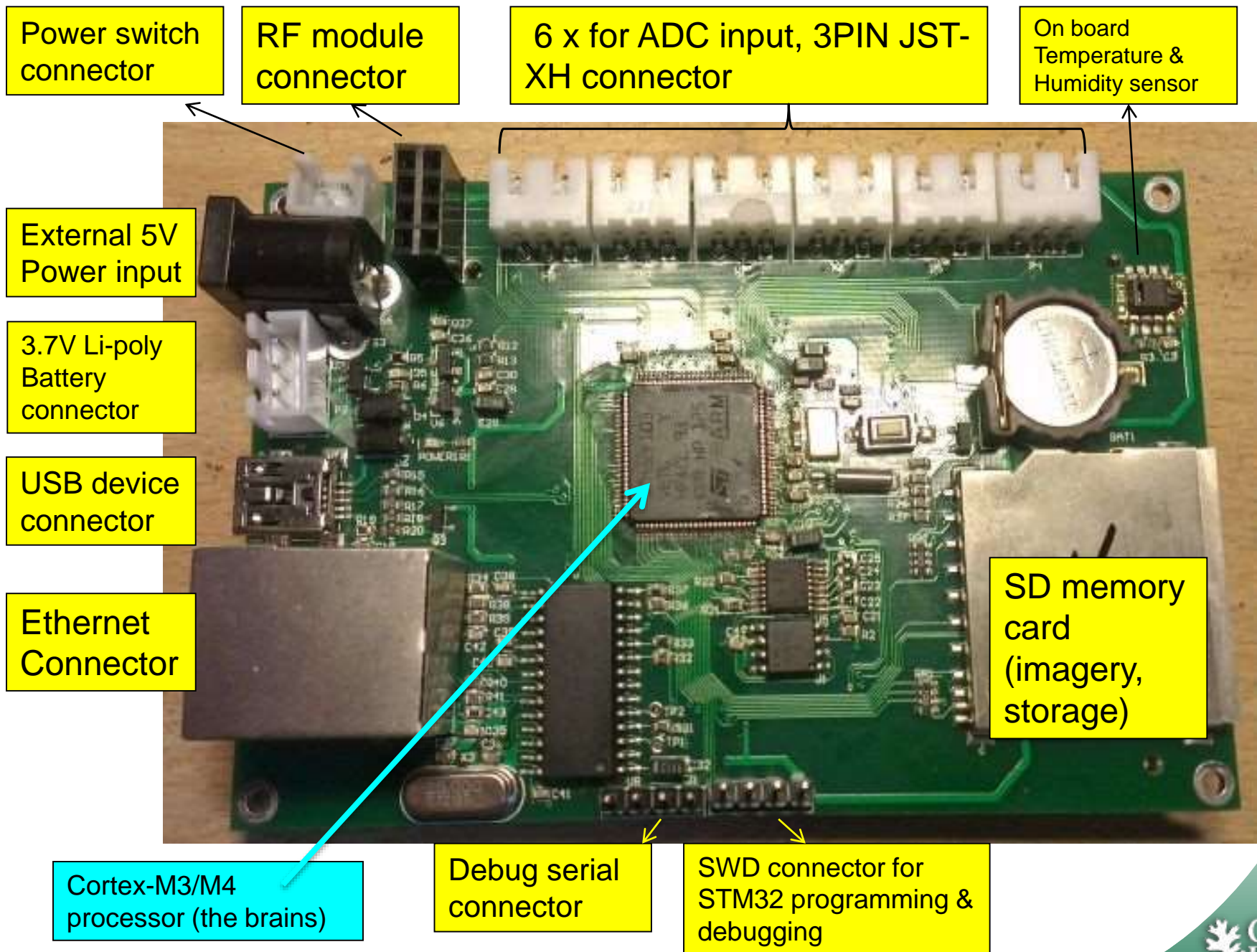


ALCOA benchmark analysis of 9 facilities has identified millions of dollars in unaccounted energy use. Application of wireless sensors could pinpoint opportunities to save energy.

ORNL “Wireless Suitcase” – circa 2012

Details...Lots of Details...



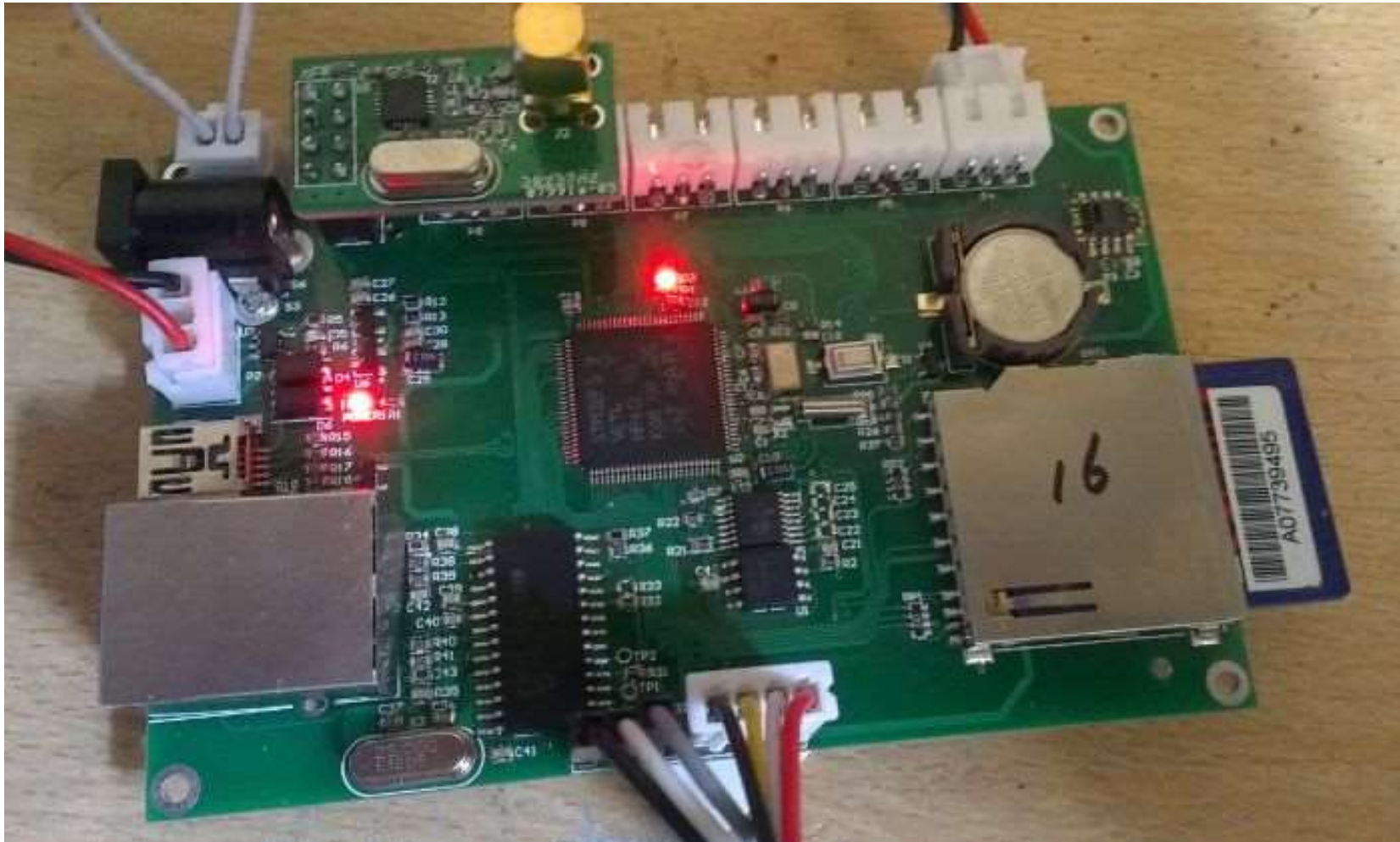


Key components:

The main parts in the schematics are:

- 1) STM32F103 processor (two processor parts, pin & function compatible) STM32F103VET6, 64K RAM, 512K Flash
- 2) Ethernet interface (RJ45)
- 3) NRF24L01 wireless interface (50m w/ 2dBi external antenna)
- 4) 2.8" TFT LCD and touchscreen
- 5) SHT10 temperature & humidity sensor
- 6) Li-poly battery with onboard charger circuit
- 7) 6x Analog inputs; the analog inputs are routed to the JST 3 pin side entry connectors
- 8) RT-Thread operating system
- 9) realtime clock (RTC) with battery backup

ORNL sensor module with connectors & wireless modules



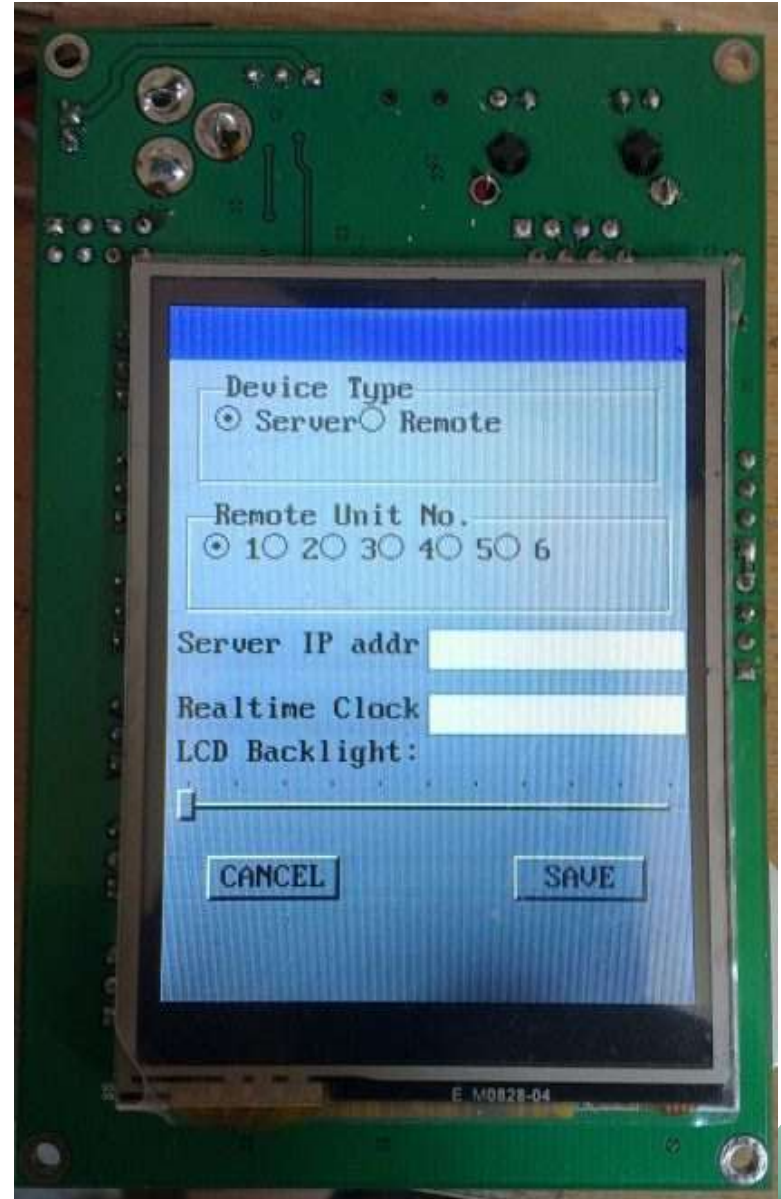
ORNL sensor module - TFT LCD touchscreen

Some features:

- * IP Addressable (static or DHCP)
- * webservice (retrieve data via http:// call)
- * Module may function as Server or Remote
(i.e., plug into Ethernet (non-wired, stand alone unit) or Wireless Sensor module communicating to a sister device that is in Server mode)
- * Touchscreen for setting clock, selecting devices

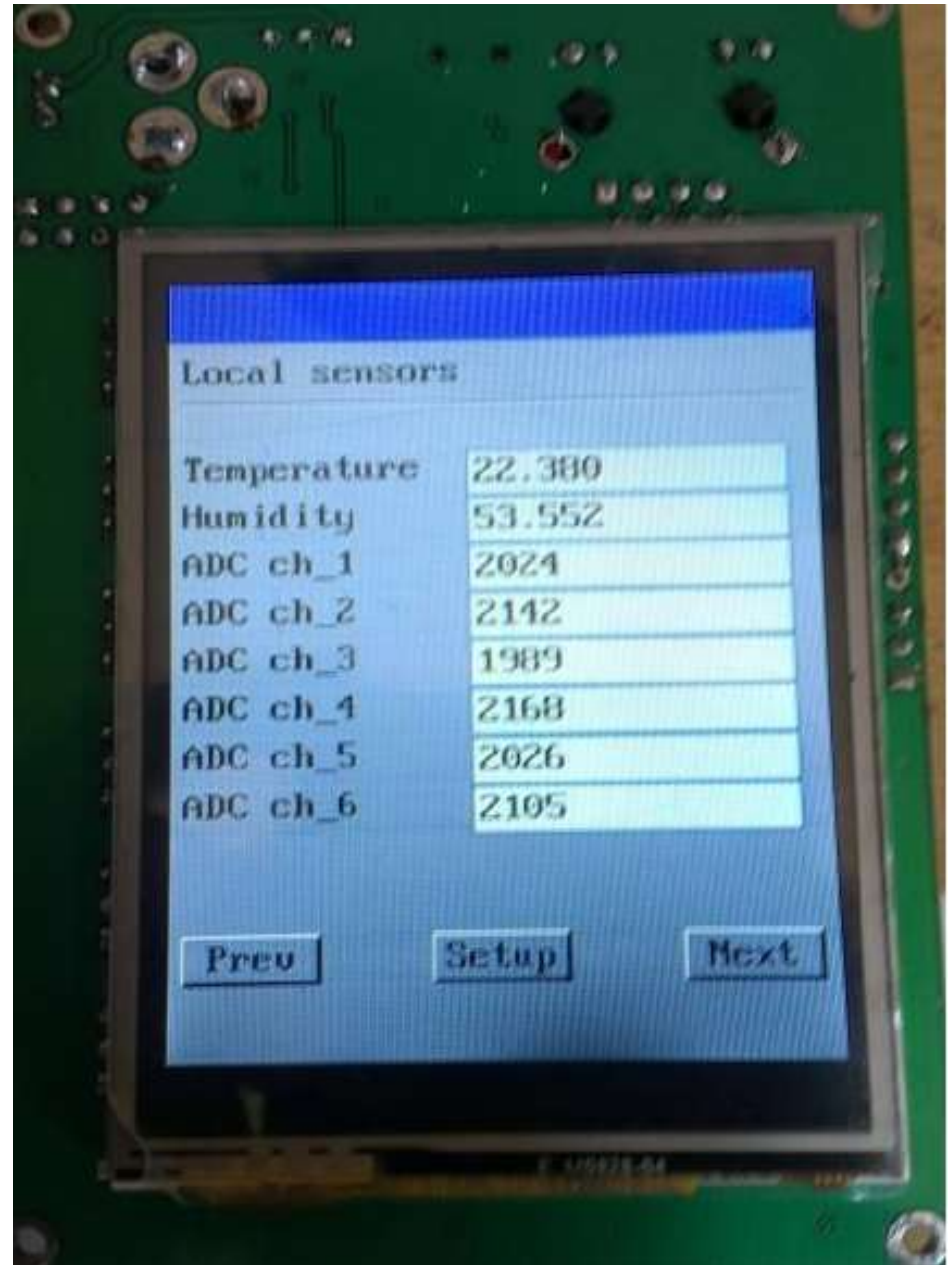
RT-Thread OS (open source)

Graphical User Interface (GUI) may be customized.



ORNL sensor module – local sensor readings

Displaying sensor readings on the “local screen”

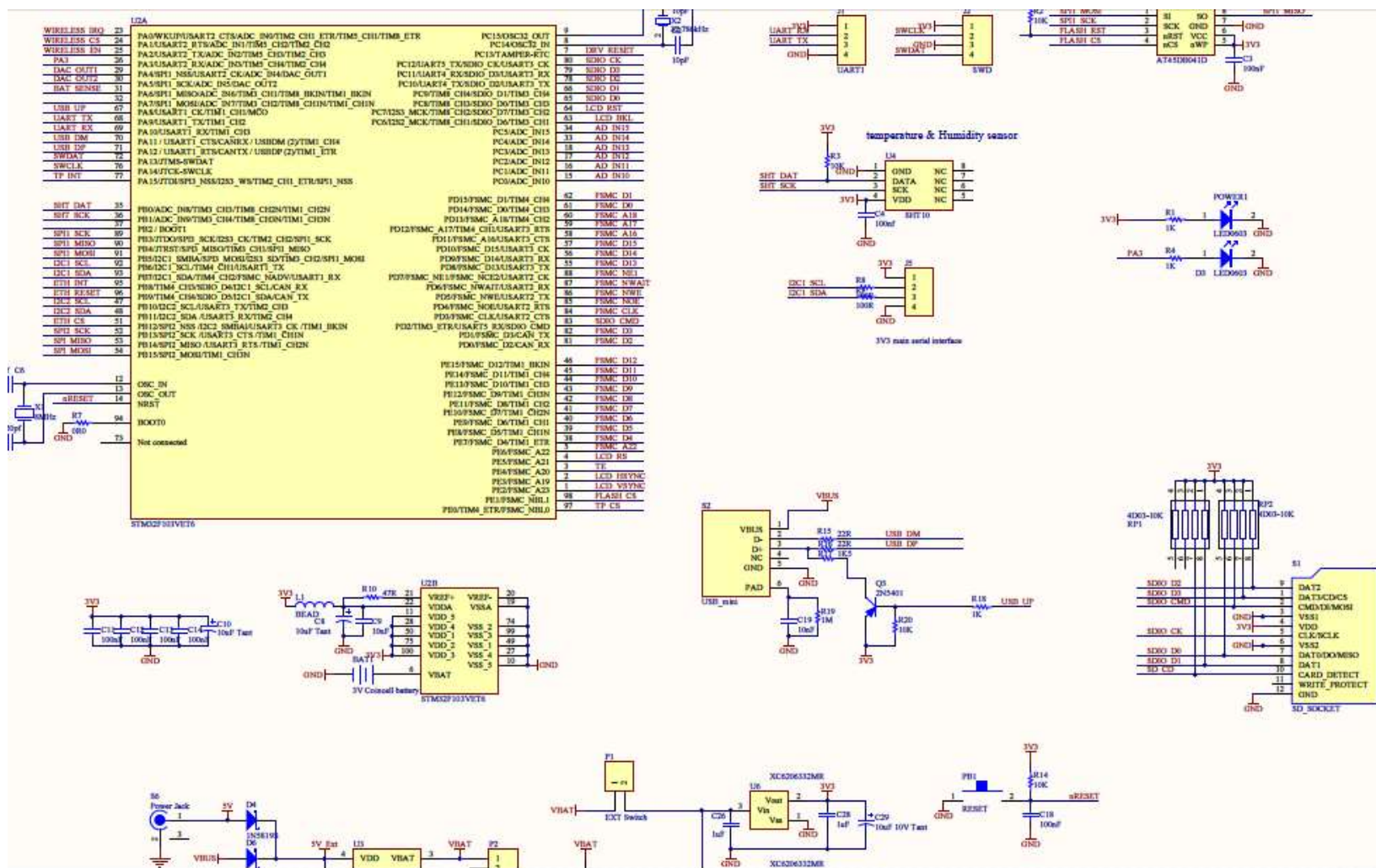


ORNL sensor module – remote sensor readings



(this is the screen on the “server”. You can use the touchscreen to select which remote module’s readings you wish to display)

Open source software
Complete electrical design (schematic, Gerber, BOM)





Firmware details...

- 1) RT-thread kernel only - 60K flash
- 2) RT-thread kernel + RTGUI (LCD graphic interface) -- 100K Flash
- 3) RT-thread kernel + RTGUI + DFS (filesystem, SD card) -- 160K Flash
- 4) RT-thread kernel + RTGUI + DFS + LWIP (light weight IP stack & ethernet) -- 250K flash

A word on sensors...

**onboard
temperature+humidity,
general purpose A/D
inputs**

**3-way ADC socket on the board;
direct interface to the following MQ-
series sensor modules:**

Semiconductor sensor for Flammable gas, Plastic or Metal cover	
Model	Target Gas
MQ-2	General combustible gas
MQ-3	Alcohol
 MQ-4	Natural gas, Methane
MQ-5	LPG, Natural gas, Coal gas
MQ-6	LPG, Propane
 MQ-7	Carbon Monoxide (CO)
MQ-8	Hydrogen
MQ-9	CO and Combustible gas
MQ214	Methane
MQ216	Natural gas\Coal gas
MQ306A	LPG, Propane
MQ307A	Carbon Monoxide (CO)
MQ309A	Carbon Monoxide (CO), Flammable Gas
MQ303A	Alcohol
MQ131	Ozone O3
MQ135	Air Quality Control (NH3,Benzene,Alcohol,smoke)
Semiconductor sensor for Toxic gas	
MQ136	Sulfureted Hydrogen (H2S)
MQ137	Ammonia (NH3)
MQ138	VOC (Mellow, Benzene, Aldehyde, Ketone, Ester)

Functionality details...

- 1) The gateway (server unit) works as a webserver; and it has a DHCP client thread running, so it can get the ip address for the network router. So when a user visits the server unit, sensor readings from remote units will be shown as a webpage in user's web browser.**
- 2) Data format - remote units will send 8 channel readings (1 temperature (32bit), 1 humidity(32bit) , 6 adc readings (16bit each channel)) in one packet.**
- 3) Up to 6 sensor units can connect to one server units - so total $8 \times 6 = 48$ sensors.**
- 4) Sensor push data to the server at fixed interval (user can determine the interval - for example 1s, 10s, 100s ...)**
- 5) Up to 6 sensors can be connected to one remote unit, plus 2 internal sensors (temperature, humidity)**
- 6) The remote unit address is configurable both on server unit & on remote unit. So potentially the remote & server units know each other.**

ORNL “Wireless Suitcase” – circa 2012

Did we mention \$43/complete device?



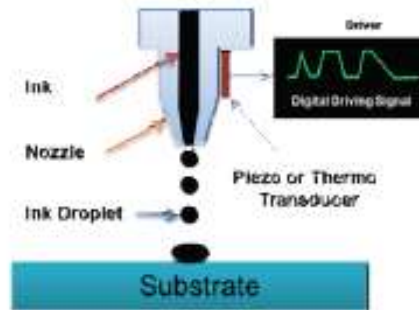
ORNL “Wireless Sensors” – circa 2013

Printable Electronics



Printing Challenges:

- Resolution
- Process tolerance
- Defect density
- Printing yield



Advances in Metal Ink Technology

	Conductivity ($\mu\Omega\text{-cm}$)	Conductivity ($\mu\Omega\text{-cm}$)
Ag	1.6	2
Cu	1.7	5
Al	2.8	5
Ni	7.0	20

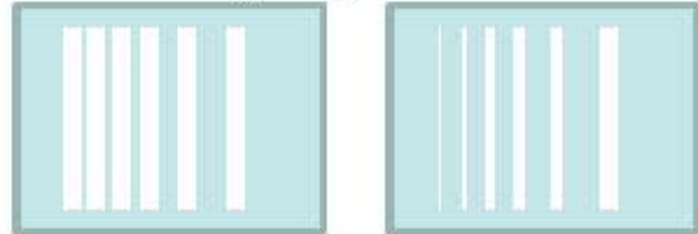
Metal Integration on Plastic Substrates

Printable Conductor

- Level 1: $R_{sh} < 200 \text{ Ohms/Sq.}$
- Level 2: $R_{sh} < 20 \text{ Ohms/Sq.}$

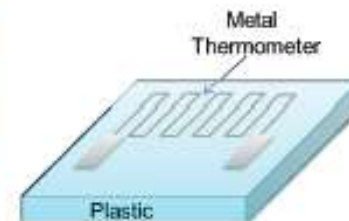
Line Width/Spacing Control

- Available Technology: 10-20 μm



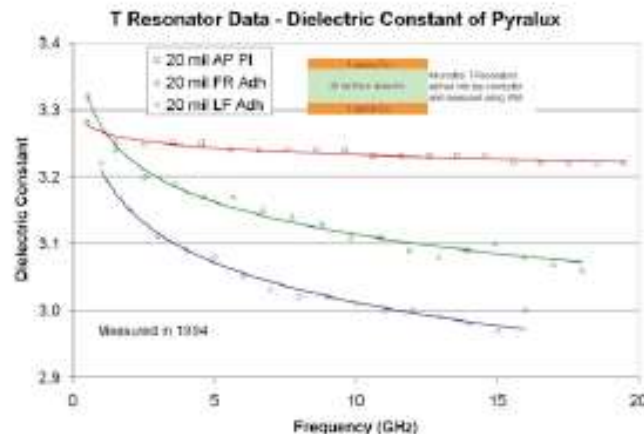
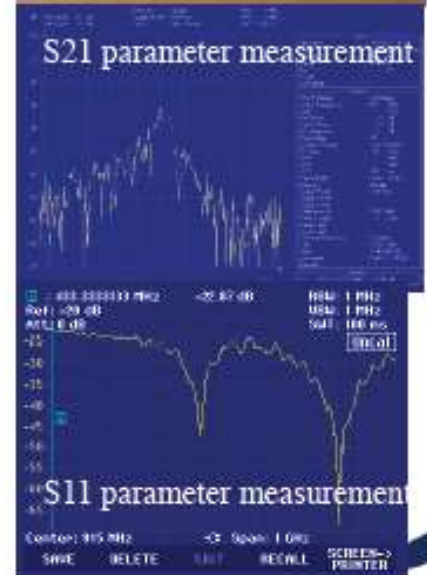
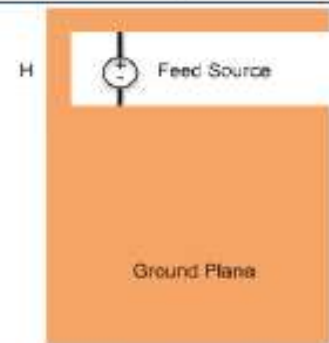
Our Focus:

- Establish plastic compatible photonic curing: Unique ORNL Setup
- Establish critical know-how: Plastic/Metal interface
- Evaluate Ink Technology: Performance of Key Metals of Interest



Printable Antenna

- Printable, flexible patch antennas for operation in ISM frequency bands (2.45GHz and 900MHz)
- Printable dielectric materials and metals for optimal radiation pattern for producing thin-profile conformal antenna
- Use of pulse thermal processing for low temperature curing, printable polymer dielectrics for high performance, and antenna radiation pattern control
- Antenna characterization in RF clean room to achieve 2-3dBi gain in 2.45GHz range



Low-Cost, Multi-Sensor Wireless Platform



Note that price!

Current wireless sensor
Platform: \$150-\$300/node

Proposed Advanced Sensors
Platform: \$1-\$10/node

Infrastructure investment already made

- Financial support and resources required for timely development

R&D

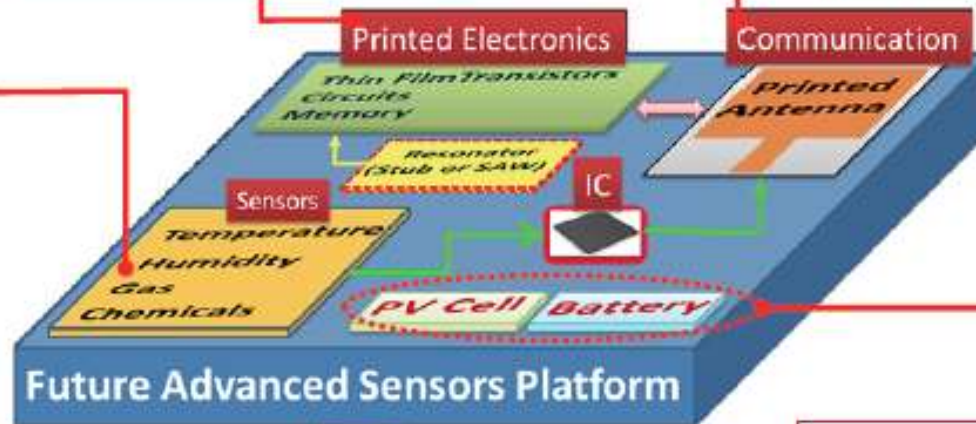
Extensive Capabilities at ORNL

- Modeling
- Design
- Test and Measurements

Proposed R&D

Core Components

- High performance thin films
- Low temperature integration
- R2R processing setup



Market Potential: Not just an improvement over existing technology

- Prospects of New market, • Enhanced Functionality

DOE Interests

- Buildings technology program (BTP),
- Advanced manufacturing office (AMO)

Energy Management Technologies

- Extensive know-how at ORNL
- Resources required to target low temperature material/device development

ORNL “Wireless Sensors” – circa 2013

More details available...just ask!

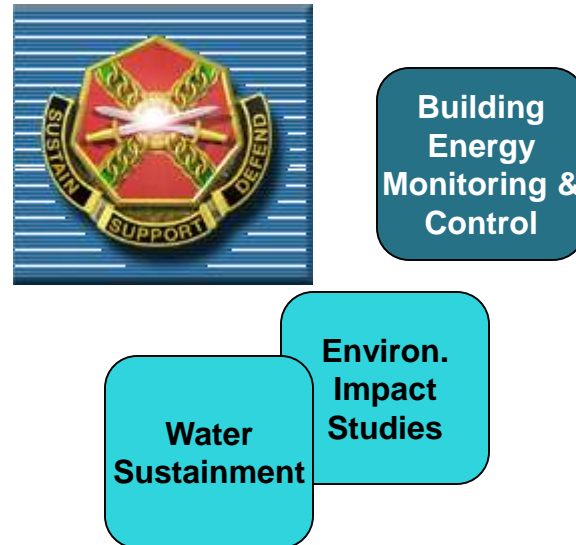


Applying Wireless Sensor Networks for Sustainability of the DoD Infrastructure

Ft. Campbell



Ft. Stewart



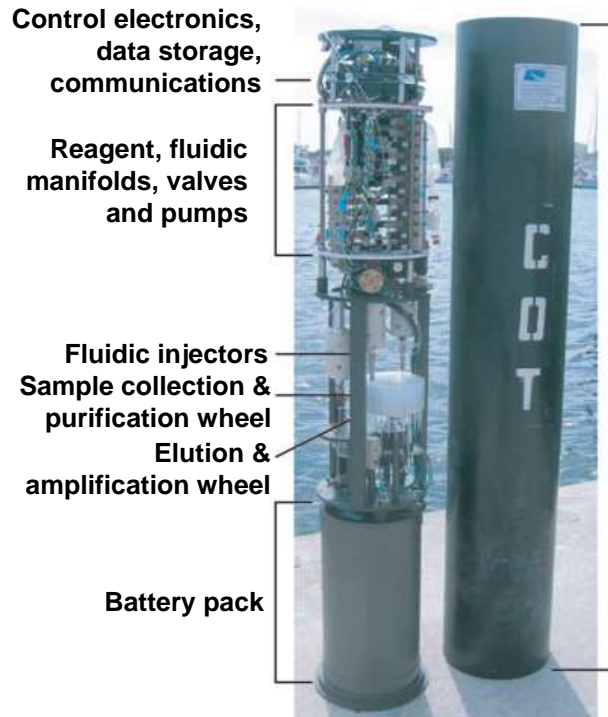
Dover AFB



ORNL teams with preferred base vendors to implement new technology for mission sustainability.

Next Generation Technology for Environmental Sensor Networks

Moving Analytical Measurement from the Lab to the Field

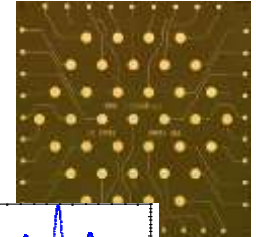


Expanding the Sensed Domain

Miniature cameras and integrated optical systems



MEMS ultrasonic transducer array

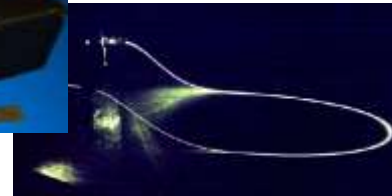


Quantifying biotic activity



External pressure vessel

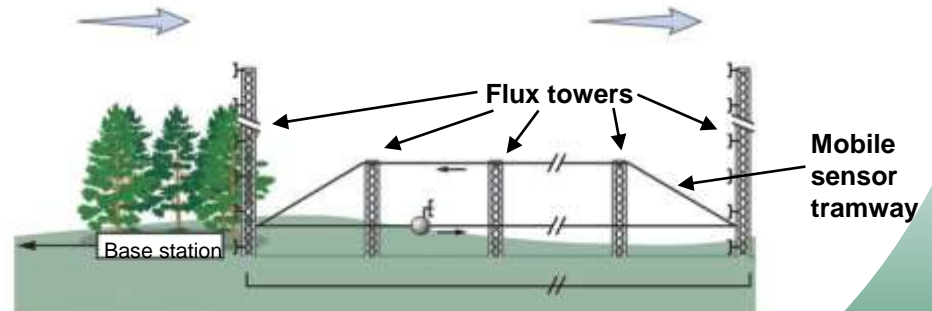
IR Imagers



Distributed fiber optic sensors

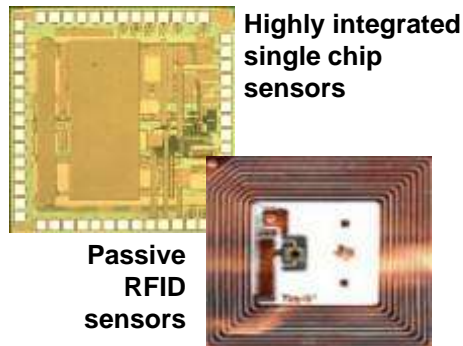
Invertebrate biodiversity surveys by acoustic resonance

Multi-modal & moving platforms

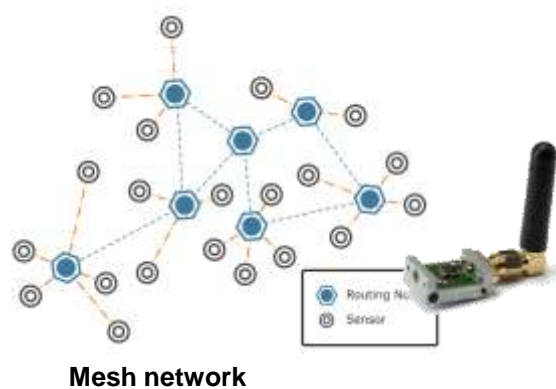
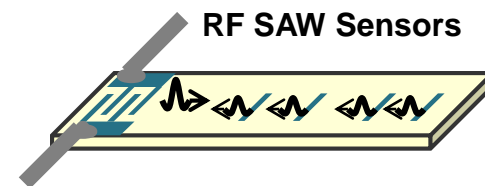
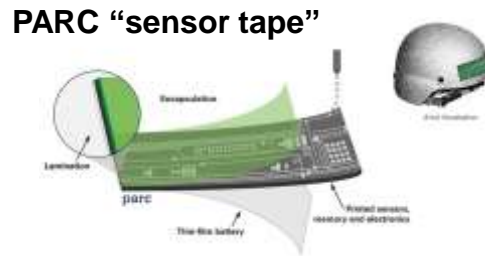


Gas fluxes and distributions

Next Generation Technology for Environmental Sensor Networks, cont.



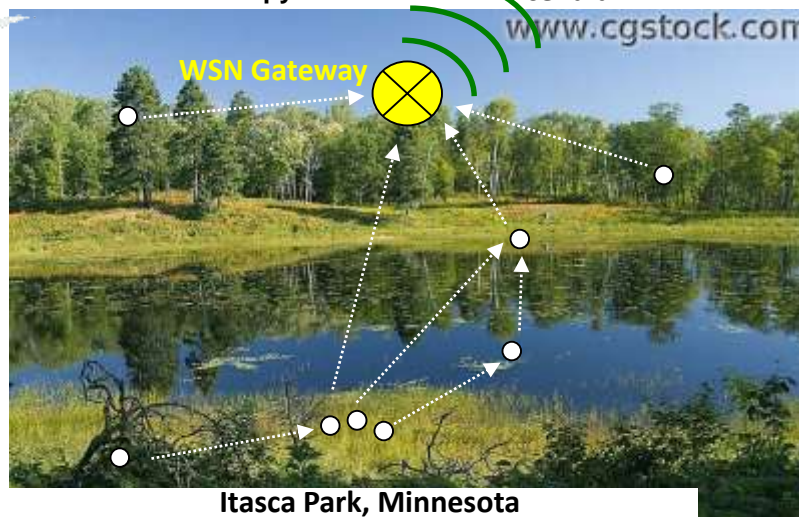
Exotic new sensor platforms



Networked on the ground
& in the "canopy"



Ubiquitous Sensor Network



This has been:

Low Cost Wireless Sensor Network Research at Oak Ridge National Laboratory (ORNL)

For more information...contact any one of us

Wayne: mangesww@ornl.gov

Peter: fuhrpl@ornl.gov

Teja: kurugantipv@ornl.gov

Tim: mcintyretj@ornl.gov

