Architecture of a Satellite-Based Sensor Network for Environmental Observation

Wei Ye, Fabio Silva, Annette DeSchon and Spundun Bhatt

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Sensor webs enable on demand, adaptive sensing across a wide range of spatial and temporal scales from both in-situ and space-based sensors

Broad vision: enable wide adoption of sensor web technology in scientific research

In-situ sensing networks are important components of large-scale sensor webs (focus of this paper)

Explore opportunities of combined in-situ sensing and space-based sensing (future direction)
Challenges in Building Sensor Nets for Science

- Rapidly deployable in remote locations by individual scientists
- Flexible to support different science applications
- Robust to harsh environments and potential failures
- Intuitive user interfaces and tools for scientists
Our Approaches

- Develop a turn-key system that addresses above challenges, called Sensor Processing and Acquisition Network (SPAN)
  - Emphasize on modular and extensible design

- How to address those challenges?
  - Remote locations: use satellite communication (or cellular)
  - Different science apps: develop a unified sensor integration framework
  - Robust operation: extensive system monitoring and failure recovery
  - User support: intuitive interfaces and tools to monitor and reconfigure the system
Outline

- Introduction
- System architecture
- Prototype implementation
- Lessons learned from initial deployment
- Conclusions
High-Level SPAN Architecture

SSG Front End (deployed in field)
- Data acquisition, meta-data tagging, reliable transmission, WAN access

SSG Back End (deployed in lab)
- Data storage, user interface

Internet

Satellite communication

Space-based sensors

In-situ sensor networks

 Scientist
Major Functions in SPAN

SPAN front end

SPAN back end
SPAN Front End (in the Field)

- **Sensor Management**
- Data Acquisition
- *Data and metadata management*
- Reliable data transmission
- **WAN access**
Unified Sensor Integration Framework

Framework for easy sensor integration

- Simple, low-level hardware to interface with various sensors
- Modularized and extensible driver library

![Diagram of sensor integration framework](attachment:image.png)
Sensor Driver Library

- **Streamlined sensor integration**
  - Mapping different sensors into system
  - Support analog, digital, serial, networked sensors

- **Software abstraction to easily control sensors**
  - Unified API to control different sensors
    - Enable or disable channels, set sampling rate, raw data or average
  - Obtain metadata for each channel
    - Sensor make, model, serial number, measurement type and unit, etc.
  - Sensor calibration

- **Modular and reusable software components**
Protocols for Data and System Management

- Designed protocols for managing data, control and status information
- Implemented protocols on CompactRIO
SPAN Back End (in the Lab)

- **Data storage**
  - Support both databases for individual scientists or shared by community

- **Provide three types of user interfaces**
  - **Command interface:** control and reconfigure system remotely
    - Start or stop a sensor, or change sampling rates
  - **Data interface:** easily access sensor data and metadata
  - **Status interface:** monitoring status of entire system
    - Component failure, availability of satellite link
Provide Different Methods to Access Sensor Data

Different access methods meet different needs

- **Live data feed**
  - real-time, no reliability guarantee

- **Database storage**
  - reliability guarantee even when components fail

- **SPAN system**

- **Private use**
  - MySQL database

- **Publish and sharing**
  - SensorBase
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Platform Consideration

- **Data acquisition system: CompactRIO**
  - Rugged platform, rich sensor interfaces, LabView programming

- **Communication technologies**
  - WAN: WildBlue satellite-based Internet service
  - Local wireless: mote-based wireless sensor network

- **Embedded PC: Stargate**
  - Drives satellite modem and provides access control

- **Database: MySQL database**
  - Robust open-source database on Linux

- **Network monitoring tools: Nagios**
  - Nice graphical interface
System Integration

Hobo data logger
Mote
Sensors

To satellite
CompactRIO
Sensors
Stargate
Back End

Front End
**Major system components**

- **CompacRIO**: connects to wired environmental sensors
- **Stargate (Linux PC)**: provides access control and connects to wireless sensors
- **Data grabber**: reliable data retrieval from front end and injection into database
- **SensorBase**: Database for scientists
- **Nagios**: system monitoring
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Ecological research

- Investigate the influence of southern California drought conditions on different species of plants
- Use constant-heating sap flow sensors to monitor the flow of water through the xylem of replicated stems of plants
- Scientist: Prof. Phil Rundel at UCLA
Deployment at Stunt Ranch

- **Complete front-end system**
  - CompactRIO
  - Stargate
  - Environmental sensors
    - Solar radiation (PAR)
    - Precipitation
    - Wind speed
    - Temperature
    - Humidity

- **WildBlue satellite comm**
- **Sap flow sensors on selected plants**
- Provided sensor data to scientists
- System operates reliably during first three months
  - No system crash
  - No data loss
  - Discovered and fixed a few bugs for second round of deployment

Correlated sensor data from precipitation, relative humidity and solar radiation
Real-time data access in SensorBase

- Provide real-time to scientists with database access
- Can be shared among different scientists

Easy access with web interface

Cleanly organized sensor data
Other Lessons Learned

- **Even the site has line power, cannot assume it is reliable**
  - We saw several instances that the power was cut due to unknown reasons
  - Needs backup battery to report emergency events

- **Protect the equipment from honeybees (and other insects)**
  - We found a honeybee hive with hundreds of bees inside our equipment box after a few months of deployment
  - Needs better sealing
Sensor webs can be a powerful technology for environmental and ecological research

- Combine in-situ and space-based sensor systems
- Dynamic reconfiguration

Our current focus is developing robust and easy-to-use in-situ sensor networks

The architecture of our system has been validated with our first prototype deployment for ecological research
Future Directions

- **Standard-based data management**
  - Had good discussion with Mike Botts on SensorML at Sensor Web PI meeting

- **Automated and distributed system reconfiguration**
  - Fast response to triggering events

- **Explore systems and applications that combine in-situ sensing with space-based remote sensing**
  - We are interested to find collaborators
Thank you! Questions?

- Project is funded by NASA ESTO’s AI ST program as “Satellite Sensornet Gateway (SSG)"
  - website: http://ssg.isi.edu