The Sensor Web: A Revolutionary Way of Seeing the Earth

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Sensor Web Overview

http://sensorwebs.jpl.nasa.gov/
Sensor Web Overview: CO₂ Example

Today: 4 s/c 'train'

Future: Seamless networking
From ground to space

In Situ Measurements

Space Measurements

Airborne Measurements

Study Area scaled to 100 M
Example: Canopy fluxes of CO₂

Study Area scaled to 100 Km
Example: regional fluxes of CO₂
Sensor Web Regions of Applicability

- **In Situ**
  - Limited areal coverage
  - Continual presence
  - Instant response time
  - Cheap hardware/deployment
  - Dense spatial coverage

- **Airborne**
  - Limited availability
  - Limited response time
  - Expensive deployment
  - Dense spatial coverage

- **Space**
  - Remote measurements
  - Non-continuous presence
  - Fixed response time (orbital)
  - Difficult to upgrade once deployed
  - Wide areal coverage
  - Limited numbers of nodes

Increasing Temporal Resolution Between Measurements

Decreasing Areal Coverage

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Sensor Web Integration Concept

REMOTE SENSING
- LIDAR
- HYPERSPECTRAL IMAGING

IN SITU SENSING
- SOLAR LIGHT
- TEMPERATURE
- pH
- HUMIDITY

Data Storage Internet Etc.

K.A. Delin 4/29/99
In Situ Sensor Web Characteristics

- Continual, virtual presence
- Limited geographical area
- Easily deployed
- Field-Evolvable Instrument (Field Upgradable / Field Programmable)
How In Situ Sensor Webs Work

Multiple, Cheap Sensor Pods

Single, Expensive Sensor Pod

Uncorrelated, Independent Measurements Yield Uncertainty

Correlated Measurements Yield Integrated Results

In Situ Sensor Webs provide Spatio-Temporal Information!

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Key Req’s for In Situ Sensor Web

1. Micro-Power:
   Req: Long-lived pod operation
   Multi-Hopping is power efficient communication link.

2. Micro-Bandwidth:
   Req: Communication over limited data pipelines
   Eliminate TCP/IP

3. Micro-Cost:
   Req: Low cost pods to limit Sensor Web cost
   Leverage COTS technologies

FRIIS TRANSMISSION EQUATION: \[ P_{\text{transmit}} \propto r^m P_{\text{receive}} \quad (2 \leq m \leq 4) \]

<table>
<thead>
<tr>
<th>Sensor Web</th>
<th>Internet</th>
<th>Deep Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Web Application Messages and other application protocols</td>
<td>(none) TCP (none)</td>
<td>CCSDS TM/TC packets</td>
</tr>
<tr>
<td>(none)</td>
<td>IP</td>
<td>(none)</td>
</tr>
<tr>
<td>Sensor Web Link Protocol</td>
<td>Ethernet, SONET</td>
<td>CCSDS TM/TC frames</td>
</tr>
<tr>
<td>R/F</td>
<td>Cable, fiber</td>
<td>R/F</td>
</tr>
</tbody>
</table>

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In Situ Sensor Web Applications

Considered here:
• Atmospheric Studies (Carbon Cycle)
• Ocean Studies (Run-Off)
• Land Management (Agricultural)
Sensor Webs and the Carbon Cycle

Sensor Web Approach:

• Permits a fine-mesh metric of quantitative CO$_2$ measurements and assessment of process variation which are interactive with other parameters across multiple environments.

• Embeds a heterogeneous set of sensors within a cognitive network.

• Measures primary and secondary cause and effect changes and optimizes measurement strategy for determination of process rates; performs spot-checks of accuracy and completeness by limited use of high-sensitivity, wide-bandwidth sensors and follow alert level occurrences.

• Learns to recognize a pattern and follow the development of patterns and the level of their repetitiveness.
# Carbon Cycle Sensor Web Specs

## 1.0 Sensor Web Description

### 1.1 Goal of Web Usage
Passive monitoring

### 1.2 Passive Monitoring / Active Exploration
Internet, Laptops

### 1.3 Ultimate Point of Uplink / Downlink
NB - Upgrade trace monitoring to include isotopic measurements, or particulates

## 2.0 Spatial Scale

### 2.1 Dimensionality
2D - or 1D of measurement - e.g. coastal region

### 2.2 Area Coverage

#### 2.2.1 Ideal
Ideal 30km x 30km for area of 300 km²

#### 2.2.2 Minimum
Minimum 100 x 100km for area of 300km²

### 2.3 Average Distance Between Neighbors
~ 50km: Question: Can they talk to each other at this distance?

### 2.4 Distribution of pods
Clumpy is acceptable, esp. if clumps are in areas of interest.

## 3.0 Measurements

### 3.1 Number of Measurements at each pod
Wind, concentration of a gas, isotope, temp, humidity. Possible ability to change what species is monitored.

### 3.2 Frequency of each Measurement
Max 4 x/day  Min 1 x/week - or - series of continuous measurements ~ every 10 minutes.

### 3.3 Precision of each Measurement

### 3.4 Local Processing / Reduction of Data
If continuous, send out average of a few hrs.

### 3.5 Total Lifetime

#### 3.5.1 Pod Lifetime

#### 3.5.2 Application Lifetime
Sensor Webs and the Ocean

Sensor Web Approach:

• Characterize the physical and chemical properties of a storm water runoff plume in Santa Monica Bay, California.

• Continual presence captures dynamic and unpredictable events such as run-off (unlike remote).

• High spatio-temporal resolution: as close as 10 m (unlike single point in situ), as often as 1 minute.

• Integrated measurement approach: Sensor Web information augments and directs satellite and UAV acquisitions.
# Ocean Sensor Web Specs

## 1.0 Sensor Web Description

### 1.1 Goal of Web Usage

Acquisition and distribution of sea floor and midwater and surface sensors. System must be portable, configurable.

### 1.2 Passive Monitoring / Active Exploration

Buoy on surface

### 1.3 Ultimate Point of Uplink / Downlink

## 2.0 Spatial Scale

### 2.1 Dimensionality

3-D

### 2.2 Area Coverage

- **Ideal**: 100's of meters
- **Minimum**: 10's of meters

### 2.3 Average Distance Between Neighbors

Meters - 10's of meters

### 2.4 Distribution of pods

## 3.0 Measurements

### 3.1 Number of Measurements at each pod

Hz monthly

### 3.2 Frequency of each Measurement

### 3.3 Precision of each Measurement

Filtering of Seismic data

### 3.4 Local Processing / Reduction of Data

### 3.5 Total Lifetime

- **Pod Lifetime**: Months - years
- **Application Lifetime**: Years

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Sensor Webs and Land Management

Sensor Web Approach:
- Characterize the microclimates associated with high-yield crops such as grapes.
- Compare detailed *in situ* measurements, such as soil moisture and ground temperature, with leaf area index.
- High spatio-temporal resolution: as close as 1 m, as often as 5 minute (unlike remote).
- Integrated measurement approach: Sensor Web information augments satellite acquisitions.
# Land Management Sensor Web Specs

## APPLICATION: Vineyard Monitoring

<table>
<thead>
<tr>
<th><strong>1.0 Sensor Web Description</strong></th>
<th><strong>Vineyard Monitoring</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.1 Goal of Web Usage</strong></td>
<td>Provide microclimate monitoring for optimum graph growth</td>
</tr>
<tr>
<td><strong>1.2 Passive Monitoring / Active Exploration</strong></td>
<td>Passive</td>
</tr>
<tr>
<td><strong>1.3 Point of Uplink / Downlink</strong></td>
<td>Internet</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>2.0 Spatial Scale</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.1 Dimensionality</strong></td>
<td>2-D</td>
</tr>
<tr>
<td><strong>2.2 Area Coverage</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2.2.1 Ideal</strong></td>
<td>500 km²</td>
</tr>
<tr>
<td><strong>2.2.2 Minimum</strong></td>
<td>10 km²</td>
</tr>
<tr>
<td><strong>2.3 Average Distance Between Neighbors</strong></td>
<td>1-5 m</td>
</tr>
<tr>
<td><strong>2.4 Distribution of pods</strong></td>
<td>evenly throughout trellis</td>
</tr>
</tbody>
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<th><strong>3.0 Measurements</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3.1 Number of Measurements at Pod</strong></td>
<td>8 (2 soil temp, 2 soil moist, light, air temp, humidity)</td>
</tr>
<tr>
<td><strong>3.2 Frequency of each Measurement</strong></td>
<td>every 5 minutes</td>
</tr>
<tr>
<td><strong>3.3 Precision of each Measurement</strong></td>
<td></td>
</tr>
<tr>
<td><strong>3.4 Local Processing / Reduction of Data</strong></td>
<td>trending to look at ground moisture</td>
</tr>
<tr>
<td><strong>3.5 Total Lifetime</strong></td>
<td></td>
</tr>
<tr>
<td><strong>3.5.1 Pod Lifetime</strong></td>
<td>6 months</td>
</tr>
<tr>
<td><strong>3.5.2 Application Lifetime</strong></td>
<td>2 years</td>
</tr>
</tbody>
</table>
SENSOR WEB TECHNOLOGY PROGRAM VISION

未来的任务
应用性
- 水文 - 土壤湿度
- 海洋生态学
- 植被冠层
- 大气化学

收益:
- 低成本校准和验证
- 分布式测量用于时间定义
- 优雅的降级和透明的替换

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- 优雅的降级和透明的替换

• Chem/bio
• NMR/Mass spec/GC/LC
• Optical/IR
• Acoustic/Geophones
• Accelerometers
• Nuclear
• RF (coherent, incoherent)
• Magnetic

低功耗处理器和通信

可扩展大型系统通信

低功耗传感器

2000

2010

网络与计算机

2010

网络与计算机

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