NASA TECHNOLOGY FOR THE EARTH OBSERVATION SENSOR WEB

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ABSTRACT

The Earth Observation Sensor Web vision is to enable on-demand sensing of a broad array of environmental and ecological phenomena across a wide range of spatial and temporal scales, from a heterogeneous suite of sensors both in-situ and in orbit. The NASA Advanced Information Systems Technology program aims to advance the use of emerging technologies for space based Earth science research and applications and infuse the sensor web concepts into space missions and data systems. The current technology investments in sensor webs are intended to advance the state of the practice in internet-enabled distributed systems, extended to on-orbit remote sensing sensors.

This paper describes the foundation for the Earth Observation Sensor Web based on a system-of-systems concept dynamically reconfigured to respond to events. Sensor web characteristics and sample use cases illustrate how these systems contribute to our knowledge of the Earth. Summaries of sensor web use cases and research highlights will be presented from some of the research projects recently funded by the NASA Earth Science Technology Office and currently underway in universities, industries and NASA research centers throughout the country.

Index Terms— *sensor web, system of systems, service oriented architecture*

1. INTRODUCTION

The goal of NASA's sensor web approach is to employ new data acquisition strategies and systems for integrated Earth sensing that are responsive to environmental events for both application and scientific purposes. Sensor webs can achieve science objectives beyond the abilities of a single platform by reducing the response time (where events unfold rapidly or where time is otherwise constrained), and by increasing the scientific value, quantity, or quality of the observation (where unique science criteria are met, or when co-incident observations are possible). Sensor web technologies are enabling dynamic and adaptive collaboration among sensing and analysis assets.

Recent technological advancements in micro-electronics, wireless communications, intelligent systems and networking have led to new remote sensing concepts reflecting the agile distributed systems enabled by the web, hence the term sensor webs. This concept was defined and published in 2002 by Delin [1] in a paper titled: *The Sensor Web: A Macro Instrument for Coordinated Sensing*. NASA's sensor web concept involves networked sensors that can interact and dynamically change their state to meet the demands of the environment into which they are placed. The sensors, be they in situ networked sensors, mobile vehicles or satellite instruments, are envisioned to interact in an environment that leverages information from many sources: analysis systems and predictive models, real time event detection systems, or observation goals driven by science or decision support system needs. Leveraging and expanding on Internet web technologies, sensor web systems coordinate and interoperate to adaptively respond to events and create customized data or information products on demand. Many technologies needed to implement this vision are currently in the research stage. However, limited versions of sensor webs have already been demonstrated, and new enabling technologies are being developed.

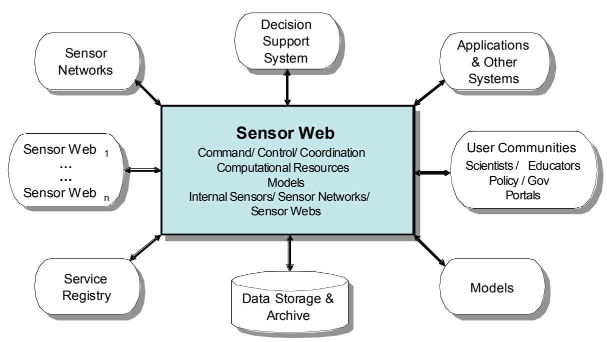

Figure 1 – Sensor Web Architecture Diagram

The architectural concept of the Earth observation sensor web in Figure 1 depicts the system-of-systems view as developed in a 2007 NASA investigator meeting on sensor webs [2]. Internal to a dynamically assembled sensor web are the sensors, sensor networks and perhaps even other sensor webs configured for a specific time-limited purpose. Computational resources, like satellite and ground-based processors and storage, support both science drivers such as event detection and the coordination of sensor web resources. Implicit throughout the architecture is a communication fabric, leveraging web technologies and optimized for sensor web activities. External to a sensor web one finds other sensor webs and sensor networks.

Available resources, both data and services, are discoverable in service registries and data archives. External models play a role in interacting with models linked into a sensor web configuration. All of these resources support users through decision support systems for societal benefits, and data systems and models for education and science analysis. The evolving sensor web concept will enable the Earth science community to benefit from the integration of many emerging information technology fields to support dynamic science objectives on demand.

2. Earth Observation Sensor Web

At the 2007 NASA workshop on sensor webs, a definition emerged to capture the vision of on demand sensing. "The sensor web is a coordinated observation infrastructure composed of distributed resources that can behave as a single, autonomous, task-able, reconfigurable observing system that provides observed and derived data along with the associated metadata by using a set of standards-based service oriented interfaces." In other words, sensor webs are distributed Earth observation systems that are dynamically configured to provide the desired products on demand, by using emerging web technologies.

There are several reasons to pursue sensor webs for Earth science. During the second sensor web workshop in 2008 [3], the NASA investigators developed use cases which will be discussed further in this paper. The motivation for Earth observation sensor webs fell into the following benefits.

1. *Improved science products*: more timely response to events; enable cross mission and multi-sensor products; reduce model uncertainty by acquiring targeted data as models inputs; and provide timely calibration and validation data.
2. *Improved science operations*: plan sensor flight paths for unmanned air and surface vehicles; design field campaigns; and simulate mission designs (ala the Operational Systems Simulation Experiment, or OSSE).
3. *Enable collaboration and save operational costs*: leverage multi-agency and international assets, for example US Group on Earth Observations (US GEO) and Global Earth Observation System of Systems (GEOSS); reuse infrastructure enabling collaboration in totally different domains such as fires and floods, or earthquakes and ecology; and reduce staff costs via automation.

Key sensor web features include the ability to obtain targeted observations through dynamic tasking requests, the ability to incorporate feedback (e.g., forecasts) to adapt via autonomous operations and dynamic reconfiguration, and improved ease of access to data and information. In the 2008 workshop, participants generated scenarios to highlight the value added by using sensor web concepts.

Given the above motivation for sensor webs, the next topic is to describe the characteristics of sensor webs. Sensors are envisioned to interact in an environment that leverages information from many sources: analysis systems and predictive models, real time event detection systems, or observation goals driven by science or decision support system needs.

NASA's Earth remote sensing assets are evolving into constellations of smart satellites that can be reconfigured based on the changing needs of science and technology. The operating missions, including the current fleet, upcoming satellites planned for launch in the next few months, and plans for the future, provide the space-based context of the Earth Observation Sensor Webs. Cooperation with the international community greatly expands the potential impact of sensor webs. For the current technology development and prototype phase in study by the AIST program, it's important to consider the scope and variety of sensors and platforms in space. As part of the 2008 workshop, the National Research Council's Earth sciences decadal survey [4] was used as a guiding document for developing sensor web use cases. In addition to space assets, in situ sensors and sensor networks are key. Within the AIST program, the southern California seismic sensor network, floating platforms for ocean science, unmanned aerial vehicles, probes, surface meteorological stations, mobile snow crafts are just a few examples of in situ sensors used to provide the observational data.

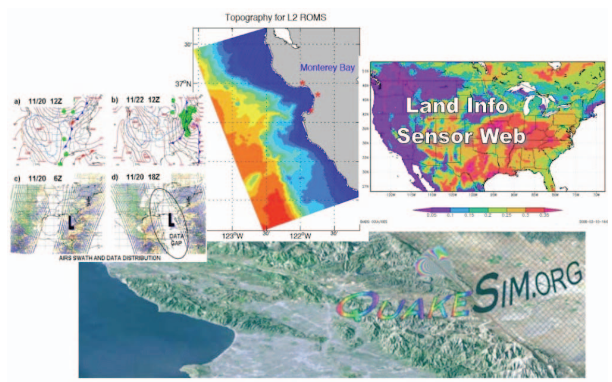

Figure 2 – Models are part of the Sensor Web

Sensor webs involve a multitude of data processing systems such as the NASA Earth Observing System Data and Information System (EOSDIS) and other agency data centers, and many science investigator led data centers around the country. As illustrated in Figure 2, sensor webs include forecasting systems, many that routinely provide predictions such as weather forecasts. Models addressing ocean and coastal processes, land assessments such as fire fuel loads, flood and earthquake predictions are just a few examples in the AIST sponsored sensor web prototypes. The above information processing assets provide remote sensing data products and predictions to inform the sensor web of detected or impending events that require additional near real time data for science and applications. The sensor web relies on portals and other user interfaces to provide insight and results to scientists or first responders in the case of natural disasters as envisioned by the GEOSS societal challenges. Leveraging and expanding on internet web technologies, sensor web systems coordinate and interoperate to adaptively respond to events and create customized data products on demand.

3. SENSOR WEB USE THEMES

The AIST program envisions intelligent and integrated sensor webs to provide on-demand data and analysis to users. The 2008 sensor web workshop focused on producing use cases to illustrate the new capabilities that sensor webs bring to support Earth science and applications. The purpose of the series of investigator workshops is to increase the awareness and understanding of the Earth observation sensor webs within and among the teams to enhance collaboration, and for the science community at large. If the benefits of the web enabled service oriented architecture is to be realized, the NASA and GEOSS science and application community need to understand the concepts and endorse the operational changes.

The use case format [4] was adapted to capture the scenarios, summarizing the people and systems that interact with the sensor web, the trigger that initiates the use case, the flow of events that transpire to respond to the trigger, and the final state of the sensor web at the end. The 2007 Earth science decadal survey provided the context for the future scenarios depicted. Investigators worked in teams to focus on some of the recommended missions addressing earth quakes, land use, soil moisture and weather applications, among others. They were challenged to address activities dealing with improved predictions, such as hurricane land fall, rapid response to natural disasters and near real time calibration and validation of sensors. They also addressed capabilities that sensor webs incorporate such as data fusion and data assimilation, workflow management for distributed services, and autonomous sensor operations.

As a result, over 40 use cases were documented and a few themes emerged. Several key capabilities are made possible by the use of sensor webs that were organized into three groups – Autonomous Sensor Operations, Autonomous Data Productions, and User Support. These groups correspond to the GEOSS architecture components – Observation System, Earth System Models, and Decision Support Systems – that map to the architecture underlying the sensor webs in the AIST program as shown in Figure 3.

Sensor webs detect events and respond by autonomously tasking sensor resources and feeding results into models in near real time. Figure 4 depicts a sample scenario and the steps taken to implement the sensor web flow. By assembling separate but collaborating sensors and forecasting systems to meet a broad range of research and application needs, sensor webs are a cost effective way to improve the use of sensor assets. Sensor web technology enables autonomous management of sensor resources, notably power and communications for in situ sensors. The ability to calibrate and compare distinct sensor results when viewing the same event, under the control of the sensor web, yields improved data accuracy. Finally, sensor webs provide mechanisms for model forecasts to influence which observations to acquire, resulting in more valuable sensor

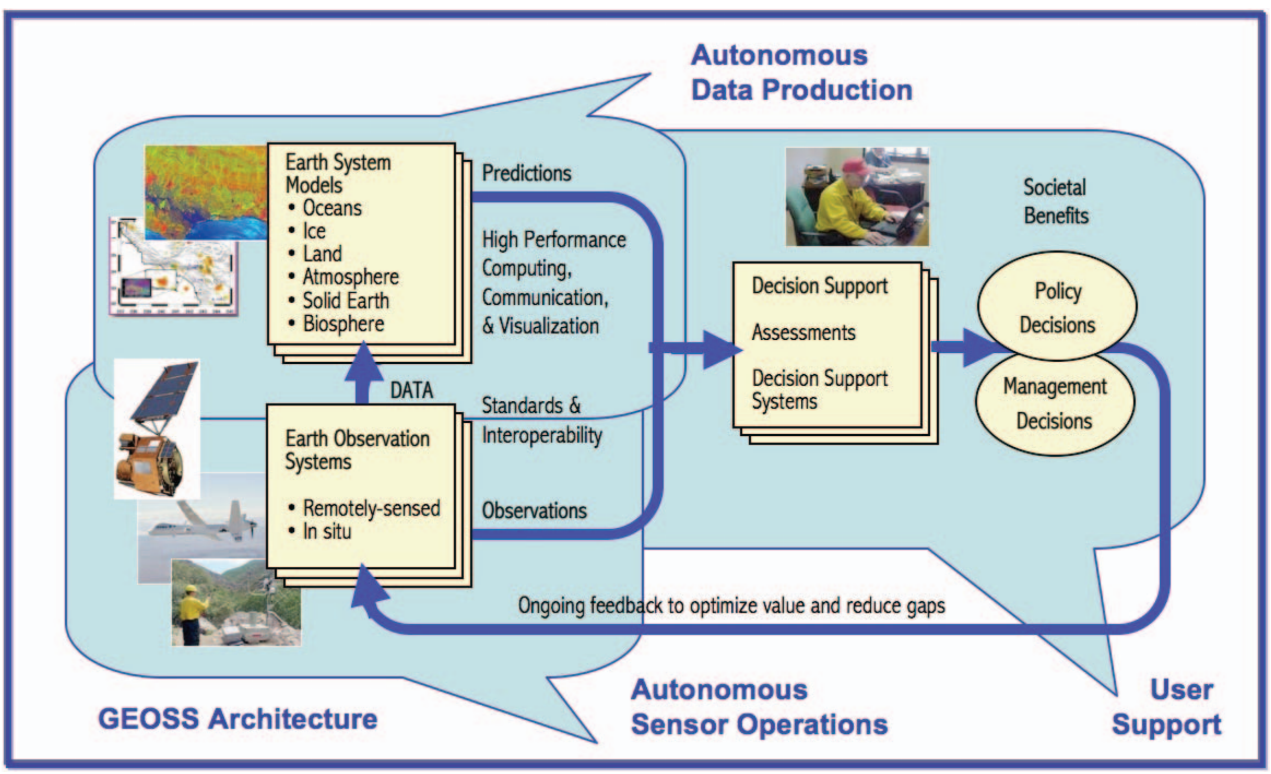

Figure 3 - Sensor Web Enabled Themes

data products. These targeted data inputs to models improve the forecast accuracy (reducing model uncertainty).

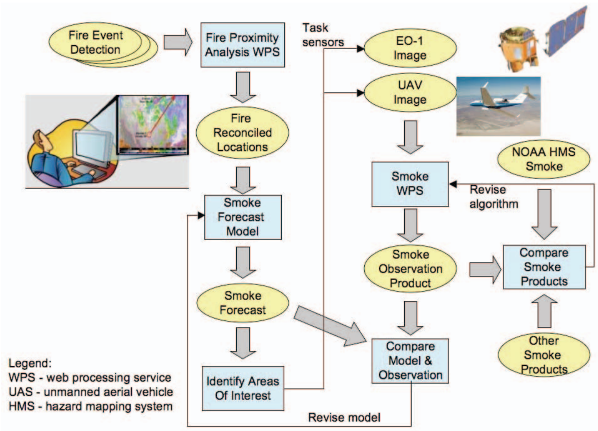

Figure 4 – Use Case Example: Smoke Forecast Model

The sensor web concept builds on the GEOSS architecture, with the key additional consideration of enabling models, data analysis and end users to provide feedback to the observation systems. Sensor webs are scalable system-of-systems, leveraging technologies allowing components to interoperate and thus support disparate data content and interfaces. Sensor webs can be implemented using repeatable patterns of assembling sensors and data processing systems, reusing the same middleware software for different application domains such as responding to a fire or a flood. Such reuse, enabled by services oriented architecture methods, has significant advantages for reducing operation costs.

4. TECHNICAL CHALLENGES

Technical challenges in implementing sensor webs lie not only at the hardware and software level, but at the system level as well. Power management is critical for tiny self-sufficient sensors. Communication and routing algorithms are needed for energy-efficient operations. This permits in situ sensor webs to operate longer in their environment and collect more scientific data. However migrating high performance processing to these constrained environments to support intelligent operations and real-time data processing will continue to be a challenge.

At the system level, many challenges still remain. The issue of cross-standards interoperability is especially challenging as the standards mature. Intelligent agents are being investigated to enable autonomous collaboration and control. The building blocks of service oriented architectures (SOA) are in the early stages of development for Earth science applications; the space segment will pose unique challenges. Service orchestration procedures and protocols are also emergent, as is the application of semantic web techniques to enable intelligent agents to discover data and service resources. Issues of data provenance and quality in dynamically configured sensor webs will require a concerted effort in the Earth science community. In order for web services to become more routinely used significant advances in security will also be needed. Fortunately state-of-the-art technology and emerging SOA management techniques are showing promise in sensor web prototypes.

ACKNOWLEDGEMENTS

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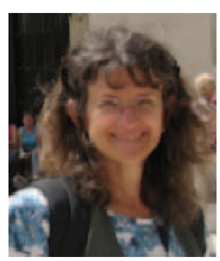
BIOGRAPHY



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