OGC Document 11-147

Sensor Webs: An OGC white paper for NSF EarthCube

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Abstract

This white paper covers the topic of Sensor Webs for providing information to National Science Foundation (NSF) EarthCube program. The paper reviewed the current status of Sensor Web technology, discussed the requirements for geospatial domain, and proposed a solution to advance existing NSF funded capabilities for building an integrated Earth observation Sensor Web System to support Earth system science research and education.

Introduction

NSF is developing the concept of "EarthCube" - Towards a National Data Infrastructure for Earth System Science[1]. The Sensor Web is one of the advanced topics to be discussed that provides an opportunity for timely and accurately observing the Earth system and for Earth science models to smartly connect with sensor observations.

This white paper was written by Open Geospatial Consortium (OGC) members and associates to contribute to development of the NSF EarthCube. This document does not represent an official position of the OGC. However, the discussions in this document could very well lead to NSF developments and subsequent OGC documents. Recipients of this document are invited to reply to the authors notification of any relevant patent rights of which they are aware and to provide supporting documentation.

OGC mission and relation to EarthCube

The mission of Open Geospatial Consortium (OGC) is to act as a standard body and forum to foster international standards for geospatial interoperability. One of the active OGC standard development activities has been the Sensor Web Enablement (SWE). Since 2001, OGC has been working on developing SWE standards and has achieved significant advances in the interoperable sensor web architecture and SWE standards. Fundamental Sensor Web interoperability standards, such as sensor planning services, sensor observation services, sensor alert services, and sensor markup language

[1]http://www.nsf.gov/geo/earthcube/index.jsp

(SensorML), have been developed. All these provide a solid set of standards, specifications, and experiences for supporting EarthCube missions.

Present status of Sensor Web

The concept of Sensor Web carries different meanings due to the heterogeneous background of its developments and applications. Nevertheless, the consensuses are that Sensor Web will make ultimate and smart connections among sensors and between sensors and models in a service-oriented architecture (SOA). The connections extend to all resources, including sensors, platforms, models, computing infrastructures, and communication networks [1–4]. The interoperation should enable a flexible, autonomous, reconfigurable, scalable, dynamically adaptive, fault-tolerant, and provenance-traceable system of systems [1,5].

The Sensor Web has been an active research and development area for over a decade. Several national and international programs as well as industrial efforts have been contributing to the development of Sensor Web. NSF programs have a tradition in supporting high impact high risk project and fundamental researches. Both the Directorate for Computer and Information Science and Engineering and the Office Cyberinfrastructure have direct research programs in developing sensor networks, sensor systems, future internet, and other sensor networking topics that are fundamental to the development of Sensor Web. They also collaborate with other NSF programs to support focused applications and R&D projects related to sensors and sensor systems, e.g. Engineering Directorate Sensor Initiative, Cyber Trust on security and privacy, Computer Systems Research (CSR) on embedded systems, storage, and applications, Information and Intelligent Systems (IIS) on robotics and data Management, National Ecological Observatory Network (NEON), EarthScope, Polar Program [6], and DataTurbine Initiative[7]. These researches provided theoretical bases and core technologies for the development and application of Sensor Web.

NASA, as the advanced Earth Observing agency and the space-based technology leader, has been actively funding more than 30 Sensor Web projects since 2005 under its Advanced Information Systems Technology (AIST) program [1,4,5,8]. The projects advanced Earth observing Sensor Web technology and its applications in Earth Science, and produced many valuable cases and prototype systems [3,4,8].

The Department of Defense (DoD) also has been very active in Sensor Web research. Its Smart Sensor Web has been focused on many advanced topics of Sensor Web technology [9,10]. Sensor interoperation and communication have been hot topics among many active research programs on Sensor Web within the DoD, including Navy Undersea Water Sensor Networks [11–13], Army Sensor Network Program [14–16], and Air Force UAV and Target Tracking[17,18].

OGC Sensor Web Enablement (SWE) has consolidated the general framework for architecture and specifications for sensor component development in the Web environment [2]. Under the overall reference system of OGC Web Services, the SWE services can be interoperated through unified Web interfaces to support unified discovery and access. It is worth to note that the OGC SWE architecture and its component Web services have been extensively applied in many of the research projects and implementations. OGC SWE along with other OGC geospatial Web service specifications provide a solid set of implementable specifications for building interoperable Sensor Web and systems.

The ISO Technical Committee 211 (ISO TC 211) -Geographic Information has developed a series of metadata standards for describing sensors and their observations, such as ISO 19130-Geographic Information-Imagery sensor models for geopositioning. Those ISO standards are essential for sensor interoperability and data provenance in the Sensor Web. Recently, ISO/IEC Joint Technical Committee 1 (JTC 1) has established working group 7(WG-7) - Sensor Networks. The missions of the working group are to seek generic solutions for sensor networks and undertake standardization activities that support and apply to the technical work of all relevant JTC 1 entities and to other standards organizations.

There are also grassroots projects spread out over different communities. Examples are GeoCENS [19], SwissEx [20], 52°North [21], W3C SSN-XG (semantic sensor networks ontology)[22], Microsoft Sensor Map [23], and Q2O [24].

Purpose

Sensor observations are indispensible source to enable the vision of understanding the Earth with EarthCube. They are capable of providing live or near-real time data to facilitate the timely monitoring of the Earth system. The EarthCube needs to adopt the Sensor Web concept and systems for supporting the discovery and access of sensor observations and ultimately providing bi-directional live connections between the sensors and the rest of Earth observing system of systems.

The OGC SWE has been proven to be valuable in many use case scenarios and implementation of Sensor Web. The SWE set of standards and protocols lays the foundation for building services based Sensor Web. Therefore, this White Paper strives to outline the requirements and possible solutions for lively connecting sensors, Earth system models, services, and networks in an open, unified, scalable, reconfigurable, and adaptive Sensor Web using the OGC SWE as the framework and foundation. In responding to the changing infrastructure and the emerging of cloud computing, further development directions are to be pointed out in light of new requirements in the new cyberinfrastructure.

Sensor Web Requirements

The requirements of Sensor Web for EarthCube can be summarized as follows.

- Core requirements of Sensor Web: Sensor Web should allow the discovery of sensors, sensor systems, and their observations and measurements, the planning and scheduling of target observing and specific processing, the encoding, accessing, and rendering of observations and measurements, and the notification and alerting of observation and product availability. All these capabilities should be enabled in the Web environment and ideally under a common framework that is suitable for Earth Science applications.
- Connecting directly sensor observations to Earth System models: Interoperation between Earth science models and sensors should be supported. Specific profiles or community profiles may be supported to better serve the specific applications without breaching the overall interoperability and standards.
- Dynamic calibration of physics-based models using real-time sensor data: Data calibration and validation is an indispensible step in Earth science modeling in order to align the raw sensor observations to physical properties of geographic phenomena. It is especially desirable to support an on-demand, real time, and physically sound calibration of sensors and sensor systems for long term live Earth scientific modeling.

- Model-driven observation requirements /adaptive sensing and feedback control: Target observing is crucial for Earth science applications. Earth Science models may need to initiate and control the new, fit, and specific observing that meets the changing requirements of modeling[5,8].
- Near-real-time/real time response: Reduction of time latency from sensor observations to meaningful Earth science products is crucial for many Earth science applications, especially true for disaster and emergency response applications. Mechanisms for shortening the time latency are highly desirable.
- Opportunities and challenges in the new era of cyberinfrastructure: The Web is expanding along the expansion of internet technology. Cyberinfrastructure is expanding its horizon and embracing many technologies that evolve into mature and dominant enabling infrastructures. Sensor Web needs to be adaptable, scalable, and extendable to the emerging environment. Noticeable, these evolving technologies include the following.
    - Service Oriented Architecture (SOA)
    - Resource Oriented Architecture (ROA)
    - Grid-computing or utility computing
    - Cloud-computing
    - Hybrid Mobile and Cloud Computing or ubiquitous computing
    - Semantic-driven discovery and integration (i.e., Linked Sensor Web, Linked Sensor Data)
    - Sensor Fusion with uncertainty propagation and the generation of lineage information or provenance
- Interoperation or "interworkability" beyond the Sensor Web: High level interoperability beyond intra-processing interoperation and data integration is desired. The interoperability may at science level (or semantic level) that leads to semantic interoperation beyond simple metadata[25].

Suggested/recommended strategy to NSF to move forward

The OGC SWE provides a solution to establish the live link between Earth science models and sensors in the Web environment. Figure 1 shows the overall architecture of the OGC solution to enable the discovery, access, commanding, and notification of sensor and its observations[4,5,8,26]. The OGC SWE is designed and built under the common OGC Reference Model (ORM)[27], Web Service Common[28], and SWE Service Model[29]. OGC Sensor Model Language Encoding Standard (SensorML)[30,31], Observations & Measurements (O&M)[32,33], and Transducer Markup Language (TML)[34], together with Geography Markup Language (GML)[35–40] and Keyhole Markup Language (KML)[41,42], define and provide comprehensive language and framework to describe, encode and access geometric, dynamic, and observational characteristics of sensors and sensor systems. Sensor Observation Service (SOS)[43] unifies the interface to access and interact with sensors and sensor systems to retrieve and manage observations and measurements. OGC Catalogue Service[44–50] defines a general cataloguing framework and standard Web interfaces with extensibility to accommodate different community and application profiles. The Catalogue Services extension package for Earth Observation Application Profile[51,52] is specifically applicable to enable the discovery and cataloguing of Earth observations for Earth science applications. Sensor Planning Service (SPS)[53,54] standardize the interfaces to plan and task sensors and sensor systems. Web Processing Service (WPS)[55,56] manages further data processing under an interoperable, chainable, and manageable interface framework. Availabilities and changes of sensor observations and their derived production can be alerted to end users through Sensor Alert Service (SAS)[57], Web Notification Service (WNS)[58], or GeoSMS[59].

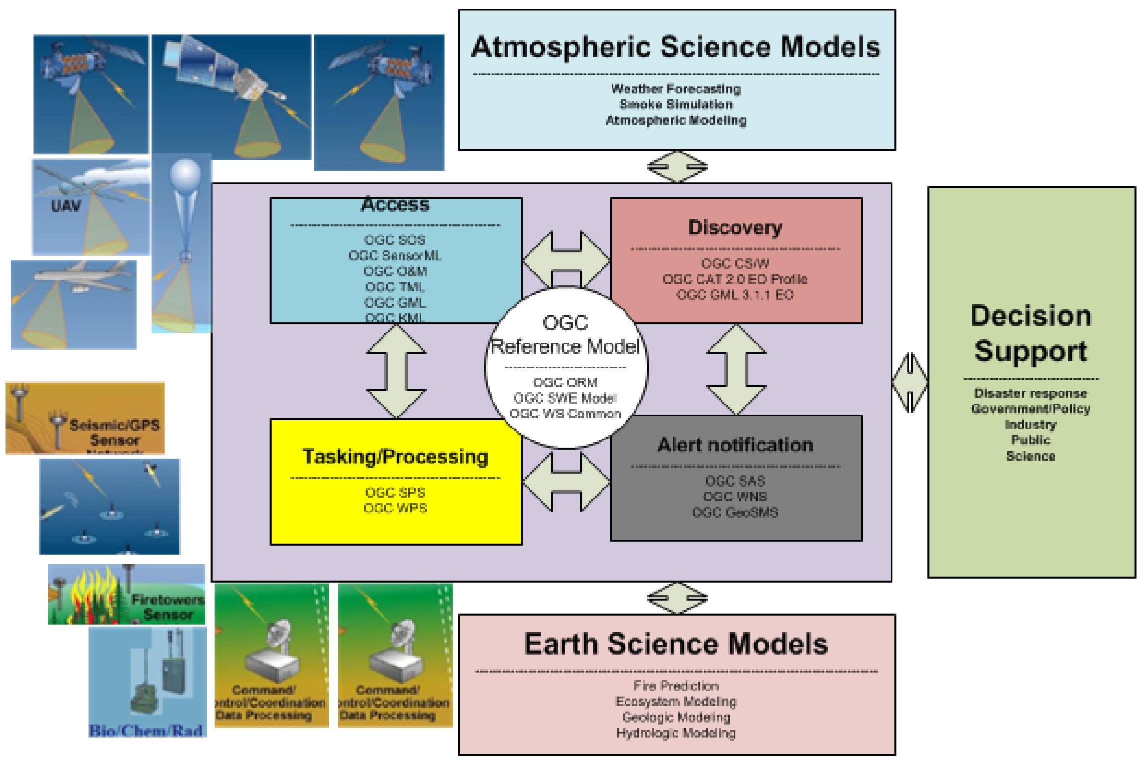

Figure 1. OGC Sensor Web Enablement Architecture

The solution makes it possible to satisfy the basic requirements of Sensor Web: (1) data serving through unified Web interface; (2) registration and discovery of sensors and sensor observations; (3) solid interoperations among all OGC Web services; (4) connecting to Earth science models bi-directionally, such as those demonstrated in SEPS [3]; and (5) event-based system to allow large data handling and notification.

In light of the coming era of cloud computing and semantic Web, further research and developments are required to satisfy the emerging requirements. The following are some aspects to move forward on the basis of the OGC SWE solution.

(1) Advance the standard and specification to meet the changing environment: clouds?
- Consolidate services and their specifications
- Profiles system architecture for different communities

(2) Core technology research and development
- Semantic discovery
- Integration
- Security
- Data-intensive: storage and all related issues

(3) Extensions and best practices
- Initiatives: community profiles
- Applications: scenarios and best practices

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