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Title: **Standards Set the Stage for Sensor Webs**

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Introduction

Defense and intelligence rely increasingly on live and stored digital data products obtained from remotely communicating sensors of all kinds: satellite, airborne and land vehicle imaging systems, fixed digital cameras and microphones, weather monitors, signal detection and tracking devices, in-situ sensors that measure environmental conditions and systems that send data about the status and health of vehicles and personnel. Industry continues to provide ever better wireless bandwidth and range, location technologies, device miniaturization, security, and price/performance. We are not yet at the point of nanotechnology "swarms" of tiny mobile intelligence gathering devices, but we do see a growing number of applications involving ever-larger numbers of network-connected -- and often widely dispersed -- sensors.

As the technologies advance and as products and applications proliferate, it becomes necessary to have a standards platform that enables

- Aggregation of similar and dissimilar sensors into "sensor webs"
- Integration of legacy applications with new sensor components
- Assurance that previously collected data will be usable with new sensor data

In much the same way that HTML and HTTP standards enabled the exchange of any type of information on the Web, the Open GIS Consortium's (OGC) Sensor Web Enablement (SWE) initiative is focused on developing standards to enable the discovery and exchange of sensor observations, as well as the tasking of sensor systems. The functionality that we have targeted within a sensor web includes:

- Discovery of sensors and sensor observations that meet our needs
- Determination of a sensor's capabilities and quality of measurements
- Access to sensor parameters that automatically allow software to process and geolocate observations
- Retrieval of real-time or time-series observations and coverages in standard encodings
- Tasking of sensors to acquire observations of interest
- Subscription to and publishing of alerts to be issued by sensors or sensor services based upon certain criteria

Within the SWE initiative, the enablement of such sensor webs is being pursued through the establishment of two encodings for describing sensors and sensor observations, and through three standard interface definitions for web services. Sensor Web Enablement standards that have been built and prototyped by members of the OGC include the following pending OpenGIS Specifications:

1. Sensor Model Language (SensorML) – standard models and XML Schema for describing sensors systems; provides information needed for discovery of sensors, location of sensor and sensor observations, processing of low-level sensor observations, interface definition, and listing taskable properties. (1)
2. Observations & Measurements (O&M) - The general models and XML encodings for observations and measurements made using sensors. (2)
3. Sensor Collection Service (SCS) – An open interface for a service by which a client can obtain observations and sensor and platform descriptions from one or more sensors. (3)
4. Sensor Planning Service (SPS) – An open interface for a service by which a client can 1) determine the feasibility of collecting data from one or more mobile sensors/platforms and 2) submit collection requests to these sensors/platforms. (4)

5. Web Notification Service (WNS) – An open interface for a service by which a client may conduct asynchronous dialogues (message interchanges) with one or more other services. (5)

The sensor web standards infrastructure defined by these specifications constitutes a revolution in the discovery, assessment and control of live data sources and archived sensor data. The goal of this article is to increase awareness of the SWE effort, encourage participation in the standards process, and spark adoption of the standards in software products and project efforts. Standards serve both technology providers and technology users by stimulating commercial activity, competition and innovation. In the area of sensor webs, these positive outcomes are particularly likely because of rapid advances in technologies involving sensors, wireless communication, position-determining technologies and Web-based geospatial services.

Background

A NASA-funded project to develop a standardized description files for planetary science sensor data began in the late 1980s. In the early 1990's Dr. Mike Botts at University of Alabama Huntsville began to investigate the benefits of using similar concepts for Earth-based sensor systems. In 1998, he presented an initial design for sensor descriptions to the Committee for Earth Observation Satellites (CEOS). To extend the modeling effort into the Web environment, he was asked to begin work on an XML encoding (see below) for sensor models based on his earlier work. He brought this modeling effort into OGC in March, 2001, because:

- All sensors have a location and sensor location is almost always important.
- OGC is the consensus standards organization that has developed and maintains the OpenGIS Specifications for interfaces and schemas that enable interoperability among geoprocessing systems such as GIS, earth imaging, etc.
- OGC provides a formal Technical Committee and rapid-prototyping testbed environment in which the specifications can be developed in an open consensus process.
- OGC's membership includes many of the agencies, corporations, and universities who might have an interest in shaping and adopting such a standard.
- Many of the individual participants in OGC are experts in complex sensors (e.g., Earth imaging systems).
- OGC has a Class A liaison with ISO TC/211 (Geographic Information / Geomatics).

- Authentication and access control will be important for Sensor Webs, and these are being addressed in the real-world settings of OGC's Interoperability Initiatives.

The initial Sensor Web Enablement work in OGC was motivated by requirements put forth by the US Environmental Protection Agency (EPA). The second OGC OWS initiative, OWS1-2, had a primary focus of extending Sensor Web to remote sensors on dynamic platforms. Part of the OWS-1-2 demonstration involved an unmanned aerial reconnaissance vehicle communicating with a ground station, as well as SensorML support for satellite sensors, ground-station profilers, and Doppler radar.

SensorML and Observations & Measurements are detailed in "Discussion Papers" and "Recommendation Papers" publicly available at http://www.opengis.org/info/discussion.htm. All the SWE specifications described in this article await further review, testing and approval before they become adopted OpenGIS Specifications. At that point they will be put in use by industry and will likely be submitted by OGC members to the ISO standardization process.

XML and Sensor Web Services

XML is a structured text format for encoding data. A standard of the World Wide Web Consortium (W3C), it is one of the core standards for Web Services. Web services are software-powered resources or functional components whose capabilities can be accessed at an internet URI. Standards-based web services use XML to interact with each other.

In the narrower OGC context, an OGC Web Service (OWS) is any service that geoprocessing software can perform, where the service is available through an http-hosted interface and where the service is accessible through interoperability interfaces defined in OpenGIS Specifications. Software interfaces based on the Sensor Web Enablement specifications first enable Web-based software to discover the existence of sensors. The interfaces also enable manual or automatic evaluation of sensors' characteristics based on their published descriptions. Information provided in the XML schema about a sensor's control interface enables automated communication with the sensor system: to determine, for example, its state and location; to issue commands to the sensor or its platform; and to access its stored or real-time data. XML-encoded documents thus support Web-based discovery of a sensor (and its stored data) and Web-based access to and exploitation of its capabilities. This object-oriented approach to sensor description also provides a convenient way to automatically generate standard-schema metadata for data produced by sensors, facilitating the discovery and interpretation of stored sensor data in distributed repositories.

SensorML

SensorML defines the information model and XML encodings for discovering, querying and controlling Web-resident sensors. The purpose of *SensorML* is to:

- provide general sensor information in support of data discovery
- support the processing and analysis of the sensor measurements
- support the geolocation of observed values (measured data)
- provide performance characteristics (e.g. accuracy, threshold, etc.)
- archive fundamental properties and assumptions regarding sensor.

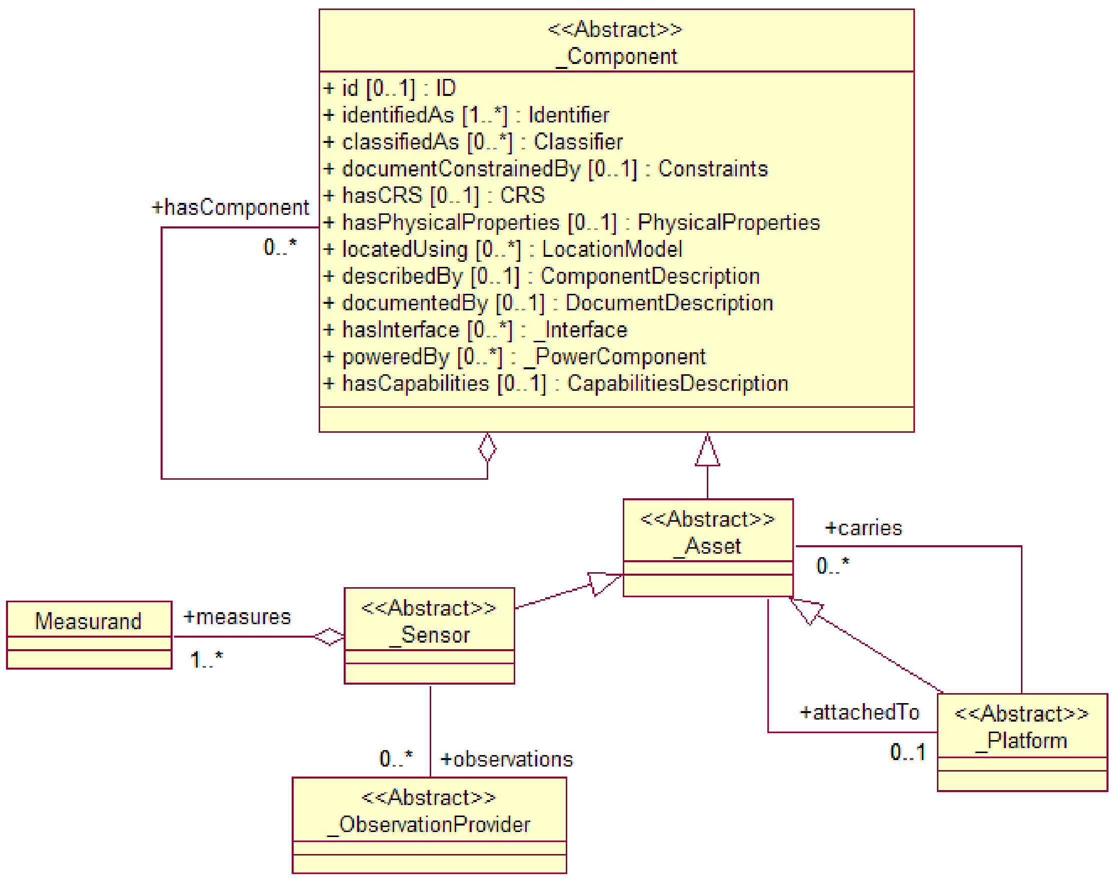

Figure 1: UML diagram showing base model for sensors and platforms within SensorML.

Figure 1 illustrates the base component model for Sensors and Platforms in SensorML. There are several properties that support “Plug-n’-Play” values, allowing for extensibility without complexity. For example, the locatingUsing property can accept several LocationModel types, supporting for instance, satellite ephemeris, dynamic aircraft state (including location, pitch, roll, yaw, velocity, and acceleration), or simple GPS position.

While not illustrated in detail here, the Measurand object within Sensor provides the primary information required to georegister and process sensor observations. While the description of sample location for a static, in-situ sensor can be quite simple, the geolocation of observations from a remote sensor on a dynamic platform can be complex, involving a collection of coordinate transformations between sensor, platform, and georeferenced coordinate spaces.

What does the actual XML code look like? SensorML for the response property for a YSI Wind Speed Sensor might include:

```
<response id=ysi_wss_0001>
    <GeneralPropertyModel>
            <dynamicRange>
                <minimum>
                    <Quantity observable type=#windSpeedunitOfMeasure=#mph>0</Quantity>
                </minimum>
                <maximum>
                    <Quantity observable type=#windSpeedunitOfMeasure=#mph>134</Quantity>
                </maximum>
            </dynamicRange>
            <threshold>
                <Quantity observableType=#windSpeedunitOfMeasure=#mph>2.2</Quantity>
            </threshold>
            <survivableRange>
                <maximum>
                    <Quantity observableType=#windSpeedunitOfMeasure=#mph>220</Quantity>
                </maximum>
            </survivableRange>
            <operationalRange>
                <minimum>
                    <Quantity observableType=#airTemeratureunitOfMeasure=#celsius>-40
                </minimum>
                <maximum>
                    <Quantity observableType=#airTemeratureunitOfMeasure=#celsius>40
                </maximum>
            </operationalRange>
    </GeneralPropertyModel>
</response>
```

Sample Application:

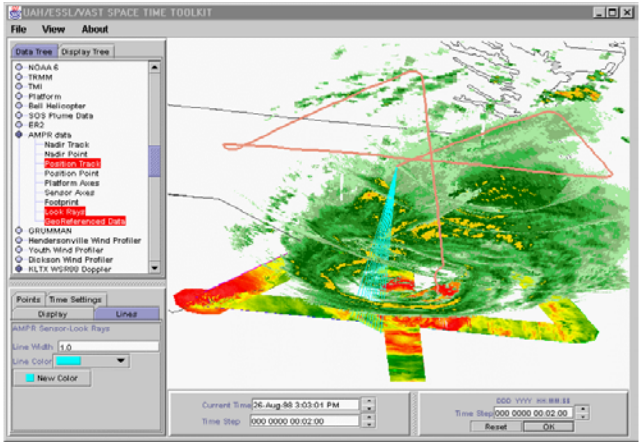

Figure 2: Diagram showing real-time styling, display and analysis of data about Hurricane Bonnie obtained concurrently from multiple heterogeneous sources.

The view of Hurricane Bonnie in Figure 2 illustrates one benefit of a common model for describing diverse sensors and sensor data: real-time styling, display and analysis of data obtained concurrently from multiple heterogeneous sources for immediate human understanding. The screen shows a hurricane view that combines data from two very different sources:

1) The green swirling masses in the figure show multiple elevations from two different Weather Service WSR88 Doppler radar sites (Wilmington, NC and Morehead City, NC).

2) The figure also shows the sensor track (pink line), look rays (blue lines), and georeferenced data (multicolored "ribbon") from an AMPR (Advanced Microwave Precipitation Radiometer) sensor on-board an aircraft. The ribbon of data represents one hour of sampled data preceding the current time (at the position of the light blue "look rays").

In this example, the sensor information, including location, was encoded using a SensorML prototype design. When sensor data is "packaged" in the XML schema described in this article, applications like this visualization application can automatically bring together data from multiple sources for real-time analysis and display. (Image is a snapshot of the Space Time Toolkit developed at the University of Alabama in Huntsville (UAH)).

Observations & Measurements

Separate from the SensorML specification, the Observations & Measurements specification (O&M) provides an information model and encodings for observations and measurements. This is required specifically for the Sensor

Collection Service and related components. The aim is to define a number of terms used for measurements and to define the relationships between them. The proposed standard discusses Observation, Measurement, Value, Observed Value, Coverage, SensorInstance, Observable, Measurand, Phenomenon, and related terms, which are presented using UML class diagrams and GML conformant XML schemas. In particular, the specification describes the separation of the concepts of *Sensor* and sensor characteristics, the *Subject* on which a measurement is made, the *Measurement* event, the *Property* being measured, the *Result* of the measurement, and other “metadata” about a measurement and the relationships between them. These distinctions lead naturally to the design of separate interfaces focusing on each concept. An observation is modeled to be a time and geo-located "feature" in the OGC feature model.

Within O&M the scope is restricted to measurements whose results are expressed as quantities, categories, temporal and geometry values. However, in certain circumstances, the result of any of the other components may be a *compound* object, such as sensor-array or network, multi-element measurement domain (esp. for imagery), series of measurements, or a vector or tuple result corresponding to a compound measurand such as a spectrum, or a compound domain such as an image.

Sensor Collection Service

A Sensor Collection Service (SCS), prototyped in the OWS program and expected to be a future OpenGIS Specification, will be invoked through a standard interface to fetch observations from a sensor or constellation of sensors. This service mediates between a client and an observation repository or near real-time sensor channels. It is designed to use the O&M and SensorML specifications.

Sensor Planning Service

A Sensor Planning Service, also expected to be a future OpenGIS Specification, will be invoked through a standard interface to assist in "collection feasibility plans" and to process collection requests for a sensor or sensor constellation. This is the intermediary between a client and a sensor collection management environment. A flood response planner, for example, might want to know what tide level sensors in a region are active and capable of providing a ten-minute average. An application designed to provide this information would benefit from being able to use such a Sensor Planning Service.

Web Notification Service / Web Alert Service

Many uses of SWE services will not require asynchronous user-service or service-service communication, as all the processing can be handled through purely synchronous exchanges. But observations that require preceding collection feasibility studies, complex control and management activities, or intermediate and/or subsequent user notifications favor asynchronous operations. A Web Notification Service executes and manages message dialogue between a client and Web service(s) for long duration asynchronous processes. The Web Notification Service is a general purpose asynchronous and stateful messaging service. It sends well-structured notification content to a client. To enable dialogue between the user and an invoking service, functionality has to be provided that enables the user to asynchronously answer with similarly structured content.

Similarly, the Web Alert Service provides a means to subscribe to and receive alerts from sensors. For example, one might wish to receive notification whenever a sensor's observation exceeds a certain threshold. Since alerts can be sent as email, messages, or http post to a URI, the Web Alert Service enables intelligent communication between sensors within an autonomous sensor network.

Non-OGC sensor web standard developments

Two other things need to be mentioned with respect to standards for sensor webs -- the TinyOS/TinyML/TinyDB approach and the possibility of "microgeography" or "indoor world" topological reference systems separate from earth coordinate reference systems.

TinyOS, TinyML and TinyDB (6) are academic and open source projects (Intel is also involved(7)) that focus on embedded wireless sensor network applications that typically involve localized networks of small devices, often including actuators or sensor/actuators as well as sensors. Often such sensor networks are comprised of fixed devices in buildings. TinyOS is a sensor network operating system that addresses the system design constraints of "dust-sized," low power devices with a few kilobytes of memory and wireless communication. Everything must be "lightweight." TinyDB is a query processing architecture for TinyOS sensor networks. It provides an SQL-like interface with a front end interface for users and the functionality to respond to the queries distributed in the network. It is designed to efficiently use network resources and to perform limited operations on the data values – either within a network or at a point where the network interfaces to another system, perhaps a larger network such as the internet. TinyML addresses the need for a standardized markup language for intra-network, as well as inter-network, communication involving embedded sensor networks. TinyML is capable of leveraging the flexibility of XML data structures with embedded sensor network reprogrammability. It is presented as a step forward in making sensor networks more accessible to the non-expert user and for archiving data retrieved from sensor networks in a self-documenting manner.

Because TinyML and SensorML are both XML-based, it should be fairly straightforward to develop interfaces between these different systems, though TinyML cannot express the range of information expressible in SensorML, and SensorML may not be able to duplicate the actuation and in-node processing facilities of the TinyOS/TinyDB/TinyML system.

At least one researcher(8) studying the operation of sensor webs and location based services inside building "microgeographies" has concluded that topology-based systems make more sense inside buildings than the earth coordinate based systems that make sense outside of buildings. Positioning systems such as GPS and cell antenna triangulation do not work reliably in buildings. The geospatial information available for buildings is typically a set of CAD files, and the technologies for sensing and reporting location in a building, though not widely deployed, typically report presence in a defined area rather than reporting a pair of coordinates.

Both the "Tiny" approach and the microgeography topology approach are different from the industry approach moving toward consensus in OGC, and both have potential implications for sensor webs.

Work-In-Progress and Plans for SWE at OGC

All of the SWE specifications described above are in draft form and have been or are being tested as prototypes in various environments. SensorML is expected to be adopted as a version 1.0 OGC Technical Specification during the Summer 2004. A simplified version of the Observation model from O&M is part of the Geography Markup Language(GML) – an OGC specification currently undergoing standardization as ISO 19136. The OGC O&M model also serves as the basis for the Assay Data Exchange language (ADX) (9) and parts of the eXploration and Mining Markup Language (XMML). (10)

Conclusions

Fortunately ahead of most sensor web development, an open, Web-based standards infrastructure is being put in place that will enable fusion of sensors into sensor webs, and fusion of sensor webs with other systems. Most notably, the standards enable fusion of sensor webs with the wide array of geospatial technologies and products that are being made interoperable in OGC's consensus process. Collections of similar sensors, for example, can comprise a "live" data layer in a GIS. The SWE standards will also create a market for a wide array of devices, software tools and systems, a market that would be much smaller if models and interfaces had to be reinvented, idiosyncratically, for each application.

However, standards are most complete when they represent consensus of a broad spectrum of users. OGC invites interested agencies and companies to investigate the draft standards in detail and provide comments, or better, help complete them. Several of these specifications are mature and simply need to be advanced through OGC's process. By the time this article goes to press, some progress toward adoption may have occurred through the efforts of the OGC Sensor Web Working Group at the June, 2004 Technical Committee meeting in Southampton, UK. Also, an OGC Sensor Web Conference, “Emerging Technology Summit III: Advancing the Sensor Web” will take place in the fall of 2004. The conference will feature keynotes and panel discussions involving leaders from a number of sectors (DHS, Emergency Response, Weather, Climate, Logistics & Transport, Environment, etc). The goal of ETS III will be to further focus the standards and interoperability requirements for Sensor Web Enablement and to identify organizations willing to sponsor or participate in the next Sensor Web testbed. Each year OGC runs one or two major testbed activities designed to extend existing OpenGIS specifications and develop new specifications through rapid prototyping. OGC will be formulating a Call for Participation and Request for Quotation in coming months.

More information can be obtained from the following links:

- OpenGIS Consortium: http://www.opengis.org/
- OGC Sensor Web Enablement:
  http://www.opengis.org/functional/?page=swe
- SensorML: http://vast.uah.edu/SensorML

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