

INTEGRATING THE OGC SENSOR WEB ENABLEMENT FRAMEWORK INTO THE OGC CATALOGUE

S.Jirka^{a,*}, D. Nüst^a, J. Schulte^a, F. Houbie^b

^a Westfälische Wilhelms-Universität Münster, Institut für Geoinformatik,
Weseler Straße 253, 48151 Münster, Germany - (jirka, daniel.nuest, janschulte)^a@uni-muenster.de

^b ERDAS SA, Quai Timmermans 14/01, 4000 Liège, Belgium - frederic.houbie@erdas.com

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ABSTRACT:

The Sensor Web Enablement (SWE) architecture of the Open Geospatial Consortium (OGC) has reached a broad acceptance. However, although the core specifications reached a mature state, the integration of a cataloguing service for sensors has not yet been achieved. Previous work focused on registries that address the specifics of dynamic sensor networks, on mechanisms for handling the semantics of phenomena and on metadata models based on the Sensor Model Language (SensorML). This work describes how existing elements supporting sensor discovery can be coupled with the already well established OGC Catalogue Service (CSW). The approach presented in this work relies on a SensorML profile specifying metadata necessary and sufficient for sensor discovery. SensorML documents that conform to the profile are automatically harvested from SWE services by a lower level registry and are subsequently transformed into an information model supported by the CSW. Finally the metadata is pushed into CSW instances and becomes available through the CSW interface. In summary, this work presents for the first time a working example how resources provided through SWE services can automatically be published through common OGC Catalogue Service instances. We expect that the presented approach is an important step in order to achieve a full integration of SWE components into spatial data infrastructures and to offer SWE services to a broader audience.

1. INTRODUCTION

Within the last years, the Sensor Web Enablement (SWE) architecture of the Open Geospatial Consortium (OGC) (Botts et al., 2007a) has reached a broad acceptance. It integrates sensors and sensor data into Spatial Data Infrastructures and thus makes it possible to easily use data measured by sensors in a broad range of applications. However, before the integration into SDIs is fully achieved, one last remaining issue has to be solved: Coupling SWE to cataloguing services. We show how cataloguing sensors is achieved by linking SWE components with the already well established OGC Catalogue Service (CSW) (Nebert et al., 2007).

This paper presents for the first time a working example how resources provided through SWE services can automatically be published through OGC Catalogue Service instances.

The remainder of this paper is structured as follows. In section 2 basic concepts like Sensor Web Enablement, sensor discovery and the OGC Catalogue Service are introduced. The definition of necessary sensor metadata elements to allow sensor discovery is presented in section 3. Section 4 shows the integration of sensor metadata into OGC Catalogues. Section 5 illustrates how the OGC Catalogue integration fits into the SWE architecture and sensor discovery frameworks. Finally, this paper ends with an outlook and a conclusion in sections 6 and 7.

2. BACKGROUND

The following three subsections give an overview of the concepts underlying the presented sensor discovery solution. First a quick overview of the Sensor Web Enablement framework is given. Afterwards we discuss what is meant by the term sensor discovery and which requirements have to be taken into account when searching for sensors and sensor data.

Finally, the OGC Catalogue Service for the Web and the eBRIM Catalogue Information Model are introduced.

2.1 Sensor Web Enablement

The use of sensor data has become very important in a broad range of applications. Often it is highly desirable to combine sensor data with other kinds of geospatial data in order to build more complex systems. To facilitate the interoperable access to sensor data and thus to allow the flexible (domain independent) re-use of sensor data within spatial data infrastructures a working group of the OGC has developed the SWE framework.

The SWE framework can be understood as an architecture consisting of a set of standards defining data formats as well as (web) service interfaces. During the development of the SWE framework, several aims had to be taken into account. Especially the following goals were the drivers of the design of the SWE architecture (Botts et al., 2007a):

- Standardised access to sensor measurements (including real-time as well as time-series data)
- Retrieval of metadata for determining sensor capabilities and the quality/reliability of measurements
- Controlling and tasking of sensors
- Alerting based on user defined criteria and sensor measurements
- Access to sensor parameters and automatic processing of measurements based upon pre-defined processes

The SWE architecture comprises two elementary parts: the Information Model and the Service Model. Whereas the Information Model addresses all aspects related to encoding sensor data and metadata, the Service Model deals with the specification of (web) service interfaces for sensor related functionality.

* Corresponding author.

The SWE Information Model is formed by the following standards:

- SWE Common: specification of basic data encoding building blocks which are re-used by all other SWE standards (Botts et al. 2007b)
- Sensor Model Language (SensorML): encoding for metadata describing sensors, sensor systems and processes (Botts et al. 2007b)
- Observations and Measurements (O&M): encoding of data measured by sensors (Cox, 2007a; Cox 2007b).
- Transducer Markup Language (TML): encoding of sensor data and metadata optimized for data streams (Havens, 2007)

The SWE Service Model offers the following standards:

- Sensor Observation Service (SOS): pull-based retrieval of sensor observations and descriptions (Na et al., 2006)
- Sensor Alert Service (SAS): subscribing to alerts based on user defined conditions (Simonis, 2006)
- Sensor Planning Service (SPS): controlling and tasking sensors (Simonis et al., 2007)
- Web Notification Service (WNS): transmission of asynchronous messages, like SMS containing alerts (Simonis et al., 2006)

Going beyond these models, the discovery of sensors is another topic that has to be addressed within the SWE architecture. However, this question is not completely tackled by existing SWE standards. This paper contributes an approach how the discovery of sensors, sensor data and SWE services can be addressed by aligning existing ideas to the OGC Catalogue Service.

2.2 Sensor Discovery

When building a sensor discovery solution, the specific characteristics of sensors and sensor networks have to be taken into account (Jirka, 2010). This concerns especially the highly dynamic structure of sensor networks (e.g. mobility of sensors, continuous addition of new sensors, defective sensors and removal of sensors) which makes it difficult to rely on conventional OGC Catalogues that have been developed to handle more static data sources. Furthermore, the specific metadata formats of the SWE architecture, especially the OGC Sensor Model Language (SensorML), have to be considered.

In addition to the specifics of sensor networks, a sensor discovery solution has to address three different types of discovery:

- Searching for individual sensors
- Searching for data measured by sensors
- Searching for SWE service instances

Previous work for enabling sensor discovery has mainly focused on registries that address the specifics of dynamic sensor networks (Jirka et al., 2009a), on mechanisms for handling the semantics of phenomena (Jirka et al., 2010) and on metadata models based on the Sensor Model Language (SensorML) (Houbie et al., 2010). Later on, this paper will show, how approaches for sensor discovery that were specifically designed to address the characteristics of sensor networks, can be coupled with OGC Catalogues in order to achieve a full integration into SDIs.

2.3 OGC Catalogue Service for the Web

Catalogue services play an important role for information discovery by both human users and computers. Albeit the availability of powerful search services and automated indexing

in the general domain, we still see an imminent need for specific metadata in expert domains. The OGC Catalogue Service (CAT) is a well-established standard for the publication, discovery, search, retrieval and management of geospatial data, applications and services by both humans and software (Nebert et al., 2007). The catalogue specification consists of several standards. The basic specification defines an information model, an interface model, and several protocol bindings. Out of the latter, the HTTP protocol binding is the foundation for all web-based catalogue services (Catalogue Services for the Web, CSW). A specific information model for SDIs is provided as an application profile for ISO 19115/ISO 19119 (ISO/TC 211, 2003; ISO/TC 211, 2005), i.e. metadata for geodata/geospatial applications and geospatial services.

The CSW-ebRIM Registry Service specification is based on the CSW part of the catalogue specification and uses the OASIS electronic business using XML (ebXML) Repository Information Model (ebXML RIM or ebRIM, OASIS, 2005). It consists of three parts:

- ebRIM profile of CSW: combination of ebRIM 3.0 with CSW interfaces on different conformance levels to facilitate the aforementioned catalogue features with metadata types and content in a well-defined XML format (Martell, 2009)
- Basic extension package: specification of fundamentals to support information about geospatial services with ebRIM (e.g. object, data and association types, service classification elements, and predefined queries) (Martell, 2009)
- Abstract Test Suite: checking capabilities of implementations (Martell et al., 2008)

The concept of an “extension package” is not yet thoroughly defined by the OGC (Steinsby, 2010). Briefly speaking it defines how specific metadata and their relations are stored in an CSW-ebRIM catalogue, i.e. classification elements (schemes, nodes and associations), slots, queries, and required object types. This extension package can then be loaded into a catalogue service instance which subsequently supports the required classes. In the context of this work we have developed an extension package that provides cataloguing of SensorML documents (see section 4).

3. SENSOR METADATA FOR DISCOVERY

When defining a Catalogue Information Model for the SWE framework it is necessary to have a solid conceptual foundation defining which metadata elements are needed for sensor discovery and how the presence of such metadata items can be ensured.

The following two subsections discuss these questions. First section 3.1 gives an overview of a minimum set of metadata elements that are needed in order to allow sensor discovery. Second section 3.2 explains how the formal definition of a sensor metadata profile can be achieved.

The explanation how this metadata is created is out of the scope of this work, but two options shall be pointed out here: This could be, and most probably needs to be, manually authored content (for example a human administrator giving keywords) supported by automatically generated and updated information (for example spatial properties derived from gazetteer services or status updates by event services).

3.1 A Minimum Set of Sensor Metadata

For allowing users to find the resources they need it is necessary that sensor catalogues provide the ability to search

for sensors based on a set of queryables. This subsection introduces a set of query parameters that has been developed within the two European Projects OSIRIS (<http://osiris-fp6.eu>) and GENESIS (<http://www.genesis-fp7.eu>). The subsequently presented search criteria have been identified as essential for fulfilling user requirements with regard to sensor discovery.

3.1.1 General Description: Users often just want to type in some keywords describing the sensors they are interested in (comparable to common search engines like Google). To support such a search request it is important that sensors are described with a set of well chosen keywords (i.e. describing the observed phenomenon and area). Also classification information like the sensor type (e.g. weather station) or the intended application domain (e.g. meteorology or hydrology) shall be provided. For allowing a better understanding of discovered sensor metadata records, a short full text description of the sensor is helpful.

3.1.2 Identification: For uniquely identifying a sensor it is important that each sensor metadata record contains a unique identifier. Such an identifier can be used for referring to the same sensor across multiple SWE service instances. This goes one step further as other solutions which are only relying on SWE service instance specific identifiers. In addition a speaking name for the sensor shall be provided.

3.1.3 Spatial Properties: Users usually search for sensor data within a certain area of interest. Thus, it is important that a sensor description contains information about the spatial properties of the sensor. Normally the position of the sensor is the most important information. However, in case of remote sensing systems the position is of less relevance as it does not directly refer to the area for which the sensor is able to provide data. In this case the geometry of the area which is observed by the sensor shall be provided as well.

3.1.4 Temporal Properties: Sensor networks are often characterised by highly dynamic behaviour. This means that sensors may move, new sensors may be deployed or defective sensors may disappear. Thus it is necessary that a sensor metadata record contains information about the time span during which it is valid.

3.1.5 Thematic Properties: An essential metadata element concerns the description of the phenomenon that is observed by a sensor. In this context it is important to distinguish between the inputs of a sensor (e.g. the observed phenomena like wind) and the outputs a sensor delivers (i.e. values for wind speed and wind direction) including the according units of measurement. These elements shall contain well-known interoperable identifiers rather than plain text as used in the general description.

3.1.6 Access Properties: After a suitable sensor has been discovered by a user, certain information is necessary in order to actually use the sensor, e.g. data retrieval or controlling. Within the SWE context this means that a user needs to know which SWE services are offering access to a specific sensor. To provide this information a metadata triple comprising the SWE service URL, the SWE service type and the identifier of the sensor within the SWE service has to be provided. Information about the sensor operator (i.e. contact details) shall be offered in addition.

3.2 SensorML Profile for Sensor Discovery

SensorML is the means for describing the metadata of sensors and sensor systems within the OGC SWE framework.

In order to ensure a broad applicability of SensorML to any possible sensor, sensor system or use case, the SensorML data model specifies a majority of its elements as optional. In addition, SensorML allows expressing the same information in several ways using different logical structures. This flexibility is intended and makes SensorML powerful.

However, for specifying a formal Catalogue Information Model SensorML's flexibility becomes cumbersome. That is why it is necessary that a minimum yet sufficient set of sensor metadata is provided by sensor, sensor network or SWE service operators. Such a minimum set of metadata and known structure is the basis for defining a formal mapping between SensorML and the ebRIM Catalogue Information Model. Furthermore such a metadata structure enables cataloguing components to automatically harvest the sensor metadata which is relevant for discovery from SWE service instances.

Based on the principles described in section 3.1 a SensorML profile for discovery purposes has been defined which ensures that users are able to search sensors based on general information (textual description and keywords as well as identifiers), spatial (area for which sensor data is needed), temporal (time span or point in time for which sensor data is needed) and thematic criteria (phenomena for which sensor data is needed). The original version of this SensorML profile is described in (Jirka et al., 2009b) whereas an updated version, which is optimized for the mapping between SensorML and ebRIM, can be found in (Houbie et al., 2010).

To define a formal SensorML profile the Schematron language was used. Using Schematron it is possible to formulate new rules that go beyond the regulations of the original XML schema. In the specific case of the SensorML discovery profile rules were defined that restrict the SensorML schemas.

Using Schematron it is not necessary to change the original SensorML schemas for making certain additional metadata elements mandatory. Instead the Schematron rules are put on top of the existing SensorML schemas using the XML Path Language (XPath) to identify elements. Thus, every SensorML document that conforms to the Schematron rules is also a valid SensorML document according to the original SensorML schemas (but not vice versa: a valid SensorML document does not necessarily conform to the Schematron rules). As a result the specified SensorML profile for discovery can be integrated seamlessly into any other existing SWE based system.

4. INTEGRATION OF SENSOR METADATA INTO THE OGC CATALOGUE

In the previous section we presented the content and format of metadata for sensor discovery. These properties can now be transferred into a catalogue service infrastructure and then comfortably be queried and retrieved.

The extension mechanisms of the OGC Catalogue are used in the OGC Discussion Paper "OGC Catalogue Services Specification 2.0 Extension Package for ebRIM application Profile: SensorML" (Houbie et al., 2010). It provides a mapping of SensorML documents to the ebRIM Catalogue Information Model and thereby allows cataloguing of sensor descriptions in a CSW-ebRIM service.

The extension package defines a generic ebRIM model suitable for a variety of sensors and specifically aims at domain-oriented profiles (e.g. earth observation) in the future. The model consists of:

- Two classification schemes: the application for which the sensor could be used ("IntendedApplication"

classification scheme) and the type of a sensor (“SystemType” classification scheme).

- Object types: These are defined for two main objects in SensorML (System and Component) as subclasses of ebRIM ExtrinsicObject (the primary metadata class for repository items).
- Two association types: the “ComposedOf” association relates a System with a sub-system (a System or a Component); the “AccessibleThrough” association relates a System or Component with a SWE service through which it is accessible.
- Slot definitions: Slots are ebRIM's mean to dynamically provide arbitrary attributes to RegistryObjects and are given for all required (queryable) properties like identifiers, keywords, and outputs (see section 3.1).
- A predefined query “findSensors”: It supports querying for all properties in a convenient way.

SensorML Components and Systems are the basic entities for the mapping, but the transformation of either of these creates more than one registry item.

On the one hand, there is a straightforward mapping between simple properties of sensors: a one-to-one correspondence between elements defined by the Schematron rules' (respectively their XPath expressions) of the SensorML profile on the one side and ebRIM object types, classification items, association items and slots on the other side. This mapping includes slot types (e.g. String, Date, or GM_Point), whether a slot is queryable, and its cardinality. These slots are then composed to a new ExtrinsicObject.

On the other hand there are the classifications of sensors, associations of sensors with each other, associations of sensors with web services, and associations of sensors with their operators. All of these lead to multiple ebRIM items. Classification nodes for both hierarchical classification schemes are created if there are new ones. The sensor is then associated with one or more of these nodes through a “Classification” element. If a System has Sub-systems or Sub-components, an association “ComposedOf” must be created. For every SWE service that is defined within a System or Component there is a Service Registry Object created along with an “AccessibleThrough” association which links to the respective System or Component. A SensorML contact element is transformed into an Organization Registry Object along with a “ResponsibleFor” association that links to the respective System or Component.

The conversion is implemented as part of a lower level sensor registry which is presented in section 5.

5. SENSOR DISCOVERY FRAMEWORKS

As previously mentioned sensor networks and the SWE framework possess specific characteristics that distinguish them from classic SDIs. One very important aspect concerns the often highly dynamic structure of sensor networks. Nowadays, mobile sensor networks are used in more and more applications. Thus, the location or area observed by a sensor can be continuously changing.

Another challenge specific to sensor networks is caused by the often limited lifetime of sensors. In wireless sensor networks sensors are usually not connected to a long-lasting powerful source of electric energy. Instead many sensors are equipped with batteries that have a limited lifetime. In this case a sensor will disappear from a sensor network as soon as the battery runs empty. To compensate these problems different strategies are applied. On the one hand sensors with empty batteries may be

replaced. On the other hand, mechanisms for reducing the energy consumption (e.g. putting sensors into a temporary sleep mode) are applied. This leads to the problem, that within a sensor network sensors may (temporarily) disappear and that there might be a steady deployment of new sensors. As a result the structure of the sensor network may change and so do the areas observed by sensors.

In consequence, the metadata of sensors and sensor networks underlie continuous change. Such a high rate of change (potentially within seconds) resulting in a high time-dependency of metadata was not specifically taken into account when the concept of the OGC Catalogue was designed. Furthermore, for general discovery purposes such a high temporal resolution of sensor metadata might be unnecessary or even undesirable.

To cope with this challenge it is possible to rely on lower level sensor registries which are capable of dealing with the high dynamics of sensor networks. These registries maintain a very detailed set of sensor metadata and offer mechanisms for quickly updating and requesting specifically time-dependent and volatile sensor metadata records. Based on this comprehensive knowledge about the available sensors and the sensor network structure, such a low level sensor registry is able to aggregate and generalize the sensor metadata to a level that can be handled by a CSW but still offers a level of detail that is sufficient for most sensor discovery purposes.

Another aspect concerns the specific metadata model within the SWE framework. Whereas the CSW relies on more general information models (e.g. ebRIM) the SWE framework is based on SensorML for expressing sensor metadata. This gap can also be handled by a lower level sensor registry which itself can be based on SensorML as a metadata model. During the process of aggregating and generalising the collected sensor metadata for the use within the CSW, it also executes the conversion from SensorML based metadata to a model like ebRIM.

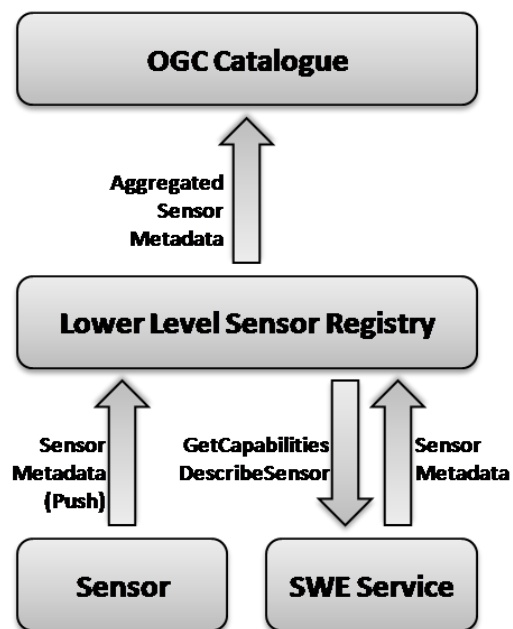


Figure 1. Link between low level sensor registry, SWE services, and OGC Catalogue

Figure 1 illustrates the combination of a lower level sensor registry with the OGC Catalogue. The lower level sensor registry is responsible for harvesting sensor metadata from SWE services that provide metadata conform to the discovery

profile introduced in section 3.2. This is achieved through a set of standardised operations: the GetCapabilities operation for retrieving general descriptions of the according SWE service and the DescribeSensor operation for accessing detailed SensorML encoded metadata.

Furthermore the lower level sensor registry offers a push interface for delivering new sensor metadata to the registry as soon as it is available. This interface has a simple structure so that it can be used by sensors or sensor controllers and at high update rates. The lower level sensor registry then aggregates and generalizes the SensorML based sensor metadata and converts it into an information model that can be handled by the OGC Catalogue. The implementation described in this paper relies on the mapping rules from section 4 and uses Extensible Stylesheet Language Transformation (XSLT, see Clark 1999) to transform a SensorML document to an ebRIM RegistryPackage containing a full representation of a Sensor, i.e. a group of registry objects, classification items and associations between these items and objects. After this, the OGC Catalogue compliant sensor metadata records are inserted into the OGC Catalogue. The time interval for executing this push transaction can be configured by the operators of the lower level sensor registries based on the requirements of the sensor networks and the expected use cases. Service interface operations to manage such a catalogue connection are available.

An implementation of the lower level registry has been developed and successfully tested within the European GENESIS project. The according implementation is available as free software through the Open Source Initiative 52° North (<http://www.52north.org/sensorweb> - Sensor Instance Registry, SIR).

6. OUTLOOK

The integration of sensor metadata into the OGC Catalogue as described in this paper is an important step in order to complete the full integration of sensors and sensor data into SDIs. However, we have identified certain aspects that will be subject of future work.

Many sensor networks that are deployed in practice are based on low level networking technologies that are not directly in line with the OGC SWE approach. One important aspect concerns peer-to-peer network organisation models. In this case there is usually no complete central knowledge about the network available. Thus, a transfer of metadata into Catalogue instances cannot be achieved. Instead such sensor network organisation models will require a modified approach. One step into this direction might be that incoming search requests are forwarded on-the-fly by OGC Catalogues to the nodes within the sensor network to perform an ad-hoc on-demand sensor discovery process. Another approach can include a layer between sensor hardware and SWE services, like Sensor Bus (Bröring et al., 2010). The analysis and experimentation with such solutions will be a topic of future work.

Another aspect where ad-hoc on-demand query mechanisms are helpful concerns all cases of time-dependent sensor availability. For example most sensors can only be parameterised with one set of values at a certain point in time. Thus, at times sensors might be blocked for certain tasks. Within a next version of the sensor discovery framework an according CSW extension providing an on-demand query mechanism taking into account the sensor availability shall be investigated.

Also, it can be expected that the SensorML Profile for Discovery is subject to a future revision as more users and use-cases come up. Within a future version it needs to be

investigated if a distinction between mobile and stationary as well as between remote and in-situ sensors shall be made. As the different metadata elements have different relevance for these types of sensors (e.g. for describing a remote sensor both the sensor position and the observed area need to be provided whereas the description of an in-situ sensor requires just one of these two elements) this should be reflected in the SensorML Profile.

Finally, the efforts to advance the standardisation process need to be continued. Currently the mapping between SensorML and ebRIM is published as an OGC Discussion Paper. For the future the current approach should be refined and improved in order to bring it to the state of an official OGC Standard. The current implementation and tests provide the grounds for that.

7. CONCLUSIONS

This paper has shown an approach for integrating sensors and sensor data which are accessible through OGC Sensor Web Enablement components into Spatial Data Infrastructures. Whereas the pure functionality for accessing sensor data, like subscribing to alerts and controlling sensors, is already covered by according standards, the link of the SWE framework with the OGC Catalogue was missing.

Within this paper a way has been shown, which allows to close this gap. Based on an underlying SensorML Profile for Discovery, which ensures that a sufficient degree of metadata is available, a mapping between the SWE world (i.e. SensorML) and classic SDI concepts (i.e. OGC CSW and the ebRIM Catalogue Information Model) has been achieved.

Although some research questions remain open for the future (i.e. the handling of sensor availability and underlying peer-to-peer organisation models), the presented approach makes it possible to search for sensor data like it can be done for any other kind of geospatial data sources. Thus, the sensor discovery framework provides a solid and pragmatic approach for closing one of the last remaining gaps between sensor networks and well established SDIs.

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