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Sensor Web 2.0: Connecting Earth's Sensors via the Internet

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***Abstract*- Sensors are everywhere, which includes space, air and ground. Earth phenomena such as disasters also occur everywhere; such as wildfires, floods and volcanoes. There is a need to rapidly deploy existing sensors to aid emergency workers and investigators. The vision for our effort is to provide users the capability to create "mash ups" (a web application that combines data from more than one source into an integrated experience), similar to that used by Google Earth users to create a composite map with overlays of sensor information and from other data sources such as weather, traffic, urban construction etc.**
We make use of Web 2.0 technology and Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) web service standards to enable access to Earth's sensors is an emerging mega-trend which will lower the cost of producing customized science by an order of magnitude. This paper will outline the key aspects of our experiments to date and implications for the future and in particular the Global Earth Observation System of Systems (GEOSS) international effort.

I. Introduction

Our team has been developing various ongoing prototypes with increasing complexity to demonstrate n an approach to interconnect sensors around the world and to enable easy access to the data from the sensors. Furthermore, we enable easy methods to combine various sensor data along with applying processing algorithms to provide users with customized data products.

In our demonstrations, we have used up to four satellites, one Unmanned Aerial System (UAS), multiple ground sensors, data algorithms and models in a variety of disaster management scenarios such as wildfire. Users, such as emergency workers, can rapidly assemble customized work flows to produce science products to help manage the wildfires. Whereas the present mashups integrate a variety of data sources, this project's mashups trigger workflows that actually task sensors via a common interfaces based on Open Geospatial Consortium web service standards. The web services are created in a Representation State Transfer (ReST-ful) service oriented architecture style. Thus the sensors which originally all had unique interfaces can now be accessed via common point and click interfaces. The architecture features Open Geospatial Consortium (OGC) compliant, platform independent web service interfaces, self-describing Workflow Management Coalition (WfMC) compliant automated work flow engines to automatically customize data products, self-describing sensor nodes, self-describing data processing nodes and decision support systems. Finally, discovery over the Internet is enabled by wrapping the sensors node, data processing nodes and workflows in Internet news feeds which can then be aggregated by Internet news aggregators such as Google burner. Thus, users can then discover these capabilities using common terms.

II. Basics of What Sensor Web 2.0 Does

Sensor Web 2.0 leverages the Internet, Web services, and Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) standards, and Workflow Management Coalition (WfMC) compliant workflows to hide the details of integrating and using an ad hoc set of sensors. This enables users to easily set up Sensor Webs via easy point-and-click interfaces with minimal use of software programmers, software engineers, and computer engineers. The pre-designed workflows represent recipes for tasking and combining data from various sensors into customized data products and also contain the knowledge of how to accomplish the task. Therefore, as time goes on, workflows will emerge to accomplish certain tasks (e.g. production of fire maps). These workflows are published via Atom Publishing Protocol (APP) news feeds, aggregated by tools such as Google burner and then discoverable by users with search engines such as Google.

Whereas previously, a scientist or emergency worker typically spent months or years together with a team of programmers to assemble sensors and data processing algorithms into workflows to accomplish an application, Sensor Web 2.0 enables even students to assemble customized Sensor Web applications in minutes or hours with no staff. Like the Internet, the usability will increase exponentially as the library of available workflows grows. Indeed, this architecture accelerates the paradigm shift from centralized silos for sensor control to decentralized, open control of any sensor.

One large effort that will reap the benefit of this technology is the Global Earth Observing System of Systems (GEOSS) – a worldwide initiative to form a network of Earth-observing systems and registered sensors that image and detect data ranging from population and vegetation density to tsunamis and major natural disasters, painting a complete, real-time picture of the Earth via shared global resources. In fact, Sensor Web 2.0 is a key enabler of this vision. More specifically, the Sensor Web 2.0 basic architecture can be used to quickly and easily make sensors accessible and controllable over the Internet.

Using these cutting-edge technologies, all needed functions are exposed as standard Web services. Thus there is a standard way to access and control the sensors and thus shield the user from the complex details via theme-based tasking. That is, the user requests a desired feature such as fires or floods and one or more sensors automatically supply the needed sensor data and algorithm steps.

Figure 1 depicts a typical selection menu along with a top level architecture. Using a Web portal integrated with Sensor Web 2.0, a user can trigger workflows that search for available sensors and then direct their actions. For example, in one of our demonstrations, a fire-behavior analyst selects wildfires in southern California as their area of interest. NASA's space-based Moderate Resolution Imaging Spectroradiometer (MODIS) data are retrieved for its Earth surface observations. One of the fire locations detected by MODIS automatically triggers a higher resolution instrument, the Hyperion on the Earth Observing 1 (EO-1) satellite to take a higher resolution image. Automatic triggers also cause an Unmanned Aerial System (UAS) to take more detailed fire imagery. The user receives notifications via instant message (IM), short message service (SMS) or other notification services (such as Twitter) when fires are detected in the area of interest and/or when a high resolution fire maps derived from one of these sensors is available. As a result, a fire analyst can focus his/her attention on the resulting detailed fire map and how to deploy needed resources rather than orchestrating the plethora of available sensors.

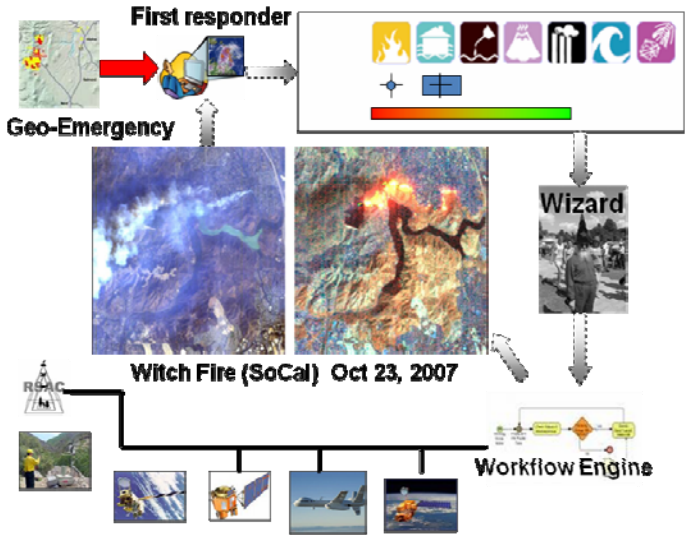

Figure 1. A user may select a theme and an area of interest. A wizard and workflow assist the user in customizing his or her customized data needs.

One of the most powerful features of Sensor Web 2.0 is its ability to easily plug in new sensors. This means that as the architecture is adapted by more users, an expanding capability to search for new sensors evolves. For example, in our fire scenario, a fire analyst could perform a Google search and find additional new sensors that he/she did not know existed. So the analyst will have a growing network of sensors and algorithms with no expenditure of additional resources in many cases – similar to the way that new Web sites become available on the Internet daily.

The user experience:

An example of a user experience is as follows. A menu presents various feature options such as fire. This may lead to another screen, which provides a variety of workflows and their description. For example, one workflow may use MODIS on NASA's Terra and Aqua satellites as a survey imager, and when a hot spot is located within a user-specified area of interest, a higher resolution image from NASA's EO-1 spacecraft is triggered. Or, the user may specify sensor constraints (e.g. resolution, coordinates, priority of imaging, etc.) and be directed to another satellite. The user may decide to integrate other related data sets via the portal within the area of interest (such as population density, vegetation, or any other GEOSS-registered data that may be of particular interest in determining the extent of the fire threat in a given location). The result is a custom data product generated "just in time" based on user needs that can now be shared with other users. It should be noted that the end result of this scenario is possible with other Sensor Web architectures; however, **the ease and automatic workflows of the result described above is unique to the technology behind Sensor Web 2.0**. Details about how this "behind-the-scenes" approach works are discussed below.

III. How it Works

Sensor Web 2.0 consists of an architecture that specifies a set of standards to be used by sensors to integrate into the "Internet" of sensors. Providers of sensors are required to encapsulate their sensor in OGC SWE Web services, which have standardized interfaces. This means the providers of sensors are not required to alter their method of accessing or controlling their sensor. They just need to provide some middleware to interface to the standard Web services. Once complete, users can access any sensor that complies with the interface specifications with standard Web-services tools such as those used by standard Web sites, using a standard Web browser.

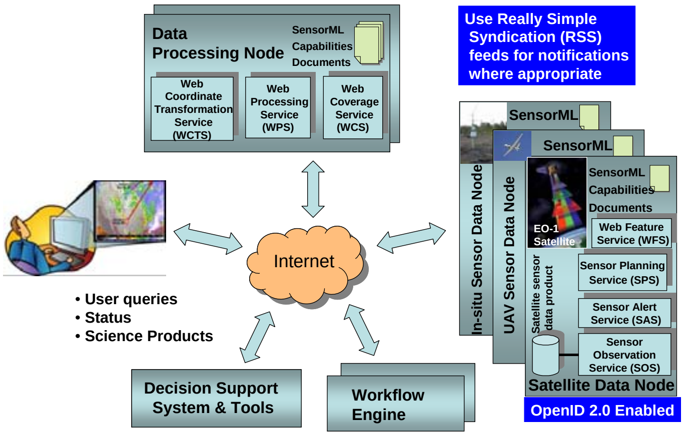

Figure2. This diagram represents a view of a user-centric Web of sensors, as realized by Sensor Web 2.0.

Sensor Web 2.0 is a user-centric architecture as depicted in Figure 2. Note that in this architecture, sensors are encapsulated as sensor data nodes which can contain self-describing documents using Sensor Markup Language (SensorML) – Web-accessible documents that are XML-based descriptions of the sensor's capabilities. The capabilities may include determining location as well as defining resolution, spectral bands, swath, and how to task the sensor. Furthermore, data-processing algorithms are encapsulated as data-processing nodes with SensorML or similar Web-accessible documents that describe what the algorithms do. These descriptions may include inputs, outputs, methods employed by the algorithm, and how to invoke the algorithm for user data. In both cases, the Web-accessible documents are created so that information about the sensors and algorithms can be discovered over the Internet and provide information on how to access the sensors and algorithms. The user can then assemble sensor data and selected algorithms into a customized workflow or service chain in an automated fashion, which includes automatic electronic delivery of data products to the users' computer desktop, thus enabling on-demand science products.
The user may interact with the sensors and workflows in many ways, covering many levels of detail. The most desirable interface is one in which the user's intent is automatically translated into the appropriate sensor and workflow. In other words, **what the user wants to see is automatically executed using the appropriate workflow and the best available sensors.**

Various possible sensors, data nodes, data-processing nodes, and workflows may exist in distributed locations. With Sensor Web 2.0, automated workflows and reasoning functions bring together all the required resources into a single functional flow.

IV. Making the Sensor Web More User-Friendly with the REST-ful Approach

Unique to Sensor Web 2.0, the architecture's primary innovation is that it takes advantage of emerging '*mashup*' capabilities that are becoming popular via the use of a representational state transfer (ReST) approach. This capability is what makes the reasoning functions and automated workflows possible, drastically increasing the user-friendly nature of the architecture. The Sensor Web 2.0 development team strategically integrated this ReSTful approach and leading-edge workflow-management tools (using open workflow execution [OpenWfE]), enabling end users to specify a series of actions and data aggregation and fusion operations for a set of distributed sensors in a user-friendly manner with the details of implementation hidden. This makes extensive use of available automation accessed via standard interfaces. For example, in the wildfire scenario mentioned in the previous section, it takes about 10 high-level steps in order to build a high-resolution fire location map:

(1) Specify the general area of interest for fires
(2) Find the "hot pixels" in the survey images taken by MODIS, resulting in active fire maps
(3) Identify the pixel of interest and translate into latitude and longitude locations
(4) Use that location to task EO-1 to take a high-resolution image at the next available opportunity
(5) Downlink the satellite data and perform first-level processing on the data
(6) Process the data to the next level, which correlates pixels in the image to their ground location
(7) Perform a classification algorithm to identify which of the high-resolution pixels are hot
(8) Transfer the pixels that have been identified as hot, along with the pixel locations on the ground, to a mapping function
(9) Produce a JPEG image that is a combination of the hot pixels and a map
(10) Send a notification to the user that the fire map JPEG is ready for pick-up electronically

It should be noted that each of the above steps has sub-steps from a variety of computer systems, which now have been automated with both ground and onboard software which are now enveloped with Sensor Web 2.0 wrappers. The total list of activities performed to achieve this product is complex. So initially, a user can specify a workflow that accesses the

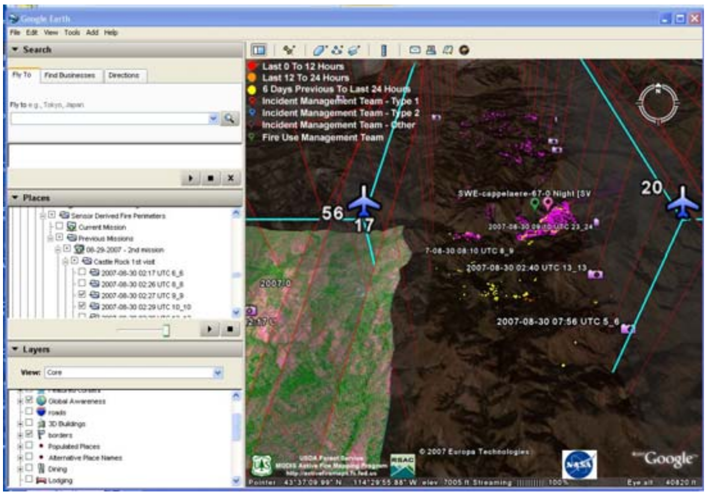

Figure 4. This screen capture shows a "mashup" of data obtained from NASA's EO-1 and a UAS, which is automatically combined from in a wildfire detection scenario. Future users would be able to search for such a scenario and use the same workflow given that the sensor assets are operationally available.

various servers in a chain that directs the servers to perform the required work. This workflow can be built in a very generalized way. So the various services are combined together in a mashup. This is made possible by Sensor Web 2.0 utilization of the ReST approach. Once the workflow chain has been specified and tested, all future users can search for this workflow and reuse the same workflow to create a fire map, **simplifying and streamlining the gathering of data and making it much more cost effective** (as an example, see Figure 4). And as users build various workflows to access various sensors and servers to create an assortment of products or data sets, a library of available products will become available. In the future, therefore, users will be able to search the Internet for product types, and various workflows that create the desired scientific product (e.g., sending a particular available UAV into a storm to provide key data about that storm) will be returned.

IV. TAKING ADVANTAGE OF WEB 2.0 AND OPEN STANDARDS

Sensor Web 2.0 addresses sensor interoperability through the use of state-of-the-art Web 2.0 capability. This enables interoperation of a heterogeneous set of sensors (space-based, air borne and ground-based) using simple, open Web-service standards. The implementation of GEOSS will be largely influenced by the emergence of Web 2.0 and OGC SWE standards. Therefore, use of these technologies as a basis for the Sensor Web 2.0 architecture is critical to the technology's ability to contribute to the successful realization of GEOSS. Web 2.0 is commonly understood as a transition of Web sites from isolated information silos to sources of content and functionality, thus becoming computing platforms serving Web applications to end users. Web 2.0 is characterized by open communication, decentralization of authority, and freedom to share and re-use — all of which are critical to the realization of GEOSS as a global network of shared resources for Earth observation.

Sensor Web 2.0 also employs OGC SWE standards, enabling discovery of sensor assets, standard data access, standard tasking, and standard alerts. In particular, the following OGC SWE services are used in Sensor Web 2.0:

- Sensor Planning Service (SPS) – A standard Web-service interface for requesting sensor acquisitions and observations. This is an intermediary interface between a user and a sensor-management system.
- Sensor Alert Service (SAS) – A standard Web-service interface for publishing and subscribing to alerts from various sensors
- Sensor Observation Service (SOS) – A standard Web-service interface for requesting subsets of data produced by selected sensors.

Additional OGC standard services used are:

- Web Feature Service (WFS) - A standard Web service to allow requests for geographical features across the Internet using platform-independent calls.
- Web Processing Service (WPS) - A standard Web service that takes a defined set of geospatially referenced inputs, applies a specific calculation defined by its owner, and produces a defined set of outputs.
- Web Coverage Service (WCS) – A standard Web service for exchanging geospatial data.
- WCS provides available data together with their detailed descriptions; allows complex queries against these data; and returns data with its original semantics (instead of images), which can then be interpreted.
- Web Map Services (WMS) – A standard Web service that produces a digital image file and is often used to display data produced by a WCS on a map.
- Web Coordinate Transformation Service (WCTS) – A Web service used to transform geographically encoded data from one frame of reference to another.

This extensive use of the OGC SWE suite of standards and Web 2.0 capabilities serves as end user insurance that Sensor Web 2.0 is leveraging the latest emerging technologies and standards.

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