

# SENSOR WEB AND GEOSWIFT - AN OPEN GEOSPATIAL SENSING SERVICE

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### ABSTRACT:

Sensor Web is a Web-centric, open, interconnected, intelligent and dynamic network of sensors that performs extensive spatial-temporal monitoring of our environment through coordinated work between multiple types and numbers of sensor networks. With the presence of cheaper, miniature and smart sensors; high-resolution remote sensing sensors; abundant fast and ubiquitous computing devices; wireless and mobile communication networks; and autonomous and intelligent software agents, the Sensor Web has become a clear technological trend in geospatial data collection, fusion and distribution.

The concept of Sensor Web is new and exciting. Research in Sensor Web is still in its infant stage and several technical issues still remain to be resolved. One of the challenges is to fast deploy intelligent and coordinated sensors into field, perform on-demand sensing, and timely distribute observations through an open distributed GIService for informed decision making. At GeoICT Lab of York University, We are developing an open geospatial information infrastructure for Sensor Web – GeoSWIFT (Geospatial Sensor Web Information Fusion Technology), which serves as a gateway that integrates and fuses observations from heterogeneous spatial enabled sensors. We are also developing a Sensor Web which composed by a group of matchbox-sized wireless sensor nodes and can be fast deployed by simply spreading those tiny nodes in the field. By integrating the Sensor Web and GeoSWIFT, the goal of fast on-demand sensing for better informed decision can be achieved. This paper first reviews Sensor Web technology and its implication for GIS. Then we introduce the components and architecture of GeoICT Lab's developing Sensor Web. GeoSWIFT, which is built on the OpenGIS standards, XML messaging technology, and its prototype are described in this paper. The examples of this integrated Sensor Web and GeoSWIFT in real-time weather information, earthquake information system, and traffic web cams are also presented in this paper.

## 1. SENSOR WEB

### 1.1 What is the Sensor Web?

The term 'sensor web' (SW) was first proposed by the NASA Sensor Web Applied Research Planning Group. In 2001, NASA provided a definition of a Sensor Web as follows (Delin and Jackson, 2001):

"A Sensor Web is a system of intra-communicating spatially distributed sensor pods that can be deployed to monitor and explore new environments."

This definition by NASA has limited the sensor web to a small scope in that it focuses on using only certain sensing instruments (sensor pods). The DoD also has a similar initiative called 'Smart Sensor Web', however, this focuses on tactical battlefield operations. It is argued here that the definition of the sensor web should take on a broader scope and vision, and that the applications should not be limited to environmental exploration or defense purposes. As sensing technologies, network technologies, and computing technologies advance, similar concepts or definitions can also be found in different research communities using different terminologies. Those terminologies, such as pervasive computing (Estrin et al., 2002), wireless sensor networks (Correal and Patwari, 2001), embedded sensing, distributed sensor networks, scalable information networks and next generation remote sensing system, partially touch on similar concepts. At the GeoICT Lab, we seek to broaden this scope and include a wide range of sensors and applications into the definition of the sensor web. We found

*Business Week* (Gross, 1999) provided a vivid and understandable description of the sensor web:

"In the next century, planet Earth will don an electronic skin. It will use the Internet as a scaffold to support and transmit sensations. The skin is already being stitched together. It consists of millions of embedded electronic measuring devices: thermostats, pressure gauges, pollution detectors, cameras, microphones, glucose sensors, EKGs, electroencephalographs. These will probe and monitor cities and endangered species, the atmosphere, our ships, highways and fleets of trucks, our conversations, our bodies – even our dreams."

### 1.2 Characteristics of Sensor Web

#### 1.2.1 Interoperable

The Sensor Web is achieved by connecting the distributed and heterogeneous in-situ and remote sensors by open, interconnected networks to an information centre that stores, disseminates, exchanges, manages, displays and analyzes the sensing information. Interoperability is the key to integrating all of these components and to achieving the vision of the sensor web.

#### 1.2.2 Intelligent

As computing technologies advance, computing resources have become seamlessly embedded into our daily lives. Intelligence can reside in all components of the sensor web by utilizing the ubiquitous processing capability. Another level of intelligence of the sensor web will stem from connectivity among sensors; a concept that is analogous to human intelligence stemming from the connection of neurons in the brain. (Koch and Laurent, 1999)

With these inexpensive and powerful embedded computing processors, small sensors are now equipped with “brains” (processing units); are able to “think” (processing data); and are able to “talk” (communicate) to each other with the integration of equipped computing processor, wire/wireless communication and embedded operation system(Liang et al., 2003).

### 1.2.3 Scalable

The Sensor Web will accommodate enormous amounts of distributed and heterogeneous sensing resources. New sensors can be added into the SW easily at later stages and without changing the existing design. To date sensor network community has pursued a variety of pioneering research activities in this field. One of the most important examples of this is in the development of ‘self-configurable and adaptive sensors’ which can be randomly ‘seeded’ to the field in large numbers without a sophisticated deployment process(Sohrabi et al., 2002).

### 1.2.4 High Resolution

The collaboration between various types of sensors and the fusion of sensing information will provide full-scale integrated sensing that has both high spatial coverage and high temporal resolution. (Figure 1.) Remote sensing has larger spatial coverage and in-situ sensing has higher temporal resolution. The SW connects both remote sensing and in-situ sensors, fuses their observations and provides integrated sensing(Teillet et al., 2002b) that has both large spatial coverage and high temporal resolution.

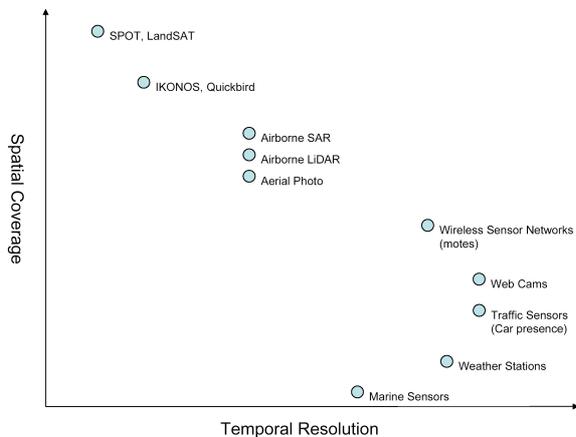


Figure 1. Sensor Web is an integrated sensing which has both large spatial coverage and high temporal resolution.

## 1.3 Layers of the Sensor Web

The sensor web is comprised of the following three layers:

- Sensor Layer
- Communication Layer
- Information Layer (Figure 2)

Through close integration of the three layers, the sensor web concept can be achieved. The following section introduces the advances, characteristics, and capabilities of each of these three layers.

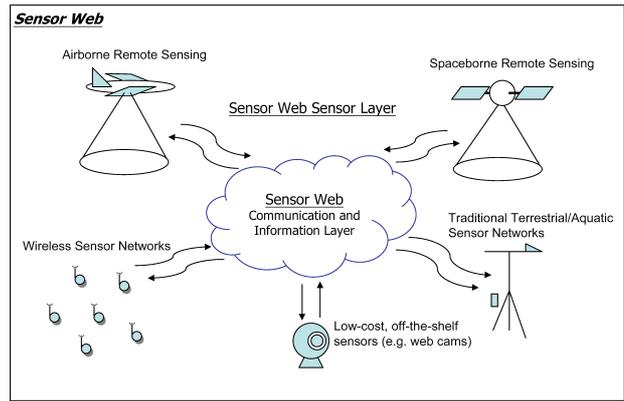


Figure 2. Conceptual Diagram of Sensor Web

### 1.3.1 Sensor Layer:

By definition, a sensor is a device that provides a usable output in response to a specific physical quantity, property, or condition which is measured (National Research Council, 1995). In the past ten years, sensor technology has been advanced significantly. Over 100 physical, chemical and biological properties can now be measured by sensors. Sensors have become smaller, cheaper, more reliable, more power efficient, more widely available, and more intelligent. Trillions of sophisticated sensors will be embedded into our daily lives, thereby providing extensive monitoring in the near future.(Estrin et al., 2001)

Sensors can be classified in several ways. One way is in terms of the medium or object that the sensors are sensing. Based on this, sensors can be classified as either in-situ or remote sensors, both of which have different characteristics and advantages. In-situ sensors are less expensive per unit, have higher accuracy, and have better temporal resolution. However, remote sensors provide much greater spatial extent than do in-situ sensors. The benefit of the SW is that it integrates both in-situ and remote sensors and thereby achieves truly integrated sensing.

### 1.3.2 Communication Layer:

The second of the three SW layers is the Communication layer, which controls the data / command transmission within and between the sensor layer and the information layer. It includes media, protocols, topologies, etc. This layer can be an Internet, satellite, cellphone or radio-based network. Configuration of the layer depends on the environment, the requirements and the constraints of the particular context.

Radio communication has long been used for meteorological sensors that obtain periodic readings of temperature, light, humidity, wind directions, etc. In urban areas, cell-phone based wireless network communication has been widely used for mobile sensors, such as GPS sensors for vehicle tracking. European Commission’s Mobihealth project is an example of using 2.5G and 3G cell-phone-based networks to transmit bio-sensors’ physical measurements. In many areas, satellite communication is still the only option for linking sensors. For example, CCRS’s proWISE project deployed weather sensors in Saskatchewan, CANADA and used satellite communication for transmitting observations back to the workstation in Ottawa, CANADA.(Teillet et al., 2002a)

In recent years, advances in miniaturization; low-power circuit design; simple, low power, yet reasonably efficient wireless

communication equipment; and improved small-scale energy supplies, have combined with reduced manufacturing costs to provide an emerging vision for sensor communication: wireless sensor networks.

Wireless sensor networks consist of compact, power efficient, battery powered nodes with low range radios and low-cost sensors. Wireless sensor networks have attracted a tremendous amount of attention and media publicity from both the research community and industry.(Hellerstein et al., 2003) A wireless sensor network is low cost, self organizing, self-configuring, and easily expandable. These features allow large scale and random sensor deployment in the field. Thus, a wireless sensor network provides better spatial coverage than traditional sensor networks and better temporal resolution than remote sensing. From a geomatics perspective it is important to note that location has been identified as the key for wireless sensor networks and that localization has become a major research focus in the field of sensor networks.(Hightower and Borriello, 2001) In the future, the aim is to make all sensors location-aware. This provides a great research opportunity for the GIS community since GIS is specialized in dealing with locational data. Figure 3 shows an example of a sensor node that is equipped with a GPS receiver.



Figure 3. A sensor board that is equipped with a GPS receiver. (MTS420CA, Crossbow Inc.)

It is expected that most communication layers within the sensor web will be hybrid systems, with different solutions being implemented under different constraints. However, ultimately the transferred sensing information is routed through the Internet to the information layer.

### 1.3.3 Information Layer:

The Information layer is the place where the sensing resources can be stored, disseminated, exchanged, managed, displayed and analyzed. Sensing resources include sensors; sensors' locations; sensors' real-time, near real-time or archived measurements; command and control to sensors; models which need sensor measurements as inputs and other related information for users' applications.

The Information Layer of the sensor web has enormous variety of data transport and access demands, data uses and data users. Interoperability is the key to a successful information layer for the sensor web. Users should be able to seamlessly access and readily use sensing resources of the sensor web despite the presence of significant heterogeneity of data, infrastructure (different setting of sensor and network layers), and user requirements. Information layers should support that data from different sources be combined and integrated. Meta data of the sensors and its measurements is also a core for an information layer. Data quality should be described, measured and guaranteed for more sophisticated applications.

One of the critical components in the information layer of the SW is to build a geospatial information structure, which spatially enables the sensor web. Any phenomenon measured by sensors must occur at a particular location. Location is an enabling key to make sensors' observations meaningful. As technology advancements in communication and sensor technologies are made, we will see more and more mobile sensors (i.e., moving while collecting measurements). An infrastructure which could store, disseminate, exchange, manage, display and analyze spatial information is vital for the sensor web. The spatial sensor web infrastructure also must meet the requirements of interoperability, openness, transparency, and intelligence, as discussed above. The goal of GeoSWIFT is to provide the missing GIService components to spatially enable the sensor web.

## 2. GEOSWIFT (GEOSPATIAL SENSOR INFORMATION FUSION TESTBED)

At York University's GeoICT Lab, our goal is to develop an open geospatial sensing service for sensor web. In order to have a comprehensive understanding of the research challenges and future applications of sensor web, we establish a testbed environment for sensor web – GeoSWIFT (Geospatial Sensor Web Information Fusion Testbed). GeoSWIFT contains the three layers we discuss above – sensor layer, communication layer, and information layer. The core of GeoSWIFT is an open geospatial sensing service, which serves as a single queryable “global sensor” for sensor web users. GeoSWIFT sensing service includes a GeoSWIFT Server and a GeoSWIFT Viewer. It serves as a gateway for sensor web users; fuses heterogeneous sensing sources and spatial information, such as vector and raster data; and provides transparent sensing information access. GeoSWIFT serves as a proof of the spatial centred sensor web concept. This real-world exercise serves to identify important areas of further work in spatial sensor web and its implication to Geomatics.

### 2.1 GeoSWIFT Sensing Service

We use a new technology framework, Web Services, to design the architecture of GeoSWIFT open geospatial sensing service. Web Services represent the convergence between the service-oriented architecture (SOA) and the World Wide Web. The basic idea of web services is similar to SOA, however, traditional SOA is tightly coupled with specific protocols. Each of the protocols is constrained by dependencies on vendor implementations, platforms, languages, or data encoding schemes that severely limit interoperability. Web services emphasize loose-coupling, openness, interoperability, and simplicity. Web Services support Web-based access, easy integration, and service reusability. For web service's openness, interoperability, and extensibility, it serves as a good foundation to build an open geospatial sensing service for GeoSWIFT.

GeoSWIFT is designed with the architecture of GIServices. GIService is to build GISystems with a service-oriented approach that allows users to access and assemble geoprocessing components that are distributed across a network through Internet. GeoSWIFT is adopting OGC Web Service standards for its sensing service. OpenGIS Web Service is a breed of web service and a standards-based framework that will enable seamless integration of a variety of online geoprocessing and geodata services. OGC Web Services will allow distributed

geoprocessing systems to communicate with each other using XML and HTTP. This means that systems capable of working with XML and HTTP will be able to both advertise and use OGC Web Services. Among OGC Web Service standards, Sensor Collection Service(OGC, 2003b) focuses mainly on the interoperable interface requirements for sensors. Table 1 shows the SCS interfaces provided by GeoSWIFT services.

Requests	Responses
GetCapabilities	The responding XML of service's capabilities conforms OGC Service Information Model Schema(OGC, 2003a), provides detailed information for a client to access the service. The provided information includes Service Type, Service Instance, Content Type, and Content Instance.
GetObservations	The responding XML of GetObservation request is encoded conforming to GML and O&M schema. It contains values, units and locations of the requesting sensor observations.
DescribePlatform	The XML response describes the sensor platform, and conforms to SensorML(OGC, 2002) schema. An example of a sensor platform can be a plane which carries a camera, several inertial sensors and meteorological sensors. The plane is the platform for those sensors.
DescribeSensor	The XML response contains detailed information of sensor characteristics encoded in SensorML. The sensor characteristics can include lists and definitions of observables supported by the sensor.

Table 1. Web Service Interface provided by GeoSWIFT Server

## 2.2 GeoSWIFT System Architecture

We now describe GeoSWIFT's system architecture, functionality of individual components and how they operate together. The purpose of GeoSWIFT is to build a small scale sensor web which consists of heterogeneous sensors and to develop an open geospatial sensing service for sensor information fusion. Three different sensing resources, network configurations and setting are implemented and tested in GeoSWIFT. Figure 4. shows the system architecture of our current implementation of GeoSWIFT.

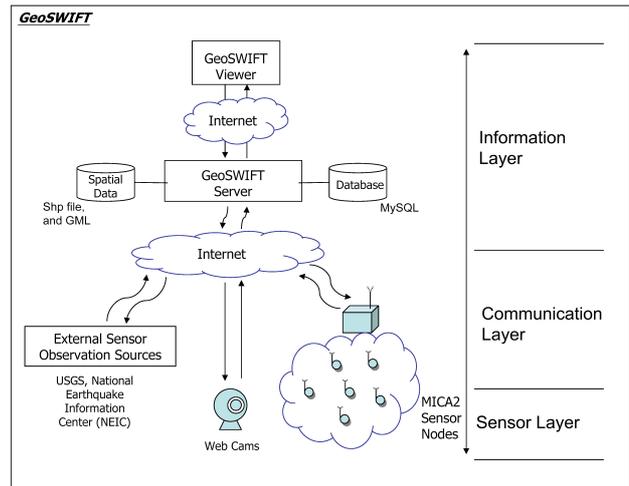


Figure 4. GeoSWIFT System Architecture Diagram

### 2.2.1 MICA2 Wireless Sensor Networks:

GeoSWIFT currently includes and has tested three sensing resources with different capabilities and settings. The first sensing resource of GeoSWIFT is a wireless sensor network. As we set forth in the previous section, wireless sensor networks give us new capabilities for sensing and collecting data about an environment. In the future sensor web, large amounts of wireless sensor network nodes will be embedded in our daily lives and provide pervasive and intelligent sensing. We set up a small scale wireless sensor network for this testbed environment.

We are using MTS-310 sensor board (sensor layer) and MICA2 mote (network layer) acquired from Crossbow technology Inc. as the sensor network nodes for GeoSWIFT(Figure 4). MTS-310 sensor board has a light sensor, temperature sensor, a microphone, a sounder, a tone detection circuit, a 2 axis accelerometer, and a 2 axis magnetometer. MICA2 provides the wireless communication capability (1000 feet maximum, outdoor), limited processing power (a microcontroller runs TinyOS), and considerable amount of nonvolatile storage (512 KB) for sensor board. The sensor board is plugged into a MICA2 node and the size of a MICA2 with a sensor board is approximately 2.0 x 1.5 x 0.5 inches.

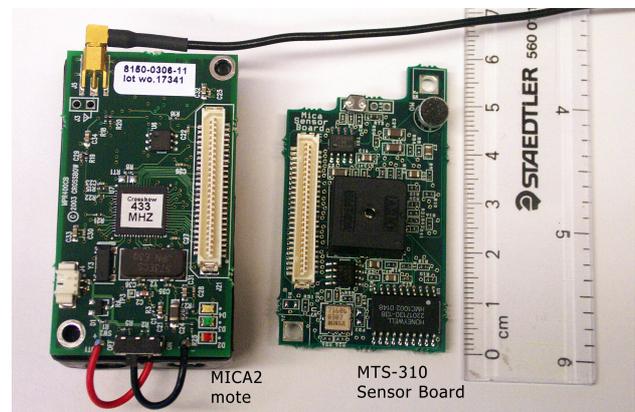


Figure 4. MICA2 motes deployed in GeoSWIFT

Communication between wireless sensor network and the GeoSWIFT sensing server is transmitted through a gateway.

The gateway wirelessly connects to the nodes and connects to the GeoSWIFT server through the Internet. The gateway is composed of an MICA2 mote plugged into an interface board which connects to a PC through RS232 based serial interface. A wireless sensor network of four MICA2 motes with sensor boards has been tested and deployed at York University.

Currently, these MICA2 are stationary sensors that performing sensing tasked at fixed locations. Locations can be acquired by additional devices such as a GPS receiver when the sensors are initially deployed in the field. In the very near future when localization techniques of sensor networks become more mature, the sensor web will have a lot of mobile sensors as moving agents to collect on-demand field measurements upon requests. An open geospatial sensing service, such as GeoSWIFT service, will become the information centre to control, manage, display and analyse the locations and observations of these widely distributed moving sensors.

### 2.2.2 External Sensor Observation Sources:

There are a lot of sensor networks geographically distributed all over the world and continuously collecting data. We have seen the development and evolution of World Wide Web. Since sensor web shares a lot of similarity with WWW, we envision that those existing sensor networks will be integrated into sensor web and sensor web will become a worldwide storage and exchanging center of the sensing resources.

Thus, we tested and integrated several existing sensor networks into GeoSWIFT. We have seen that some of the sensing information is already available online, such as Environment Canada's Climate Online, USGS's NEIC (National Earthquake Information Center) for earthquakes, NOAA's METAR for worldwide weather stations. Those existing Internet accessible sensing resources have obstacles for integrated sensing, such as sensor web, because these networks are using different transfer protocols and encode in proprietary data formats. Their data are not interoperable, not human readable, and not machine readable.

GeoSWIFT server retrieves the data from these sensing information services through Internet, serves as a wrapper, and provides a unified protocol (web service), an standard based data formats (XML, GML) for sensor web users. In the current integration, METAR and NEIC are the two external sensor observations sources in this testbed. Through GeoSWIFT sever, users don't need to deal with the different protocols and data formats of METAR and NEIC. By following the web service standards and interfaces, users can concentrate in application through collaboration and harmony between sensing resources.

### 2.2.3 Web Cams:

Low-cost off-the-shelf sensors, such as web cams, microphones have become widely available. Those sensors can interface to low-cost PCs which provide strong processing power and can easily broadcast sensing observations (which are video, still images, sounds, etc...) over the Internet. These sensors are rich resources for the sensor web and can be applied to a lot of applications, such as environmental monitoring and safety surveillance. In this testbed, we tested our concept by integrating City of Ottawa's traffic web cams in GeoSWIFT. These web cams cover most of the important intersections of downtown Ottawa and give viewers a sense of real-time traffic conditions. The web cams in Ottawa feed near-real time still images into GeoSWIFT and GeoSWIFT connects users to web cams by embedding Xlink to the web cams in GML responses

upon users' requests. We can foresee that a lot of applications will be done by including these low-cost off-the-shelf sensors into the interoperable infrastructure of the sensor web.

## 3. DISCUSSIONS AND FUTURE WORK

An open geospatial sensing service can be the centre which stores, disseminates, exchanges, manages, displays and analyzes the spatial sensing information for sensor web. In GeoSWIFT, we've integrated three sensing resources into GeoSWIFT. At later stages of GeoSWIFT, more sensing resources, especially remote sensing data (e.g. satellite remote sensing imageries, Lidar point clouds, etc), will be tested and integrated into current system.

Wireless sensor networks, such as MICA2 we are using in GeoSWIFT, bring great opportunities and challenges to current spatial data infrastructure. These tiny motes and moving agents will change the way how we collect data for GIS. These tiny motes and moving objects will generate enormous amounts of data and data types for GIS. The processing power and embedded operation system of MICA2 provides the capability for GeoSWIFT sensing service to send command and control to the nodes, and nodes change the behaviour according to the commands.

By integrating external sensor observation sources, such as METAR and NEIC, we expand the scope of GeoSWIFT to the level of an interoperable sensor web. The sensor web should be able to leverage existing sensing resources and shouldn't focus on using certain sensing instruments and proprietary communication protocols. The spatial component of those existing sensor observation services is weak. In both METAR and NEIC, locations of the observations are recorded in geographical coordinates in text format. By providing a standard based web service interfaces (OGC web specifications) and data format (GML), GeoSWIFT includes these external sensor observations into sensor web and makes these two sensing resources interoperable and more widely available. Web cam is the remote sensing sensors currently included in GeoSWIFT. Web cams represent another type of sensing resources of sensor web, which is low-cost, off-the-shelf and yet powerful.

In the future, GeoSWIFT will include more different types of sensing resources and remote sensing data is especially of high priority (e.g. satellite remote sensing imageries). Real-world applications will be built upon our currently system.

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## REFERENCES

- Correal, N. and Patwari, N., 2001. Wireless Sensor Networks: Challenges and Opportunities, *MPRG/Virginia Tech Wireless Symposium*.
- Estrin, D., Culler, D., Pister, K. and Sukhatme, G., 2002. Connecting the Physical World with Pervasive Networks. *IEEE Pervasive Computing*, 1(1).

- Estrin, D., Girod, L., Pottie, G. and Srivastava, M., 2001. Instrumenting The World With Wireless Sensor Networks, *International Conference on Acoustics, Speech and Signal Processing (ICASSP 2001)*, Salt Lake City, Utah.
- Gross, N., 1999. 21 Ideas for the 21st Century, *BusinessWeek online*.
- Hellerstein, J.M., Hong, W. and Madden, S.R., 2003. The Sensor Spectrum: Technology, Trends, and Requirements. *SIGMOD Record*, 32(4): pp.22-27.
- Hightower, J. and Borriello, G., 2001. Location Systems for Ubiquitous Computing. *IEEE Computer Magazine*, 34: pp.57-56.
- Koch, C. and Laurent, G., 1999. Complexity and the Nervous System. *Science*, 284: pp.96-98.
- Liang, S.H.L., Tao, V. and Croitoru, A., 2003. The Design and Prototype of a Distributed Geospatial Infrastructure for Smart Sensor Webs., *The 6th AGILE Conference on Geographic Information Science*. Presses polytechniques et universitaires romandes, Lyon, France, pp. 303-311.
- National Research Council, 1995. Expanding the Vision of Sensor Materials. National Academy Press.
- OGC, 2002. Sensor Model Language (SensorML) for In-situ and Remote Sensors. OpenGIS Discussion Paper. M. Botts.
- OGC, 2003a. OWS 1.2 Service Information Model. OpenGIS Interoperability Program Report. J. Lieberman.
- OGC, 2003b. Sensor Collection Service. T. McCarty.
- Sohrabi, K. et al., 2002. Scaleable Self-Assembly for Ad Hoc Wireless Sensor Networks, *2002 IEEE CAS Workshop on Wireless Communications and Networking*, Pasadena, California, USA.
- Teillet, P.M., Gauthier, R.P. and Chichagov, A., 2002a. Towards Integrated Earth Sensing: The Role of In-situ Sensing, *ISPRS First International Workshop on Future Intelligent Earth Observing Satellites (FIEOS)*, Denver, Colorado, USA.
- Teillet, P.M., Gauthier, R.P., Chichagov, A. and Fedosejevs, G., 2002b. Towards integrated Earth sensing: Advanced technologies for in situ sensing in the context of Earth observation. *The Canadian Journal of Remote Sensing*, 28-6: pp.713-718.