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THE DESIGN AND PROTOTYPE OF A DISTRIBUTED GEO-SPATIAL INFRASTRUCTURE FOR SMART SENSORS WEBS

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1. INTRODUCTION

So far, over 100 physical (light, pressure, humidity etc), chemical (gas, liquid, solid, etc) and biological (DNA, protein, acoustics etc) properties can be sensed by using in situ sensing technology. With the presence of cheaper, miniature, faster, and smart in situ sensors, and the increasing availability of abundant ubiquitous computing devices, wireless and mobile network access, and autonomous and intelligent geospatial software agents, distributed networked in situ sensing becomes clearly a technological trend. Sensor webs can perform as an extensive monitoring and sensing system that provides timely, comprehensive, continuous and multi-mode observations. This new earth observation system opens up a new avenue to fast assimilation of data from various sensors (both in situ and remote) and to accurate analysis and informed decision makings.

One of the critical components in developing a sensor web is to build a geospatial information infrastructure, a backbone that connects the heterogeneous in-situ sensors and remote sensors over the wired or wireless networks. This paper describes a distributed GIServices architecture, which serves as a gateway that integrates and fuses observations from spatially referenced sensors. A GIServices prototype -GeoServNet which is being developed in GeoICT Lab, York University is also introduced in this paper.

2. SMART SENSOR WEBS

2.1 What is smart sensor webs

“A system composed of multiple science instrument/processor platforms that are interconnected by means of a communications fabric for the purpose of collecting measurements and processing data for Earth or Space Science objectives.” This is the definition of Sensor Web from NASA Sensor Web Applied Research Planning Group. Sensor Web can be seen as an advanced smart sensor network.

Business week provide a vivid and easy understanding description of smart sensor web [1]:

In the next century, planet Earth will don an electronic skin. It will use the Internet as a scaffold to support and transmit sensations. This 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."

2.2 Smart

The most unique characteristic of a sensor web is that they are smart [2]. Thanks to the advances of semiconductor technologies, microprocessors become cheaper and faster than ever. According to Moore's law [3], the number of transistors on a given piece of silicon would double every couple of years. In fact the growing rate of computation power today is even faster than that and the price of computing processors has a massive drop in a short period of time as well. With those cheap and powerful embedded computing processor, the small sensors are equipped "brains" and are able to "think". They can "talk" to each other with the integration of equipped computing processor, wire/wireless communication and embedded operation system. Capable with computing power, these smart sensors only transmit useful information. It will significantly reduce the bandwidth requirement for the communication between sensor and servers and also save the computation power and storage space of central computers which digest the sensor observations.

2.3 Mobile

With wireless communication and real-time positioning technologies, sensors are no longer to be fixed at a certain location and do not require any additional wiring. Sensors will be mobile and installed everywhere as micro scale moving agents monitoring our planet restlessly. Wireless communication is a consequential trend of the way which devices communicate with each other in the near future. In one or two years, we will no more see those disordered lines behind our machines, because wireless protocols like Bluetooth, 802.11a and 802.11b will replace those virtual lines and cords. 2.5G and 3G mobile phone technology will also largely increase the bandwidth of mobile phone network. Internet connection will exist everywhere. Location is an essential property for sensors as well. A measured value must be observed at a particular geospatial location at a particular time. Real-time positioning technologies, such as GPS, AGPS, RFID, RTLS and cell-phone positioning make it is possible to acquire accurate real-time location of the sensors with low cost and low power consumption. By integrating both wireless communication and positioning technologies, sensors can collect data without spatial boundary and time constraint.

2.4 Cheap and Reliable

The very essence of a smart sensor web, with its multiply redundant pods, allows for an instrument to be "reseeded". Because of the advances of MEMS technology, a sensor web would be a relatively cheap instrument. Individual sensor could be regarded as expendable because of the low cost of each sensor. The cheap small sensors could be made as redundant and/or as dense as desired by simply distributing as many nodes as desired over the target area. For example, as various sensor pods drop out of the web because of spent batteries or damaged transducers, it is possible to spread new sensors to replace the old sensor pods. Redundancy would, of course, render the sensor web tolerant to failures of individual pods [4] [5]

2.5 High resolution

Compared to remote sensors, in-situ sensors have higher accuracy and faster data capture rate because it captures ground truth. However, in the past, remote sensing provided greater spatial extent than in-situ sensing does. With the smart sensor webs which are deployed in greater spatial extent than the old in-situ sensing networks, the observation with both high spatial and temporal resolution can be achieved. By real-time transferring the captured data back to central research site using wire/wireless network communication technology, near real-time analysis and modelling is possible. A typical application could be environmental monitoring, smart spaces, medical applications, and precision agriculture [6] [7].

3. DESIGN GOALS

A sensor web is generally composed of multiple science instrument/processor platforms and sensors that are interconnected by means of a communications fabric for the purpose of collecting measurements and processing data for Earth or Space Science objectives. Such networks of sensors (sensor webs) can perform as an extensive monitoring and sensing system that provides timely, comprehensive, continuous and multi-mode observations. This new earth observation system opens up a new avenue to fast assimilation of data from various sensors (both in situ and remote) and to accurate analysis and informed decision makings [8]. One of the critical components to implement the goal of sensor web concept is to build a geospatial information infrastructure, a backbone that connects the heterogeneous sensors or sensor webs over the wired or wireless networks. The design of the infrastructure needs to satisfy the following goals.

3.1 A mechanism for sensor discovery

A sensor web consists of a large number of sensors which link with each other and the concept is just like the concept of World Wide Web today. Sensor webs might have the similar problems which today's WWW has. How to find the sensor which meets exactly user's interest definite will become a challenging issue.

3.2 Integration with existing sensor networks

There are already many existing sensor networks. For example, USGS publishes real-time water data through internet [9]. The National Weather Service of National Oceanic and Atmospheric Administration (NOAA) in US also broadcasts meteorological data over Internet [10]. In York University, we also have a meteorological observation station which update observations each 10 minutes and publish on web [11]. There are many sensor networks already existing and operating there but each sensor network has its own standards, protocols and data formats. Utilizing those existing sensor sources will save considerable amount of money and resources. It is a necessity to accommodate, utilize and leverage the existing sensor networks for the GIServices for Smart Sensor Webs.

3.3 Accommodating a variety of observables and observed values

Observable is a phenomenon that can be observed and measured, such as temperature, gravity, chemical concentration, orientation, number-of-individuals. An observed value describes a natural phenomenon, which may use one of a variety of scales including nominal, ordinal, ratio and interval. Different types of sensors perform different types of measurements and collect different observations. The design can't be a customized design for limited types of sensors and needs to be extendable and flexible enough to accommodate various sensor types.

3.4 Georeferencing the sensor observations

Each measurement performed by a sensor must be at a particular geospatial location at particular time. The infrastructure needs to be geo-spatial enabled, such as support geo-data and geo-processing. A simple example could be allowing users request the observed values of a particular sensor within a certain spatial extent.

3.5 Providing open access

The concept of Smart Sensor Webs is similar to World Wide Web. Smart Sensor Webs shares many similarities with WWW. The openness of WWW allows millions of computer connected over it, makes WWW so powerful and completely changes our daily life. Design of the geo-spatial infrastructure needs to be open as well. It needs to support the inter-connections and collaborations between different sensor webs

4. A DISTRIBUTED GISERVICES ARCHITECTURE FOR SMART SENSOR WEBS

4.1 A Web Services Approach

We use a new technology framework, Web Services, to build the architecture of the GIServices for smart sensor webs. Web Services represent the convergence between the service-oriented architecture (SOA) and the Web [12]. SOA has evolved over the last 10 years to support high performance, scalability, reliability, and availability. However, traditional SOA are 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. The Web Services architecture takes all the best features of the SOA and combines it with the Web [13]. The Web supports universal communication using loosely coupled connections. Web protocols are completely vendor-, platform-, and language-independent. Web Services support Web-based access, easy integration, and service reusability. Web Services satisfies our requirements to build a geospatial infrastructure for Sensor Webs with openness, interoperability, and extensibility. Web Services now are developing as standards in W3C group and will become future standards for World Wide Web. Due to these reasons, Web Services serve a perfect foundation to build such an open infrastructure for Sensor Webs. The figure below shows the general web services architecture (Fig. 1).

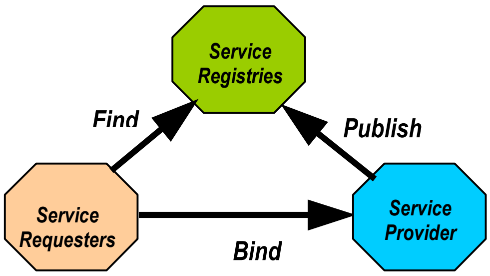


Fig. 1 A general web service architecture

The basic architecture describes the interactions between three roles:

- Web Service Provider
- Web Service Requesters
- Web Service Registries

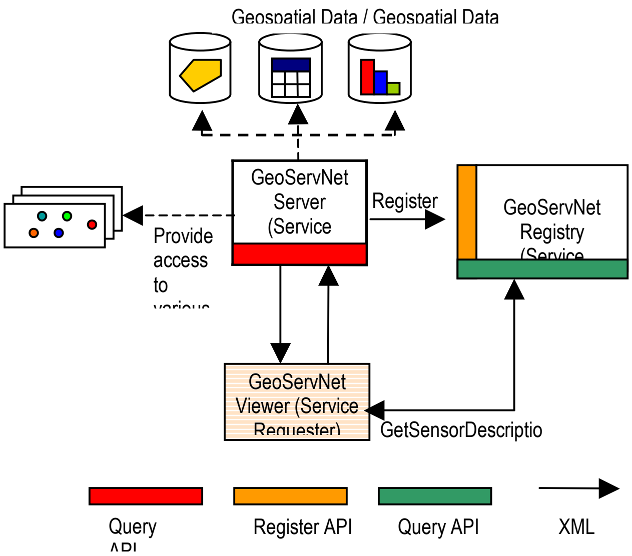
Web service providers develop and define Web services and then publish them to Web service registries or make them available to Web service requesters directly.

Web service requesters perform a find operation to locate desired services made available by Web service providers and then request those services from either Web service registries or the publishers directly. Once the service has been located, Web service requesters can then bind to those services.

Web service registries serve as centralized directories and repositories for Web services defined and published by Web service providers.

4.2 A distributed GIServices prototype for Smart Sensor Web – GeoServNet

GeoServNet is designed with the architecture of GIServices [14] [15] and is developed by GeoICT Lab, York University, Canada. The figure below illustrates the components architecture of GeoServNet



Components Architecture of a geospatial infrastructure for Sensor Webs

4.2.1 Service Provider - GeoServNet Server

The role of GeoServNet Server is to provide a web-enabled interface for sensor systems and other geo-spatial information as well. GeoServNet Server acts as a wrapper which hides the different communication protocols, data formats and standards of sensor systems behind the server and provides a standard interface for clients to collect and access sensor observations and manipulate them in different ways. In this way, various clients only need to follow the standard interfaces which provided by GeoServNet Server, and are not required to deal with the annoying protocols of various sensors. In order to accommodate various sensors in a sensor web, the standard interfaces play a vital role to keep the whole architecture efficient, extensible, and interoperable. The standard interfaces provided by GeoServNet follow OGC specifications such as SensorML [16], Observation and Measurement Schema [17] and other OGC Web Service standards [18].

4.2.2 Service Registry – GeoServNet Registry

A Service Registry provides a mechanism to register and categorize web services that are offered and to locate Web Services that users would like to consume. A service registry itself is also a web service.

One of the most challenging and practically relevant objectives in the design of open, distributed infrastructure for smart sensor webs is the ability to locate, access, and use arbitrary sensors. And in dynamic, heterogeneous environments it is advantageous to allow late binding between sensors and clients; that is, a client will generally not know in advance where a desired sensor is located [19]. GeoServNet Registry is the component that supports the run-time discovery and evaluation of available sensors offers.

GeoServNet Registry provides a common mechanism to classify, register, describe, search, maintain and access information about Sensor Webs and other Web Services. Such offers play a central role in publishing, finding, and binding to network-accessible services. GeoServNet Registry is a key component in such a service-oriented architecture that manages shared resources and facilitates service discovery. GeoServNet Registry allows:

- Sensor providers (such as GeoServNet Server) to publish descriptive information about sensor types and instances
- Clients to discover information about sensor types and instances which meet clients' interest.
- Clients to access (bind to) sensor providers.

The Registry Service defines a common information model and standard operations that allow clients to interact with registry instances, regardless of their role or content, in order to discover, access and manage sensor observation data, geospatial data and services.

4.2.3 Service Requestor – GeoServNet 2D/3D Viewer

GeoServNet 2D/3D viewer acts a service requestor role in the whole service-oriented infrastructure for linking smart sensor webs. A service requestor first sends a query to the service registry, such as GeoServNet Registry, whereto find a suitable service provider, for example GeoServNet Server, and then binds itself to the provider.

Sensor Web comprises a large number and different type of in-situ and remote sensors which will produce massive and diverse data that can challenge our ability to process and manage the data. How to accommodate various sensor types in a viewer and deliver valuable information to the end user becomes a challenging task. The great density and diversity of these data, however, offers the opportunity to take advantage of interactive 3D visualization techniques that can improve the efficiency and accuracy of processing, and provide an unprecedented perspective of sensor observations.

GeoServNet Viewer is an interactive 2D/3D visualization web-based GIS client, and was specifically designed to facilitate the interpretation and analysis of very large, complex, multi-component geospatial data sets through Internet. The services-oriented design gives it the capability to dynamically accommodate diverse sources of geo-spatial data rather than limited with its proprietary system and its own standard.

GeoServNet Viewer fuses both 2D and 3D interactive visualization and fully supports the standard functions in a desktop GIS. It is built based on Java and Java 3D technology which means platform independent and no software installed needed. The figures below shows two screen capture of 2D GeoServNet viewer and 3D GeoServNet viewer respectively.

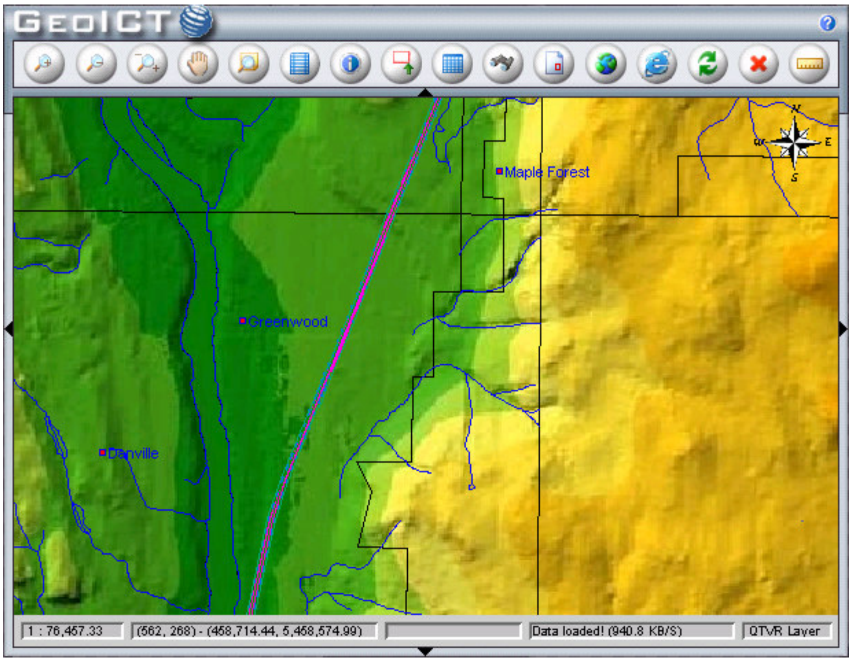


Fig. 2 GeoServNet 2D Viewer

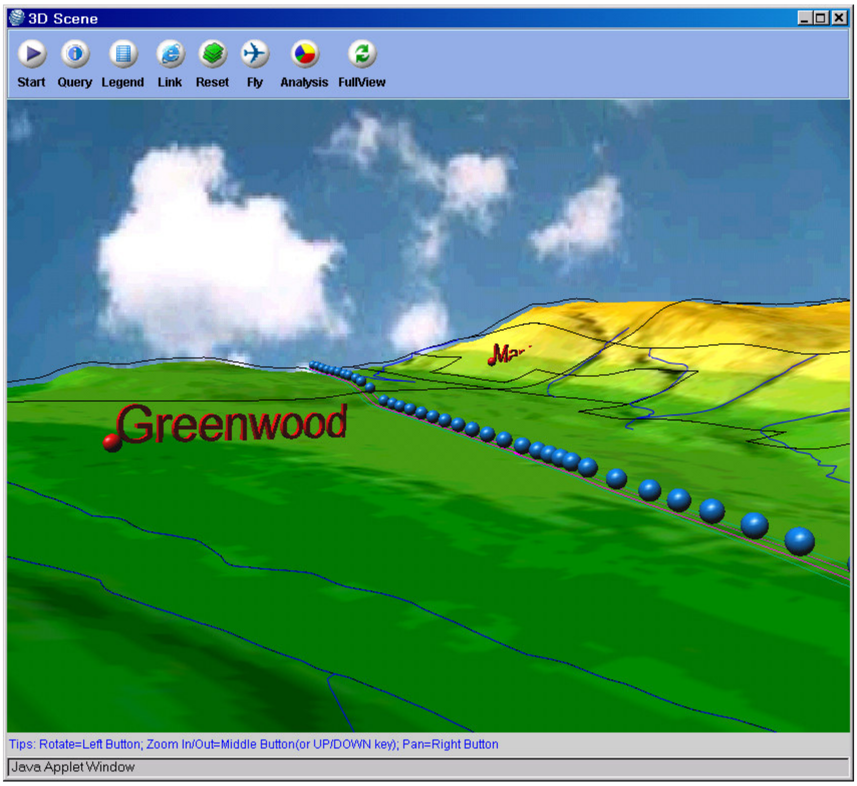


Fig. 3 GeoServNet 3D Viewer

5. CONCLUSIONS

The web service based architecture is designed to accommodate various platforms, data formats in the hybrid IT world. Various types of sensor data formats, geo-spatial data sets could circulate within this open infrastructure; this architecture also supports dynamically and late binding between sensors and clients. The proposed architecture also provides great extensibility. Sensors could be added into existing sensor web after the designing stage, and old existing sensor network can be linked to new sensor webs as well. Within this proposed infrastructure, sensors can be interconnected as the computers on Internet.

GeoServNet, the prototype introduced here, serves a solid foundation to build such a sensor web infrastructure. GeoServNet platform was built for the purpose of interoperability and extensibility; it is implemented by following OGC Web Service standards and Java standards. GeoServNet serves a very good platform for an open distributed geo-spatial infrastructure for smart sensor webs.

In the future, we will try to integrate the very fast evolving IT based web services technologies, such as SOAP protocol, UDDI registry and WSDL into our current prototype GeoServNet. It is believe that porting OWS services to the IT standard Web Services will offer the following advantages [20]:

- Distribution – It will be easier to distribute geospatial data and applications across platforms, operating systems, computer languages, etc.
- Integration – It will be easier for application developers to integrate geospatial functionality and data into their custom applications.
- Infrastructure - The GIS industry could take advantage of the huge amount of infrastructure that is being built to enable the Web Services architecture – including development tools, application servers, messaging protocols, security infrastructure, workflow definitions, etc.

The next step for the development work of this proposed infrastructure is to integrate those technologies into current prototype and make this sensor web infrastructure more universal and interoperable.

6. ACKNOWLEDGEMENTS

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