Development of System and Software

INTEGRATION OF WEB PROCESSING SERVICE AND SENSOR OBSERVATION SERVICE FOR DISTRIBUTED GEOPROCESSING USING REAL-TIME DATA

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Abstract : Web Processing Service (WPS) introduces a standard method, which allows developers to provide geoprocessing service along with access from different client platforms. It offers dramatic improvement that users can utilize Spatial Data Infrastructure (SDI) of shared community and computational capabilities. With increasing availability of sensor network, an interesting issue of integrating and utilizing a real-time observation is being raised. Sensor Observation Service (SOS) is an open standard web service interface for requesting, filtering and retrieving observations and sensor information from sensor network. The main objective of this study is to develop a comprehensive web-based GIS system enabled spatial analysis functionality coupled with real-time observation from remote field sites based on open standards. The prototype system for environmental monitoring has been developed to demonstrate how the integration of both open standards is done. In this prototype system, the SOS is able to perform as SDI for WPS by on-the-fly integration.

Key words : Web Processing Service (WPS), Sensor Observation Service (SOS), Open standards, Sensor network

1. Introduction

With rapid urbanization and population influx in urban area, water resource is going to be a scarce and precious resource in many urban and rapidly urbanizing cities of the world in the coming decades. Monitoring water quality and managing water resource requires implementation of database and IT solutions that are robust, scalable and able to interoperate with public health and community information systems to provide timely and accurate information to researchers, planners and citizens. The traditional ways of gathering field information on water have been through field surveys and analyses of water chemistry in wet laboratories on the water samples collected in the field. Such techniques are time consuming, require manpower and laboratory facilities and budget resources to manage and maintain database systems.

In our earlier studies, we have tried to use widely available technology such as e-mail robots for Water Infrastructure Information System (WIIS) that allow enhanced participation in water resource management (Raghavan *et al.*, 2001). The WIIS system is based on non-standard database architecture, therefore

interoperability across other systems is lacking. The WIIS system is suitable for data collection in specific projects targeted at limited gathering data in a limited geographical extent. Systems such as the WIIS lack scalability, interoperability and robustness for handling large data volumes in vastly bigger urban metropolis. In recent years, the rapid development of microelectronic and wireless technologies has made the networking of smart sensors for a broad range of measurement and control application (Song *et al.*, 2005). Such sensor observation network opens up a new avenue that offers a very practical and cost-effective solution for rapid assimilation of data from field sensors (Liang *et al.*, 2005).

Most online GIS service systems provide centralized geospatial services based on a client/server computing architecture. To broadly access and efficiently utilize valuable data, GIS services have been made available widely through telecommunication networks. Widespread availability of Internet and related services (e.g. World Wide Web) has played an important role to provide the general public access GIS services almost anywhere and at anytime. However, the fully utilization of the available

spatial data over the network connection has not been done due to limited abilities of currently available services to gather and process data. Hence, an interesting possibility for providing users geoprocessing services and access to near real-time data are increasing (Heier and Kiehle, 2005; Kiehle *et al.*, 2006).

An integrated computing environment, combining field sensor observations with distributed geospatial processing could provide real-time monitoring and timely information to decision-makers. This paper presents the implementation of distributed geoprocessing framework based on WPS (Web Processing Service) and integration with SOS (Sensor Observation Service) as real-time data source. The system has been implemented entirely using Free and Open Source Software (FOSS). In this paper, we introduce the basic concepts and current system of WPS and SOS. Further, incorporation of WPS and SOS architectures and case study of a geoprocessing coupled with real-time data source are presented.

2. Web Processing Service

The integration of standard-based GIS program and web-based service represents the future direction of Internet GIS, which is most likely to be geoprocessing services. Therefore, the creation of a wide range of services that can be accessed across the Web, and web services can perform actions and return the output in standard format to client. The Open Geospatial Consortium (OGC) Web Processing Service (WPS) proposed specification is intended as a solution for developing web-based geoprocessing for easily sharing algorithms and functionality. This specification defines a mechanism and procedure by which geoprocessing task will be carried out on a remote server. One or more processes (e.g. Normalized Difference Vegetation Index (NDVI), spatial intersection, buffering etc.) are provided on WPS server instance (OGC, 2005).

Since geoprocessing services are delivered in the Internet's

open and standards-based environment, it will make access to and use of geodata much easier and less expensive for better decision making. The utilization of Web Coverage Service (WCS) as data source for geoprocessing has been included in WPS specification. Since both of services are Service Oriented Architecture (SOA) relied on XML document, communication of machine-to-machine is feasible (Ninsawat *et al.*, 2007). Remote sensing data are delivered across the network with a distributed WCS request from WPS server by generic internet connection (Figure 1). Diverse distributed WCS request is probable to disseminating the sharing spatial data between organizations. Not only the Spatial Data Infrastructure (SDI) of remote sensing data is accessible, but also Web Feature Service (WFS) which mainly provides access to vector data is possible in a same manner. For example, Friis-Christensen *et al.* (2007) developed a prototype system that enables users to search dataset for available land cover data from SDI using catalogues service and selects those required to assess fire damage areas using statistical analysis of WPS.

WPS operations can be performed using a standard web browser by submitting requests in form of Uniform Resource Locators (URLs) via HTTP GET or HTTP POST. However, WPS is usually not invoked directly. More often, it is launched by a client application that provides the user with interaction interface. This client may be a web-based application or a desktop GIS application. The Execute operation allows WPS clients to run a specified process using input parameter values provided and returning the produced output. The produced output of analytical process can be download for visualizing (rendering) or further analysis at local user machine or integrated with other web services. WPS also supports long-running processes which depend on the complexity of calculation. A process completion status is indicated in the ExecuteResponse document which immediately returns to client after Execute request as shown in

Figure 1. Implementation of Web Processing Service architecture using FOSS.

Figure 2. The overview interaction of execute request between client and server.

Figure 2. In this study, PyWPS package was used to develop a WPS server. PyWPS is written in Python programming to utilize GIS functionalities from GRASS GIS software (Čepický and Becchi, 2007). Thus, the programming code of spatial analysis algorithm is minimal. However, in order to adapt for more specific tasks, functionality can be improved or extended by adding new module to the Free and Open Source GRASS GIS backend.

3. Open Sensor Web

3.1 Sensor Network

With the prices of networkable sensing devices dropping, the volume of information begin collected by networked sensors has increased dramatically in recent years. Over 100 physical, chemical and biological properties can be sensed using in-situ or remote sensing technology. A collection of these sensor nodes forms a sensor network, which is easily deployable to provide a high degree of visibility into real-world physical processes as they happen. The Economist (2007) argued that in the coming years, communications chips will be embedded in a host of everyday objects, which are able to communicate with other devices, serviced and upgraded remotely through computer networks. Further, sensors on buildings and bridges can run them efficiently and ensure they are safe. Wireless sensor system can measure temperature, humidity and control irrigation systems. Sensor web network can perform as an extensive monitoring and sensing system that provides a comprehensive and timely of earth observation at all-levels of local, regional and global (Tao *et al.*, 2004). Fukatsu and Hirafuji (2005) implemented long-term monitoring in a field mainly focusing on agriculture activities. The sensor-node “Field Server” equipped with a web server and wireless LAN was introduced for a remote field monitoring system by which many Field Server can be managed and periodically collect monitoring data via the Internet connection from remote place. Approximately 40 Field Servers are currently deployed in various parts of Japan, the United States, Thailand, China, Korean and Taiwan providing various kind of phenomenal information at field such as air temperature, relative humidity, intensity of solar radiation etc. The weather forecast information in South Africa is accessible via a subscription supplier database from South Africa Weather Service (<http://www.weathersa.co.za>). The weather information is reported in XML document, which allows other service application to online seamlessly, utilize this data set.

3.2 Sensor Observation Service

There are already numerous of sensors deployed around the globe collecting an enormous amount of data. These sensors enable data gathering for diverse applications and differ in capabilities such as range, modality and planning. However, the lack of integration and communication between these networks often

Figure 3. Sensor data consumer in data operation context.

leaves such valuable information underutilized. The SOS standard is a part of Sensor Web Enablement (SWE) specification (OGC, 2006), which is a meant to facilitate the development of a standard command, control and observation of disparate and geographically distributed network sensor constellations.

SOS performs the function of data archive after field observation data are submitted from distributed sensor network. SOS provides the framework wherein, the sensing resources, which include sensor's description, sensor's location, real-time or archived measurement and other related information for service users, can be stored, disseminated, managed, displayed and analyzed. As shown in Figure 3, SOS implementation architecture defines the interfaces and operations that enable scalability for nationwide sensor deployment and interoperability despite the presence of heterogeneous sensing data, manufacturer, and network infrastructure. Users are able to seamlessly access, filter and retrieve geographically distributed sensor observation data. In this study, a SWE Suite from 52 North (<http://52north.org/sos>), which is an open partnership organization, developing open source software with focus on interoperable web services and data encoding models for SDI, is used to operate SOS task to make sensors and sensor data archives accessible via an interoperable web-based interface. A feeder framework package is also included in this software suite for inserting observation data into the SOS database. The interface for inserting data is done by either push or pull mechanism directly from smart sensor equipments or other web service data store. It is used by Germany in contribution to the Tsunami warning system deployed in the Pacific and Indian oceans. It has also been used in fire monitoring systems in South Africa as well as in the watershed management system in the Netherlands.

4. Open service architecture sharing

4.1 Collaborative framework of OGC specifications

OWS-4 (OGC Web Services Phase 4) presented by OGC (2007), can be used in several application scenarios. Appropriate response is facilitated by utilizing many different data sources through web services that implement the OGC's standard such as access to map images from Web Map Service (WMS) server for spatial data. One or more online catalogs of sensor provide the means for decision makers to determine the location and other details from SOS server. The sensor data and metadata could be immediately found, accessed and displayed on a map. The interoperability and SOA capability allow sensor devices to plug-n-play so that they can rapidly share, integrate and apply information. Various kinds of application could be developed to fully utilize the available spatial web service efficiently and time effectively by a collaborative work of existing OGC specification.

4.2 WPS and SOS integration

The approach of WPS efficiently enables analysis of geospatial data for an on-demand GIS mapping. However, the essential data for accurate and up-to-date modeling of environmental situations also needs to be efficiently gathered. SOS compliance could fulfill such needs by the acquisition of real time data for the environmental monitoring. In this study, we have integrated WPS with SOS to create a comprehensive real-time data gathering and geoprocessing system that would require minimum human interaction.

Due to the capability of WPS of providing access distributed geospatial data across the network (such as WCS and WFS), it is possible to utilize the observation from SOS server. The result from SOS is encoded in XML following the OGC's Observations & Measurements (O&M) schema, which is one of SWE specifications. O&M schema defines semantic objects consisting of measurements at each location of sensor. The observation document includes a phenomena result, sensor coordinate and sensor name.

Presently, WPS are not able to directly use this observation data in further processing. In our present system, the observation from each sensor is converted to a feature object as Geography Markup Language (GML) document, which is an acceptable data format for WPS as shown in Appendix. After generating the GML document, integration in WPS fairly simple and straight forward. The example is now presented to experiment the feasibility of using WPS and SOS together to create enhanced Web-GIS functionality that provides an analytical capabilities for near real-time data

5. Prototype system for water quality monitoring

In order to demonstrate the integration of open standards of

WPS and SOS, an example of web-based application for water quality monitoring has been developed. The system provides a spatial analytical service to calculate Water Quality Index (WQI) utilizing real-time sensor data. The sensing data are input into a modeling to generate and achieve WQI map. WQI method was developed by the National Sanitation Foundation (NSF) in 1970. The WQI is a tool for simplifying the reporting of water quality data. Traditional reports on water quality trends typically consisted of variable-by-variable, water-body-by-water-body statistical summaries. This type of reporting is of value to water quality experts and managers, but it is often inaccessible to non-experts (Zandbergen and Hall, 1998). The WQI fills a gap by providing meaningful summaries of overall water quality while producing output that is accessible to non-specialists.

Eight water quality parameters are used to determine the WQI: temperature change, pH, dissolved oxygen, total nitrogen, total phosphate, total dissolved solid, conductivity and turbidity. After determining the WQI values, the water resource is ranked by relating it to one of categories in Table 1.

In this demonstration, simulated sensor nodes are used to supply a water quality measurement value to SOS. A script programming is periodically executed as cron job to generate a sensor report document. The generated document is encoded as XML document that contents all water quality measurement values and time stamp of each sensor node. SOS accesses a generated document and then loads data into the system. Subsequently, the returning Observation and Measurement document is converted to a geospatial data encoded as GML file format to enable WPS computation.

Not only a process of WQI map from sensor information is done, but also a computation of Turbidity index map and Sea Surface Temperature (SST) map from ASTER satellite image are produced. The satellite image is requested from distributed WCS server following OGC compliant specification. After acquiring full resolution satellite image, a relative Turbidity index (Stumpf and Pennock, 1989) and Multi-Channel SST (MCSST) (Matsunaga, 1996) are calculated.

The front-end of water quality monitoring system was developed as the web-client application to collect all necessary parameters for computation process and send Execute request to WPS server. AJAX (Asynchronous JavaScript and XML) technology was used to construct asynchronous connection using the XMLHttpRequest object to efficiently manage requests and results from WPS service as presented in Figure 4. The representative of water quality map from the WQI calculation using real-time data from sensor nodes can be visualized in the distributed web-client application and also available for user to download its.

The WQI computation algorithm is accessible as WPS. The algorithm is implemented as a series of commands, which oper-

ates on two main parts 1) Preparation dataset and 2) Calculate WQI value. In this demonstration, the preparation of dataset mainly involves with a sensor measurement data. Initially, the target SOS location and measurement date are extracted based on the client request. Subsequently, the XML request file is created on-the-fly as an attached request document that is sent via HTTP POST-Request to SOS server. After obtaining an observation document from SOS server, the conversion python script is executed in order to convert it to GML file format. Finally, the measurement values of sensor nodes are available to be processed by WQI computation (Asadi *et al.*, 2007). Then, the result map of WQI computation is reclassified into five classes as shown in Table 1. Subsequently, the output of process, which is composed of WQI map, Turbidity index map, SST map and sensor feature with all water quality measurements are returned to the client. The client, here is a web application, but generally can be any kind of HTTP client that can access a web service and send WPS Execute request. The output result of process can not only be visualized on the web-client application (as shown in Figures 5, 6 and 7) but can also be available for further analyses on clients own local computer.

6. Conclusions

Nowadays, the Web-GIS is very extensively developed and is being widely used as scores of Internet users are gaining exposure to using spatial data for day-to-day needs. For most advanced usage, Web-GIS should include spatial analysis and spatial modeling capabilities. This paper has described the integration of three OGC-compliant open standards to create a comprehensive geoprocessing service utilizing remote sensing image for sharing SDI and real-time data from sensor observation network. WPS, which is most likely to become the future direction of Web-GIS, performs the computation of spatial data from distributed data sources and returns the outcome in a standard format, which allow client to visualize the results even do further analysis by desktop GIS applications. The interoperability capabilities and SOA of web services allow to incorporate real-time data using diverse sensor nodes measurement available from SOS and remote sensing data from WCS. This integrated system offers significant benefits over the traditional decision-making framework by providing timely and comprehensible results.

In this study, an environmental monitoring application for water quality was successfully demonstrated. This system was entirely developed using FOSS tools and can be easily adapted for other monitoring needs. The WQI map generated using WPS could serve as useful information to monitor, evaluate and quantify on the water quality and allow for making better-informed decisions on water resource management. Two main developments have been accomplished and fully presented in this experimental prototype system. Firstly, the accessing phenomena data

component from SOS provided a comprehensive web service data source for WPS. Secondary, the GML conversion component that provides GML features for WPS computation using geographic features from the Observation and Measurement document. Both these developments were also successfully carried out for dynamic and interoperable integrated applications. The developed components will eventually allow easier and more rapid developments of geoprocessing service with real-time data for various applications by dynamic integration of many open-standard web service components.

Since the geoprocessing service and sensor web service are being delivered in the Internet's open and standards-based environment, it will make access to and use of geodata as well as real-time data much easier and less expensive for better decision making. The standardization-based development allows the assortment of GIS application users to perform complex analysis and build their own specific scenarios in the web-based on spatial and non-spatial information with interconnections not only at the web page level, but also from one SDI service to another. Kiehle *et al.* (2007) addressed that the WPS could be made more flexible by providing a service chaining manner which would allow user to define their own workflow units based on Web Service Orchestration (WSO). The implementation of WSO into WPS will be attempted in the future research.

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Figure 4. Integrated web service of water quality monitoring system.

Figure 5. The example result of water quality monitoring system.

Figure 6. The example result of turbidity index calculation using ASTER image via WCS.

Figure 7. The example result of SST map calculation using ASTER image via WCS.

Table 1. Water quality index categories.

Water quality index	Description
0 – 25	Excellent
26 – 50	Good
51 – 75	Poor
76 – 100	Very Poor
> 100	Unfit For Drinking (UFD)

- in *GIS*, vol. 11, no. 6, pp. 799-818.
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Appendix

Because of current limited interoperability between WPS and SOS, WPS can not directly use the observation document from SOS. Then, the data in observation document are extracted and parse into feature object as GML document. The detail of conversion is presented below.

Figure A1 shows an example of measurement information in observation document at sensor "station4". The element of `<om:featureOfInterest>` (as shown in Figure A1, Note A) provides descriptions and geo-coordinate value associated with a Spatial Reference System (SRS) of sensor. This information is necessary to produce feature geometry as GML document. The measurement values are extracted from `<om:result>` element (Figure A1 , Note D) by using supplementary information in `<swe:encoding>` element (Figure A1, Note C). Some additional information is required such as phenomena properties and observation date which shows in `<om:resultDefinition>` element (Figure A1, Note B)

A python script has been developed to convert SOS results in GML document using a SAX (Simple API for XML) parser. The SAX parser has two notable advantages over the DOM and XSLT parser which are slower and requires large memory to load entire document tree. Figure A2 shows an example feature encoded in GML document. The `<Turbidity>` element (Figure A2, Note A) provides a measurement value from the SOS. Additionally an observation timestamp is stored in `<gml:validTime>` element (Figure A2, Note B).

```

<om:member>
  <om:CommonObservation xsi:type="om:CommonObservationType">
    ...
    ...
    <om:featureOfInterest> ---Note A
      <sos:GeoReferenceableFeature gml:id="1004">
        <gml:name>station4</gml:name>
        <gml:location>
          <gml:Point srsName="EPSG:4326">
            <gml:coordinates>136.10965216065 35.246504961638</gml:coordinates>
          </gml:Point>
        </gml:location>
      </sos:GeoReferenceableFeature>
    </om:featureOfInterest>
    <om:resultDefinition> ---Note B
      <swe:DataDefinition>
        <swe:dataComponents>
          <swe:DataGroup>
            <swe:component name="dateTime">
              <swe:Time definition="urn:ogc:data:time:iso8601"/>
            </swe:component>
            <swe:component name="Turbidity">
              <swe:Quantity definition="urn:ogc:def:phenomenon:OGC:1.0.30:Turbidity"/>
            </swe:component>
            <swe:component name="pH">
              <swe:Quantity definition="urn:ogc:def:phenomenon:OGC:1.0.30:pH"/>
            </swe:component>
          </swe:DataGroup>
        </swe:dataComponents>
        <swe:encoding>
          <swe:AsciiBlock decimalSeparator="." tokenSeparator="," tupleSeparator="@@"/> ---Note C
        </swe:encoding>
      </swe:DataDefinition>
    </om:resultDefinition>
    <om:result>2007-06-04T16:53:00Z,41,5@@</om:result>--Note D
  </om:CommonObservation>
</om:member>

```

Figure A1. An instance of measurement result.

```

<gml:featureMember>
  <ogr:aoi gml:fid="1004">
    <ogr:location>
      <gml:Point srsName="EPSG:4326">
        <gml:pos>136.1096521606535.246504961638</gml:pos>
      </gml:Point>
    </ogr:location>
    <ogr:NAME>station4</ogr:NAME>
    <Turbidity>41</Turbidity> --- Note A
    <pH>5</pH>
    <gml:validTime> --- Note B
      <gml:TimeInstant>
        <gml:TimePosition>2007-06-04T16:53:00Z</gml:TimePosition>
      </gml:TimeInstant>
    </gml:validTime>
  </ogr:aoi>
</gml:featureMember>

```

Figure A2. The corresponding GML instance.

要 旨

リアルタイムデータの分散型空間処理のためのウェブプロセッシングサービスと センサーオブザベーションサービスの統合

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ウェブプロセッシングサービス（WPS）は異なるクライアントプラットフォームからのアクセスに対応したジオプロセッシング（空間処理）サービスを開発するための標準化手法を提供する。共有コミュニティの空間データ基盤（SDI）や計算処理能力を利用者が活用できることは画期的な進歩である。センサーネットワークの利用の増加にともない、リアルタイム観測の統合と活用が注目されつつある。センサーオブザベーションサービス（SOS）は、センサーネットワークからの観測値とセンサー情報の要求、フィルタリング、および検索のためのオープンスタンダードの Web サービスインタフェースである。本研究の目的は、遠隔地からのリアルタイム観測を組み込んだ空間解析の機能をもつ統合的な Web-GIS システムをオープンスタンダードに基づいて開発することである。両者のオープンスタンダードをどのように統合するかを示すために環境モニタリングのためのプロトタイプシステムを開発した。このプロトタイプシステムでは、SOS はその場その場でデータを集積する WPS のための空間データ基盤（SDI）として機能することができる。

キーワード：ウェブプロセッシングサービス，センサーオブザベーションサービス，オープンスタンダード，センサーネットワーク

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