Real-time Monitoring Portal for Urban Environment Using Sensor Web Technology

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Abstract—**Taking advantage of the large-volume but low-cost datasets remotely sensed in urban areas by ubiquitous sensors or sensor networks, there is a need of real-time environmental monitoring portal or geospatial infrastructure for effectively or efficiently collecting and serving vast field data over web. Based on Open GIS Service Specifications defined by OGC Sensor Web Enablement (SWE), this paper presents an Internet based urban environment observation system that can real-time monitor environmental changes of temperature, humidity, illumination or air components in urban area. This system two functionality components. One is to collect and archive the environmental data from low-cost sensor network with user-customized time frequency through the proprietary system interfaces, the other is to support those datasets to be reformatted following Earth Observation (EO) specification and to be browsed or retrieved through the open interoperation interface of Sensor Observation Service (SOS). The real-time monitoring system is developed using Open GIS Specifications and Open Source Geospatial Software. The test-bed system is demonstrated as follows. The sensor kit deployed for constructing environmental monitoring network refers to the hardware implementation by GIS Research Group of OCU under Prof. Venkatesh. Currently, the factors of temperature, humidity, carbon dioxide and oxygen are sensed through outdoor sensors. The sensor data archive database is established using PostgreSQL and PostGIS platform and the web service system is run over Apache server. The data collection service and sensor data web service are programmed using Python, while the data visualization services are implemented using OpenLayers and Mapserver.**

Keywords-Real-time Environmental Monitoring, Geospatial Infrastructure, Sensor Web Enablement, Sensor Observation Service, Open Source Geospatial Software

I. INTRODUCTION

There have been many types of sensors developed for urban environmental monitoring, for example, temperature sensor, humidity sensor, illumination sensor, windy sensor, or various gas sensors (carbon dioxide, carbon monoxide, methane, hydrogen, oxygen, water vapor, etc.). Most sensors are based on elements of which one of the parameters (resistivity, dielectric constant, Hall voltage, etc.) shows a small change in response to one or more measurands. The advanced semiconductor technology enables the integration of these sensor elements and signal conditioning circuitry on one chip, making sensors highly compact, small size, cost-effective, high sensitivity, very stable and extremely simple to apply for environmental monitoring.

The new progresses in micro-electronics and wireless communication technology make it possible to construct the sensor network of ground observation stations to automate or semi-automate field observation on large area, even on dangerous or inaccessible areas[1]. Therefore, the huge-volume remotely sensed data consolidates the geospatial infrastructure for monitoring urban environment. The ground truth data collected synchronously are needed for better organized for further processing[2]. There have been some proprietary environmental monitoring system developed for large integrated projects, for example, FieldServer II[3], Sensor Service Grid [4], Live-E![5] and SANY[6]. In the urban areas, the sensor networks covering various geographical and temporal scales may continuously produce vast amounts of information related to earth environment as satellites did, so there is a great need to integrate those sensors and serve institutions, governments or users transparently or openly.

The OGC SWE (Sensor Web Enablement) Framework presents many opportunities for adding a real-time sensor dimension to the Internet or Web, through which the Web-accessible sensor network can be simply discovered and accessed using standard protocols and application program interfaces [7]. In other words, the standard interfaces enable to pull together all information sensed from either ground sensor network or satellite sensors for providing a comprehensive understanding of urban environment.

The sensor network based urban environmental monitoring system has not yet widely applied and proprietary software solutions are still expensive. This paper presents an easy to-do approach to make low-cost combo sensor kits using sensor units (elements) and to develop an Internet-accessible field server using PICNIC network cards. Based on low-cost sensor network, we propose an open source solution for geospatial infrastructure for urban environmental monitoring that is implemented to be compatible with OGC SOS interoperation specification under OGC SWE Framework. The open source geospatial platforms are deployed, including the database system - PostgreSQL/PostGIS, the mapping system - Mapserver and Openlayers, and the web platform - Apache. The Python is used as a glue language to integrate all the open system together through the OGC Interoperation interfaces.

II. Materials and Methods

A. Field Servers

The field server is an Internet-based multi-channel sensing device, which measures physical environmental parameters by multi-sensors and supports remote users to obtain those digital observation values by HTTP protocol. It is made of two parts – compact sensor kit and PICNIC board.

1) Combo Sensor Kit: There have been many types of sensors developed for environmental monitoring, for example, temperature sensor, humidity sensor, illumination sensor, windy sensor, or various gas sensors (carbon dioxide, carbon monoxide, methane, hydrogen, oxygen, water vapor, etc.). Most sensors are based on elements of which one of the parameters (resistivity, dielectric constant, Hall voltage, etc.) shows a small change in response to one or more measurands [8]. The advanced semiconductor technology enables the integration of these sensor elements and signal conditioning circuitry on one chip, making sensors highly cost-effective, high sensitivity, very stable and extremely simple to apply.

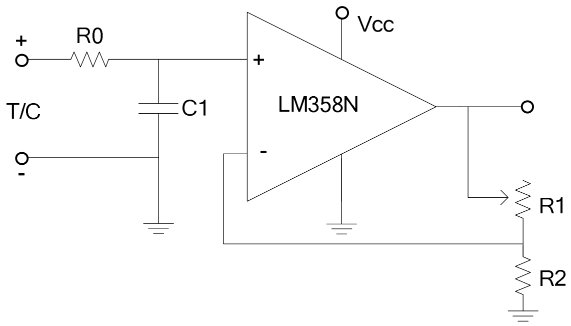


Figure 1. A robust signal amplifier

The combo sensor kit was developed as a solution to real time environmental monitoring. Four analog sensors that detect temperature (LM35DZ), humidity (CHS-UGR), oxygen (KE-25) and carbon dioxide (TGS4160) respectively are integrated into the combo sensor kit in this work. These four sensors use the changes in analog voltage to reflect environmental perturbations. To increase the sensing resolution or precision, we added a signal amplifier to amplify the millivolt signal into a more readable analog voltage, on the order of 0 to 5VDC (Figure 1). This circuit is based on a dual op-amp IC (LM358N). The C1 is essential to minimize the interference of small hiccup in the signal output by sensors. The gain is calculated as (R1+R2)/R2.

These sensors that are lightweight and small size require extremely little mounting space, so we make a compact combo sensor kit in which all sensors and their amplifier circuits are integrated on one digital board (Figure 2). As all sensors contain the necessary circuitry with very low current consumption, their power supplies are from PICNIC board. On the board of combo sensor kit, one 26-pin parallel I/O port is developed through which the sensors communicate with PICNIC board and obtain 5V voltage power supply.

2) PICNIC Fieldserver: PICNIC means PIC(Peripheral Interface Controller) plus NIC (Network Interface Card). The PICNIC board (Figure 3, TriState Inc.) mainly consists of one control CPU (PIC16F877A 20MHz) and three built-in interfaces (Ethernet 10Base-T, Serial Port and Parallel Port). The built-in protocols support ARP, UDP, TCP, HTTP, ICMP and DHCP, which make it possible for PICNIC system to activate as one Internet-based field server to support remote data retrieval by HTTP protocol.

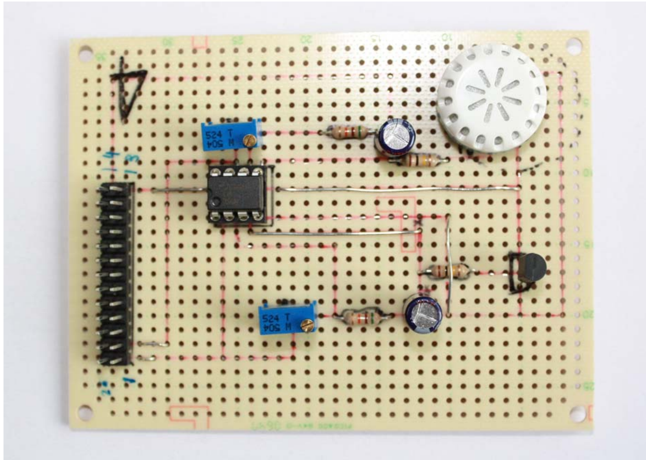


Figure 2. The combo sensor kit

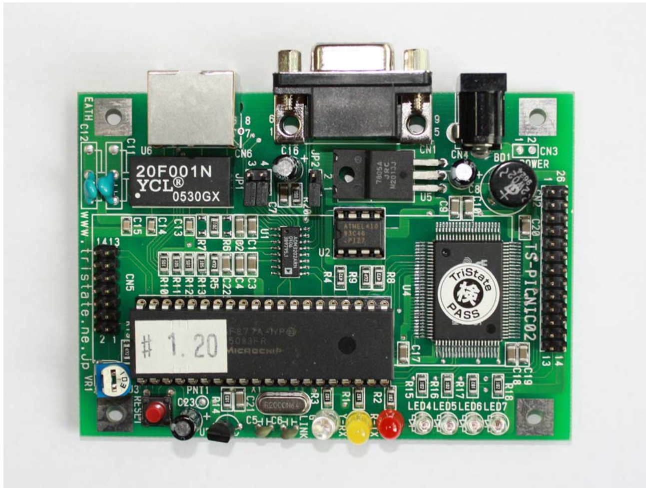


Figure 3. PICNIC board

The combo sensor kit is mounted to PICNIC board by the parallel I/O port. On parallel port, there are one channel for power supply, four analog channels (all for input) and eight digital channels (four for input and four for output). Through the parallel port linkage, those sensors are connected to analog channels. The changes of sensor output voltages in response to environmental measurands are detected by PICNIC and thereafter converted to digital values by control CPU. Other machines connected with PICNIC by Ethernet 10Base-T port can obtain those sensed data and the metadata about PICNIC server using HTTP protocol.

B. *Sensor Network*

In environmental monitoring, the sensor network is deployed over a region where some phenomenon is to be monitored, such as temperature, humidity or air quality. The sensor network consists of spatially distributed sensor nodes. All sensor nodes are remotely monitored, controlled or managed by monitoring system running on Web server. The communication among monitoring system and sensor nodes is based on Internet, and these sensor nodes utilize wired or wireless communication devices to connect to Internet. The sensor network diagram is shown as Figure 4.

The connection devices used by sensor nodes depend on the area where they are placed. For indoor applications, the compact sensor kit can be linked to Internet simply by wired Ethernet adapters. For outdoor applications, it may be linked by wireless Ethernet converters (i.e. Buffalo AirStation WLI3-TX1-G54). For field applications, it can be connected by wireless data transmit units that support GPRS - General Packet Radio Service (i.e. LZ713C GPRS DTU).

Each sensor node activates as one PICNIC field server. Once sensor kits acquire environmental parameters, these sensed data will be obtained by monitoring system using HTTP. Then the monitoring system takes care of data parsing, data archiving, data retrieval and data security.

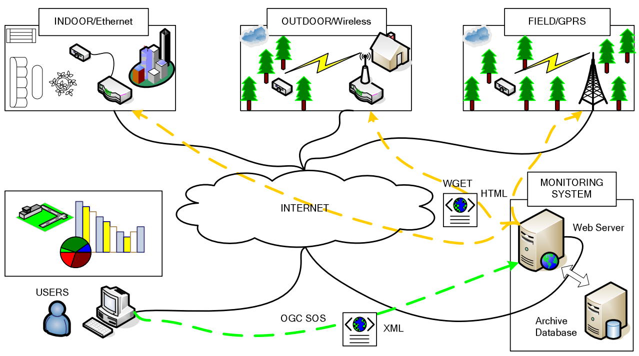


Figure 4. Sensor network diagram

C. *Urban Environmental Monitoring System*

1) System Structure: The monitoring system is a web based geospatial infrastructure for archiving field sensed data. At the core part of the system is a centric archive database that stores metadata of sensor nodes (i.e. identifier, sensor type, setup time, geographic location, calibration parameters, units of meter, accuracy, status, sampling freq. etc.) and physical data sensed by sensor nodes (i.e. identifier, time, values etc.). The database system collects physical sensed data from sensor nodes by its built-in PICNIC interface, meanwhile it provides users with XML-formatted data by open interoperation interfaces of OGC standard services. The system has a multi-layers structure as Figure 5.

2) Processing: The monitoring system includes two important data processing functions – proprietary data collection and standard data service. Concerning the extensive application experience of the object-relational database, we select open source PostgreSQL/PostGIS to store all the data from sensor network, rather than object-orient XML-database.

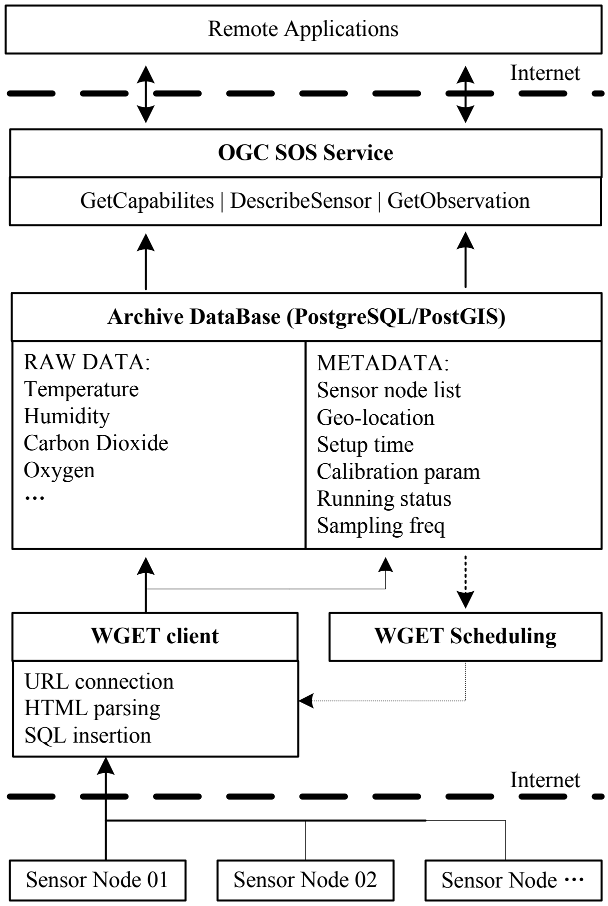
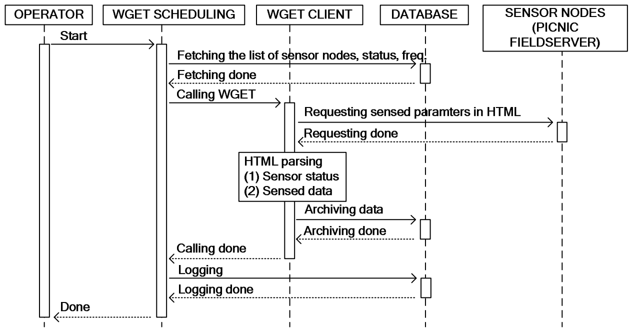


Figure 5.Monitoring system structure

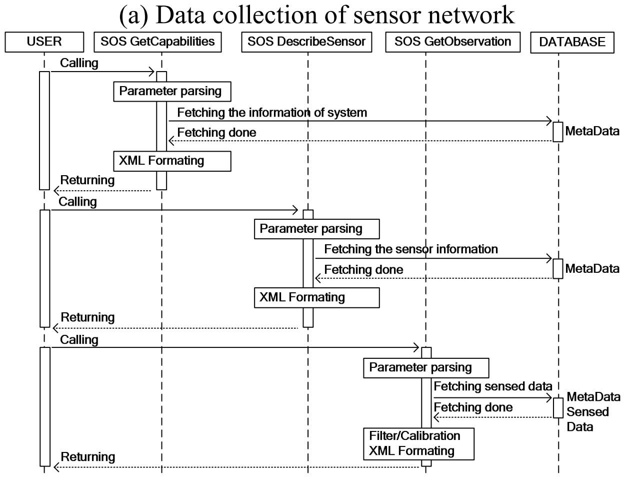
The proprietary data collection process is controlled by WGET Scheduling Module shown by Figure 6(a). The Scheduling Module fetches the list of sensor nodes and their sampling frequency data and uses these parameters to schedule the calling of WGET Client module for periodically collecting sensed environmental data. The frequency of data collection of one sensor kits depends on the response time of sensors, for example, 60 seconds needed for CHS-UGR humanity sensor to reach 90% of actual humidity as for from 30 to 85(%) relative humidity. The WGET Client is concretely responsible for remote data collection. It first creates the HTTP connection with PICNIC Fieldserver, then fetches the HTML page that contains the environmental data measured by sensors and auxiliary information of PICNIC Fieldserver, then extracts the data that need to be archived by parsing HTML text, and finally inserts those sensed data into the archive database.

The standard data service is done by OGC SOS module shown by Figure 6(b). There are three mandatory functions implemented to serve sensor-related data by web application programming interfaces, GetCapabilities, DescribeSensor and GetObservation of OGC SOS. The GetCapabilities function provides clients with service metadata about a specific SOS

System, including metadata about the supported functions and the tightly-coupled data served. The DescribeSensor function helps users to obtain detailed information of sensor characteristics encoded in SensorML that includes the sensor information about the observable properties, locations, contact information, etc.



(a) Data collection of sensor network



(b) Data service by OGC SOS

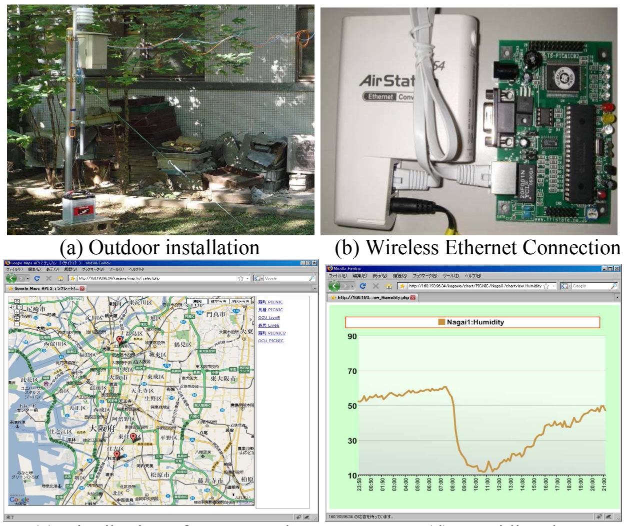
Figure 6. Data processing flowchart of monitoring system

The GetObservation function provides users with a service to retrieve observation data structured according to the Observation and Measurement (O&M) specification. Within the function, it includes four processing steps: (1) the data is first retrieved from archive database according to user request, (2) these data is then filtered to remove the noise observation data that are usually caused by electro-magnetic field near combo sensor kits or some other reasons, (3) these raw data are calibrated using the calibration parameters related to the sensor the raw data produced, we make external calibration to assure accurate measurement although the sensors we adopted in this experiment have their precise inherent calibration in circuit, and (4) the calibrated data is encoded in O&M specification for outputting. The returned O&M file is shown as follows:


```
<?xml version="1.0" encoding="UTF-8"?>
<om:Observation xmlns="http://www.opengis.net/om/1.0"
xmlns:gml="http://www.opengis.net/gml"
xmlns:om="http://www.opengis.net/om/1.0"
xmlns:swe="http://www.opengis.net/swe/1.0.1"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/om/1.0/om.xsd">
<gml:name>PICNIC Fieldserver Data</gml:name>
<om:samplingTime>
<gml:TimePeriod>
<gml:beginPosition>2009-04-01T12:40:00.000-09:00</gml:beginPosition>
<gml:endPosition>2009-04-01T12:41:00.000-09:00</gml:endPosition>
</gml:TimePeriod>
</om:samplingTime>
<om:procedure xlink:href="urn:picnic:combosensor"/>
<om:observedProperty xlink:href="urn:picnic:env_param"/>
<om:featureOfInterest xlink:href="urn:picnic:transient"/>
<om:result>
<swe:DataArray>
<swe:elementCount><swe:Count><swe:value>2</swe:value></swe:Count
></swe:elementCount>
<swe:elementType name="Components">
<swe:SimpleDataRecord gml:id="DataDefinition">
<swe:field name="time">
<swe:Time definition="urn:ogc:property:time:iso8601"/>
</swe:field>
<swe:field name="Temperature">
<swe:Quantity definition="urn:picnic:Temperature">
<swe:uom code="degC"/>
</swe:Quantity>
</swe:field>
<swe:field name="Humidity">
<swe:Quantity definition="urn:picnic:Humidity">
<swe:uom code="%"/>
</swe:Quantity>
</swe:field>
<swe:field name="CO2">
<swe:Quantity definition="urn:picnic:CO2">
<swe:uom code="ppm"/
></swe:Quantity>
</swe:field>
<swe:field name="O2">
<swe:Quantity definition="urn:picnic:O2">
<swe:uom code="%"/>
</swe:Quantity>
</swe:field>
</swe:SimpleDataRecord>
</swe:elementType>
<swe:encoding><swe:TextBlock decimalSeparator="." tokenSeparator=","
blockSeparator="@@"/>
</swe:encoding>
<swe:values>
2009-04-01T12:40:00.000-09:00,18,70,21,401@@
2009-04-01T12:41:00.000-09:00,19,69,21,401
</swe:values>
</swe:DataArray>
</om:result>
</om:Observation>
```


III. APPLICATIONS

The compact sensor kits and the open monitoring system have been deployed for urban environmental monitoring experiments in Osaka City University and for urban gas measurement test-bed in University of Chinese Academy of Sciences. The real-time monitoring system for urban environment is a web server based back-end system that runs on Apache, which does not only retrieve data from the sensor network but also supports users to query and visualize environmental datasets. The field demonstration is shown by Figure 7.



(a) Outdoor installation (b) Wireless Ethernet Connection

(c) Distribution of sensor nodes (d) Humidity charts

Figure 7. Demonstration of sensor nodes

The interactive system is developed using Openlayers, Google map, SWF Charts and Mapserver, which visualizes the geo-locations of sensor nodes and displays the sensed data tables or charts. The map system first calls the DescribeSensor() function of SOS service, then parses the SensorML feedback message for extracting the metadata information of sensors, including geographic location, and finally overlay the geo-location data with background Google map for Openlayers display. The observation data illustration system is programmed using PHP / SWF Charts, which display the observation data of sensors in various chart styles, i.e. curve, scatter histogram etc. The data illustration system first calls the GetObservation() of SOS service, then parses the Observation & Measurement Data for extracting the observation data, and finally rendering those data using flash swf.

This demonstration proved the feasibility of developing low-cost sensor network for urban environmental monitoring. It provides a simple solution to low-cost compact sensor kits and geospatial infrastructure system. The solution is compatible with OGC SOS specification and all programs are based on open source geospatial software, which enables our proposed environmental monitoring system simple and easy to apply.

IV. Conclusions

In environmental monitoring, the field server for constructing outdoor sensor network is a Web-based field observation device, which detects field environmental parameters and publishes them on Internet in real-time. To reduce the cost of constructing sensor network, we proposed an easy-to-do and open solution to the web-based fieldserver that contains a combo sensor kit that output analog signals in response to the changes of environmental measurands and a PICNIC network interface card that performs A/D conversion and output digital values. Corresponding to the sensor network, we present an open source geospatial solution to geospatial infrastructure for managing vast amount of field data collections from the sensor network. The collected data is archived in open source PostgreSQL/PostGIS, while it is published through the open service interfaces under OGC SWE Framework, that supports the interoperation of OGC SOS or WMS. The compatibility of the services of monitoring system with OGC SWE makes it possible to process the environmental datasets from various geographical or time scaled sensor networks using OGC WPS in future.

Acknowledgment

We thank Prof. Muneki Mitamura at Graduate School of Science, Osaka City University and Mr. Naoki Ueda at Locazing Inc., who provided us with valuable suggestions on designing the PICNIC Sensor Box. This work was partly supported by the National S&T Major Project of China (No. 2009ZX05039-004).

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