Sensor Web for River Water Pollution Monitoring and Alert System

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1. INTRODUCTION

Development of new technologies brings many ways for environmental protection and maintenance. Sensor Web (Gross, 1999) is a tendency in scientific research with wide use and implementation possibilities. It has extraordinary significance for science, environmental monitoring, transportation management, public safety, facility security, disaster management, industrial controls, facilities management and many other domains of activity. Using GIS as a platform for data visualization in combination with Sensor Web, enables us to create systems for environmental monitoring and protection.

River pollution has been a major problem in the developing countries, especially in the Balkan region. Fast industrial growth has led to increscent in quantity of chemical materials used in industry, as well as in industrial facilities which use the chemicals as raw materials. As a result of this there is an increased emission of dangerous materials into the air, water and soil. Although water problems occur in specific locations and regions, they are in fact global problems in that their frequency, magnitude, and potential effects are increasing rapidly.

Concerning that water is one of the most important natural resources and one that will determine future prosperity and stability, we developed the River water Monitoring and Alert System (RWMAS) that will enable operators in crisis management centers to discover and prevent water pollution.

The remainder of the paper is organized as follows: The second chapter describes different technologies applicable for environmental protection and existing implementations. The third chapter describes sensor web enablement for crisis management, its general architecture, components and activity flow. The fourth chapter presents the specific implementation of proposed architecture for the River Water Pollution Management and Alert System, followed by conclusions in the fifth chapter.

2. RELATED WORK

Geographic Information Systems (GIS) is technology that can be integrated into various system frameworks. GIS enables capturing, storing, analyzing, and displaying geographically referenced information. It allows us to view, understand, question, interpret, and visualize data in a way that is quickly understood and easily shared. GIS technology can be used for scientific investigations, resource management, and development planning.

Sensor Web, on the other hand is a technology that enables tracking sensors, obtaining their data and make it available through the Web. According to (Gross, 1999) the Sensor Web is a special type of Web-centric information infrastructure for collecting, modeling, storing, retrieving, sharing, manipulating, analyzing, and visualizing information about sensors and sensor observations of phenomena.

We now have two separate technologies, GIS and Sensor Web. The point where they meet is a system where the GIS provide maps and objects, and Sensor Web provides interface to sensor data. A general overview of one such system, where geo-location of sensors is interpreted on map, where sensors can be queried, and their data represented, is further described in the following section.

In order to use, share and present data received from sensors we need to use a standardized set of protocols and semantics.

The Open Geospatial Consortium, as a leading organization in the development of standards for geospatial and location based services, has introduced a set of standards called Sensor Web Enablement (SWE). SWE consists of three Markup Language specifications including SensorML (Botts, 2006), Observation and Measurement (O&M) (Cox, 2006), Transducer Markup Language (TML) (Havens, 2006), and four Web Services specifications based on the assumption that all sensors are connected to the web, including Sensor Planning Service (Simonis, 2005), Sensor Observation Service (Na and Priest, 2006), Sensor Alert Service (Simonis and Echterhoff) and Web Notification Service (Simonis and Wytzisk, 2003). This set of services and specifications contributes to exploiting Web-connected sensors and sensor systems of all types: flood gauges, air pollution monitors, stress gauges on bridges, mobile heart monitors, Webcams, satellite-borne earth imaging devices and countless other sensors and sensor systems. OGC specification also include protocols for data access, such as Web Map Services (WMS) (de la Beaujardiere, 2006), Web Feature Services (WFS) (Vretanos, 2002) and Web Coverage Services (Evans, 2003; Lee et al., 2005).

Technologies, specifications and protocols mentioned above allow various disaster management and environmental applications. An application for detection and monitoring the spread of wild fires (Terhorst, et al. 2008) uses Sensor Web technology for wild fire detection in Africa. Their aim is to use the Sensor Web to observe specific fire-related phenomena described in the wild fire ontology and employ machine reasoning to determine fire risk.

The South East Alaska MOnitoring Network for Science, Telecommunications, Education, and Research (SEAMONSTER) (Heavner et al., 2007) is a smart sensor web project designed to support collaborative environmental science with near-real-time recovery of environmental data. Their work is focused on the Lemon Creek watershed and understanding both physical and biological as a collection of interconnected systems. Project is an effort to implement a sensor web available for science, education, and sensor web technology evaluation and advancement.

3. SENSOR WEB ENABLEMENT FOR CRISIS MANAGEMENT

Architecture of the Crisis Management (CM) system for environmental protection is based on Sensor Web technology, GIS and OGC set of specifications and services called Sensor Web Enablement.

General overview of the system architecture

The system architecture consists of the following elements (as illustrated in Figure 1): **Operator** (system operator) located at the Crisis Management Center (**CMC**), **Graphical user interface** (GUI), **Databases**, the **Decision Making Agent** (DMA) and **Data Access Layer**.

Graphical User Interface is a Web GIS. The user interacts with the GUI, which represents data received from different data sources (sensors or community services).

Crisis Management Center (CMC) is a center for resolving numerous problems related to environmental protection. CMC activities are gathered around making decisions on the basis of gathered information about the environment and acting in order to prevent pollution of the observing environment.

Decision Making Agent (DMA) is a component used for comparing and analyzing data obtained from different sources, making action plans, running on demand or automated actions and proposing action plans to crisis management center operator.

Data Access Layer represents implementations of different OGC SWE services which enable access to different data sources. This layer is the intermediary between an operator and a data collection management environment.

Databases stores data received from sensors, as well as data received from community services and GIS data.

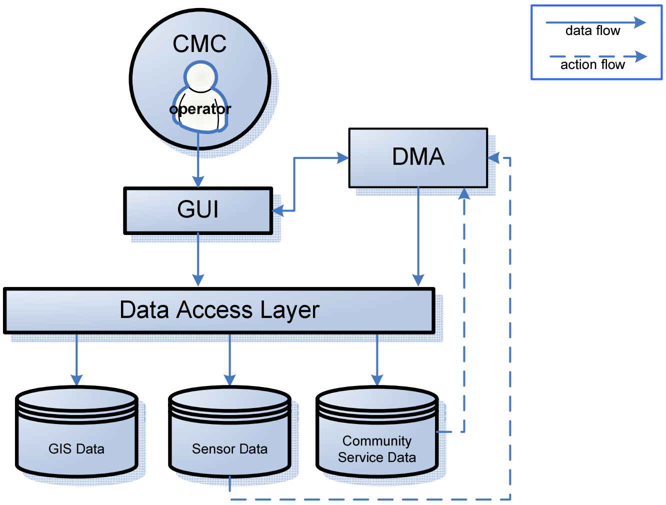

Figure 1: General overview of the system architecture.

The DMA component and activity flow

The central component in the activity flow is the Decision Making Agent (DMA) (as shown in Figure 2). The DMA is responsible for executing automated spatial queries, data acquisition from sensors and Community services, and decisioning and acting based on the set of operator demands, or programming logics. The DMA component is implemented using Web services technology.

The DMA component has two major roles. First role is to process automatic measurements based on operator demands. The second role is to decide if there has been major changes in measuring parameters, and offer some actions to the operator or act accordingly (if operator allowed this during DMA configuration). Instead of using only values received from different types of sensors in the process of deciding whether there has been pollution in the observing environment, CMC operators are provided also with data received from community services. All data is compared and analyzed by DMA and on that basis conclusions are presented to the operator with greater reliability.

The remaining parts of the activity flow include (as shown in Figure 2):

Three services: Sensor Observation Service, Web Notification Service, Sensor Alert Service. Their role is to collect data from sensors, manage sensor actions in real time and deliver notifications to end users. The services are implemented on the basis of OGC SWE specifications.

The Community service is a Web service for collecting data from users concerning the environment. It allows users to send information in various ways about their observations of the environment. For example, a certain user could send a picture of dump, which would be useful when decision is made about the various sources and causes of pollution. Community data services should register within system in order to be able to interact with the system and send collected user data in various formats (e.g. pictures with descriptions, textual messages …).

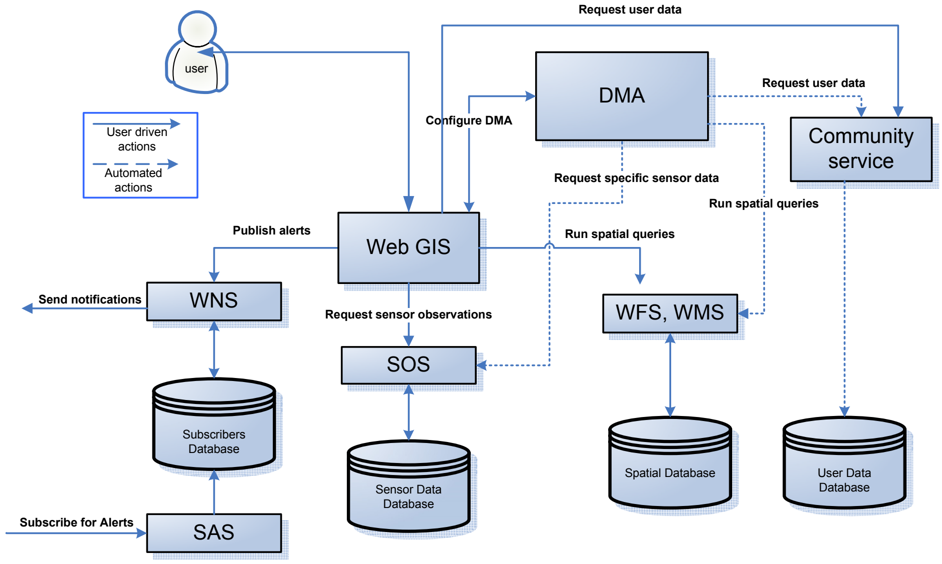

Figure 2: Activity flow.

Sensor Observation Service (SOS) – Standard Web service interface for requesting, filtering, and retrieving observations and sensor system information. This is the intermediary between a client and an observation repository or near real-time sensor channel.

Sensor Alert Service (SAS) – Standard Web service interface for publishing and subscribing to alerts from sensors. Users outside this system who would like to receive observation information and alerts can subscribe to this system using SAS.

Web Notification Service (WNS) –This service is useful when many collaborating services are required to satisfy a client request, and/or when significant delays are involved in satisfying the request. It provides a means to alert people, software, or other sensor systems of results or alerts regarding phenomena of interest.

Web GIS (Bogdanovic et al., 2008) is an application for visualization of spatial data, integrated with sensor data and community services data. It has a standard set of functionalities, such as multiple maps view, panning of maps, moving trough maps, etc. For the basic functions like showing maps and geodata Web GIS uses Web Map Service (WMS) and Web Feature Service (WFS).

Activity flow

The activity diagram (shown in Figure 3.) shows basic activities performed in the system by user (in this case operator) or configured DMA component.

The user operator located at the CMC ***Request Sensor Measurements*** in order to check measuring parameters. He can also perform at the same time two more activities ***Request user Data*** and ***Request Spatial Data***, in order to have a more detailed view on the observing environment.

On the basis of received data operator can ***Analyze Data*** and decide about the actions to be performed. If a possible threat is detected operator can ***Send Alerts*** in order to inform objects of interest. If the operator gets some conclusions about who is responsible for the threat, he can inform them as well.

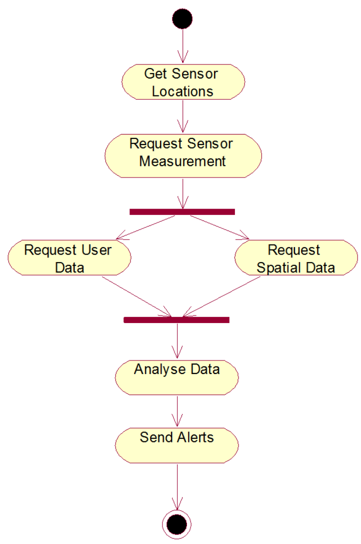

Figure 3: Activity diagram

There are two types of actions that can be performed in the system. First types of actions are ***operator driven*** actions.

Operator driven actions can be disassembled in two actions. Firstly there are actions associated with sensors and community services. Operator can ask for sensor observations trough Sensor Observation Service. He can send request to WMS, and WFS services if he needs to see where the sensors are geographically situated. Operator can check the community service data, and finally, when is needed he can publish alerts and notifications using Web Notification Service.

Secondly there are actions associated with DMA. Operator can configure DMA agent - define a set of sensor data queries or spatial data queries to be executed, or rules to be performed and controlled automatically by DMA.

The second types of actions are ***automated actions***. Automated actions are performed by DMA on the basis of operator configuration. DMA can demand sensor observations continuously in certain period in time, and cross-reference the given values with data obtained from community service database. On the basis of predefined criteria DMA can decide whether the vital parameters are beneath or above certain level, and propose actions to the operator.

Operator configures DMA in order to give a set of rules and actions to be performed automatically in some period of time. For example operator can fill a simple form to initiate specific measurements to SOS, which will be saved into database. There is a predefined set of spatial queries among which the operator can choose one to execute, which is the most appropriate for the current situation.

GIS data represents a collection of geographical data, maps, vector objects, raster objects. This component of the system represent different data dependent of the purpose of usage. For example if the final implementation of the system is used for water management, the GIS needs to incorporate data about rivers. GIS data is saved in spatial database over which can be executed operator driven or DMA automated spatial queries. Operator can choose a type of query executed by DMA agent that will be triggered by some event on the sensor. An example query would be to request objects to be drawn on the map if they are classified as polluters (as illustrated in Figure 4.a).

a) **SELECT** {objects} FROM {SpatialData D} **WHERE** {object.property **IN** {polluters}}

b) **SELECT** {parameter } **FROM** {SensorData D1, SensorData D2 }
WHERE {D1.loc IN (R1) **AND** D2.loc **IN** (R2) }

c) **SELECT** {metadata} **FROM** {UserDatabase U} **WHERE** {U.loc IN (R1) }

Figure 4: Example data queries.

Sensor data is obtained trough Sensor observation Service. SOS is a standard Web service interface for requesting, filtering, and retrieving observations and sensor system information. Operator driven or DMA automated queries are executed over sensor database. For example, user can request the measuring parameters received from the sensors located in two different regions (as illustrated in Figure 4.b).

User Data Database stores user collected data concerning environmental protection. For example someone can send a picture of environment (waste water, wild dump), with a small description of what is in the picture and its geo location. User data can be filtered and searched in different ways. On possible query could be for finding the metadata (user description) for some location (as illustrated in Figure 4.c).

4. RIVER WATER POLLUTION MANAGEMENT AND ALERT SYSTEM

Architecture described in previous section has been implemented for River Water Pollution Management and Alert System (Markovic and Stoimenov, 2008). This system will help in solving numerous problems relevant for the ecosystem degradation of the Nisava River, which are the result of the presence of a large number of concentrated and diffused pollutants along the Nisava watershed. The system will enable operators in CMC to act accordingly to discover and prevent water pollution.

The design of sensor web system, selection of sampling methods and variables to be measured must be based on an understanding of fluvial processes as well as the requirements for water use. Water quality can be described by a single variable or by any combination of more than 100 variables. For most purposes, however, water quality can be adequately described by fewer than 20 physical, chemical, and biological characteristics. Full selection of variables must be made in relation to assessment objectives and specific knowledge of each individual situation. The basic set of parameters that has to be surveyed in the case of river water include: temperature, electrical conductivity, pH, dissolved oxygen (DO), and total suspended solids (TSS) (Velickovic and Miljojkovic 2006). Depending on the values of measured parameters, the decision of water pollution can be made.

Physical and chemical measurements in river streams can be made at discrete intervals to provide a nearly continuous record of stream water quality. Major factors in the operation of a continuous water-quality site include selection of sensors and types of monitors, the type of monitor configuration, site selection, location of the sensors in the stream cross section, the use and calibration of field meters, and the actual operation of the water pollution detection. Sensors need to be placed in the measuring stations, constructed at the river beds. Sensor information is sent trough GPRS devices to Web GIS application, on demand or on given interval of time.

One use-case in the River Water Pollution Management and Alert Center

One specific use-case based on the diagram explained above will be elaborated more thoroughly in this section. The use-case presents situation when operator is requesting observations from sensors, in order to decide whether the water is polluted and to present data about the discovery on Web GIS (as shown in Figure 5).

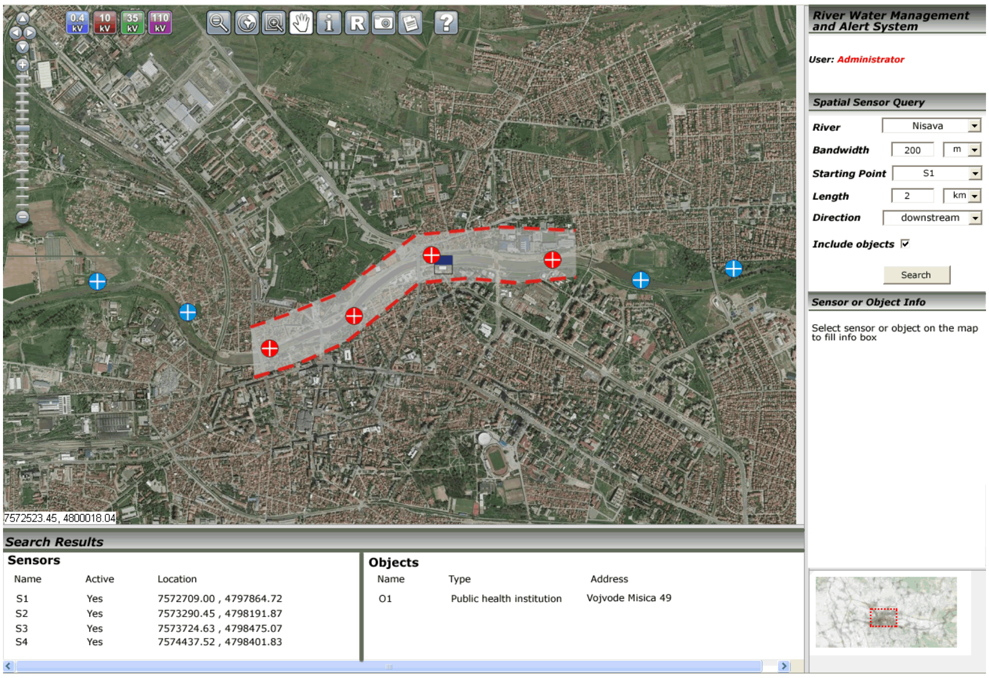

Figure 5: River Water Management and Alert System

All sensors are visualized trough Web GIS Client. Sensors that are not part of operator query are painted in blue. Operator queried sensors are painted in red. In this particular case, map is centered on the Nisava River. In this particular case operator ran a spatial query to find all sensors starting from sensor S1, 2km down the river stream, and 200m in bandwidth. Operator can choose to include nearby objects in search results. Search results are shown separately for Sensors and Objects. Sensors search results include information about sensor name, activation and location. Object search results include object name, type and address. If the operator selects certain sensor or object its detailed information is shown in the info box.

The system offers also other possible actions to the operator. Operator can configure DMA component, in order to run automated measurements and actions. The process of configuration goes as follows:

1. First thing operator must do is to define a triggering event. That event is the measured parameter received from sensor whose value is below or above given level. In this first step operator configures DMA to run periodical queries over sensor data. An example condition can look like C1 in Figure 6.
2. The second step in this configuration is to tell to the DMA the actions to be performed if the event occurs. Operator can define a set of actions A1-A3 (as illustrated in Figure 6).

C1: Check parameter X for two days period and on five minutes interval

A1: *IF* parameter X > *value THEN* execute A2 *ELSE* C1

A2*:* Request user metadata (user photo with description - check consequence of pollution)
Query polluter's database (check possible causes of pollution)

A3: Report data to the operator.

Figure 6: River Water Management and Alert System

After DMA sends a report to the operator, the operator can choose whether to notify polluters and objects of the possible threats or causes of pollution.

Besides the above explained use-case, the system also offers other possibilities to the operator. System is extendable. It is possible to add new functionalities, include fire detection, flood detection, etc.

5. CONCLUSION

Sensor Web has provided infrastructure for collecting and processing data from distributed and heterogeneous sensors. This set of technologies has found various implementations, especially in the area of environmental monitoring. The Sensor Web architecture for crisis management, described in this paper, provides active monitoring of measuring parameters and timely responses in cases of environmental disasters. The River Water Management and Alert System built on this architecture enable access, control and management of river water pollution. There are many ways of upgrading this system and making it more efficient and completely automated. The future work includes modifications and improvements of the current system architecture and its implementation. The DMA component can be further improved by incorporating a knowledge-based engine, in order to run independently and automatically report alerts to the operator in the crisis management center.

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