Using Wireless Sensor Networks in the Sensor Web for Flood Monitoring in Brazil

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ABSTRACT

Flood is a critical problem that will increase as a result of climate changes. The problem of flooding is particularly challenging over the rainy season in tropical countries like Brazil. In this context, wireless sensor networks that are capable of sensing and reacting to water levels hold the potential of significantly reducing the damage, health-risks and financial impact of events. In this paper, we aim to outline our experiences with developing wireless sensor network for flood monitoring in Brazil. Our approach is based on Open Geospatial Consortium's (OGC) Sensor Web Enablement (SWE) standards, so as to enable the collected data to be shared in an interoperable and flexible manner. We describe the application of our approach in a real case study in the city of São Carlos/Brazil, emphasizing the challenges involved, the results achieved, and some lessons learned along the way.

Keywords

Flood Monitoring, Wireless Sensor Networks, Sensor Web, Service-oriented Architecture, Brazil.

INTRODUCTION

In recent years, there has been increasing concern about the environmental risks and potential hazards of natural disasters, especially owing to the growth in the number of these occurrences. In Brazil, the problem of floods has been a particular cause of alarm to society.

The main effects of flooding are material, human, economic and social losses in flooded areas, infection from waterborne diseases and contaminated water. As well as the risks to life suffered by families in these areas, the economic damage has also imposed the burden of having to recover from their financial losses, without taking account the harm caused to public bodies. Thus, it is important to be able to warn the people who are most at risk and the public bodies concerned, so that the effects of these disasters can be alleviated.

Given this situation, the monitoring of river levels is essential. However, carrying out monitoring as an isolated task will not put an end to the human and financial losses. This requires an analysis of the data obtained from the monitoring with the aim of supplying the relevant information to the responsible bodies so that they are in a position to predict when these events are likely to occur. This will enable them to make decisions with a view to taking precautionary measures to reduce the severity of the impacts and ensure that the people at risk are given adequate warning.

With this in mind, this work proposes the use of wireless sensor networks along the riverbeds to monitor the water level and to draw on this source of information to assist the responsible bodies and vulnerable communities during the decision-making process. Furthermore, our approach is based on the "Sensor Web" paradigm, in order to provide interoperability with a variety of end-user geographical applications that are able to consume data via standardized web services.

CHALLENGES

During the rainy season floods are a constant problem in Brazil. This is becoming particularly critical in towns or cities surrounded by large rivers, like the city of São Paulo. Before the effects of flooding can be alleviated, there is a need for precise and complete information in advance, about the current level of the rivers.

In the light of this, geospatial information is of particular value since it can be used to examine changes in the river levels in a specific or regional geographical context. However, at present most of this information is scattered in different sources and not coordinated. This raises the challenge of how to manage and make available the information that is needed to build up the resilience of the communities that are most vulnerable to the risk of sudden downpours.

One of the main technologies that can assist the management of environmental risks is represented by geospatial software platforms known as Spatial Data Infrastructure (SDI) (Rajabifard and Williamson, 1999; Masser, 2005). There are two essential requirements for the development of an SDI in the context of flooding: a) interoperability: the need to integrate the heterogeneous data sources; b) flexibility: the ability to adapt to the wide range of situations and specific needs of different scenarios.

The development of a support system for decision-making is complex and depends to a high degree on the specific context being handled, since the sources of information and coordination processes among the interested parts can vary considerably from one context to another. Another main challenge for the application developer is how to integrate data that has been acquired from different types of sensors. For this reason, the Service Oriented Architecture (SOA) can provide a suitable technological solution because the use of services can encapsulate the characteristics of the different sources of information in a standardized services format, as well as provide flexibility in applications.

In this context, the web services technology allows a standardized and technologically neutral means of access for spatial data applications. These services seek to enable the exchange and use of geospatial information that is stored in heterogeneous information sources (Tu and Abdelguerfi, 2006). The Open Geospatial Consortium (OGC) uses SOA concepts to make interoperability viable in the use of spatial data for different companies and technologies.

OGC's Sensor Web Enablement (SWE) working group has devised a set of service standards, which allow the integration of sensor data derived from sensors in the spatial data infrastructure (Jirka, Broring and Stasch, 2009). Thus, the Sensor Web conceals the underlying layers, i.e. the network communication details and heterogeneous sensor hardware, from the applications built on top of it. It thus allows users to share sensor resources more easily (Broering et al., 2011). Although the adoption of OGC standards is becoming widespread throughout the world, there are still few practical applications that examine the specific difficulties of the use of geospatial services for environmental monitoring, particularly for rivers.

APPROACH

In the light of the aforementioned challenges, we developed a sensor prototype integrated in a system of georeferenced web services. Our approach includes the development of a software and hardware platform, which will be described in the following sections.

Hardware

Initially, the first prototype was built by using SunSPOT (Sun SPOT World, 2013), although it was necessary to adapt them to the conditions of Brazilian rivers (Hughes et al., 2011). However, the main drawback of SunSPOT was the very limited range of wireless communication which became a crucial factor as the project progressed. When tests were carried out between a node (a SunSPOT mote located on the banks of the river) and the base station (a SunSPOT mote that receives the wireless signal from the prototype and which remains connected to the computer) the results obtained, with regard to the range of the wireless equipment, were unsatisfactory which meant that the project as a whole was not viable.

In view of this, a new hardware platform was sought with the aim of obtaining a good range of wireless communications between the nodes, with a good cost/benefit. On the basis of this, the platform using Xbee motes (Digi, 2012) was developed. Compared with the old platform, this had several advantages such as lower energy consumption, a smaller physical size, and a greater range of communication between each node.

In this manner, the data that reach the mote are directly transmitted to the base station or to a mote that is nearer if the base station is outside the coverage area of the transmitting node; this will repeat the procedure until the data are in fact transmitted to the base station. This type of network is known as mesh networks After the data have been stored at the base station, they are processed in real time by the server.

Software Implementation

In order to achieve interoperability, our implementation adopts the Sensor Web Enablement standards defined by the Open Geospatial Consortium (OGC) (Botts et al., 2008). This decision derived from the fact that these specifications have become de facto standards in industry with regard to georeferencing applications (Alves and Davis, 2006). The OGC defines the *Sensor Observation Service* (SOS) as a service designed for the handling of data originating from sensors in an interoperable way.

In particular, we chose to use the SOS framework provided by 52 North German initiative for Geospatial Open Source software (Jirka, Broring, Kjeld, Maidens and Wytzisk, 2012; 52North, 2012). The advantage of 52N software is that it is open source code distributed under the terms of the GNU licence, which allows it to be easily adapted. The software framework consists of an application server and a data server. The application server is implemented using Java Servlet and the Apache Tomcat web server. The data server is based on a PostgreSQL database management system and its extension to the PostGIS geographic database.

In the context of our project, the data is inserted in the database through a call to a RESTful web service running in the base station The idea is that the base station establishes a connection directly with the server and requests the insertion of the data collected by the sensors. Then the server authenticates the request and decides whether or not to allow the aggregation to the database. The aggregated data are readily available to any requests from clients via web services.

Three operations from the original SOS specification (Botts et al., 2008) have been implemented in the server of this project: *GetCapabilities* (makes metadata available for the service in a general way), *DescribeSensor* (supplies metadata regarding the sensor in particular), *GetObservation* (supplies observation data from a particular sensor).

Additionally, a prototype client was devised based on a spatial data framework geared towards service oriented architecture services, since one of the objectives of the project is to develop a software architecture that is robust, interoperable and scalable at the same time. As a basis for the construction of this SOA architecture, the web service standards defined by the Open Geospatial Consortium (OGC) were also employed.

The OGC specifies the Web Map Service (WMS) as the provider of an HTTP interface for the demand of images and georeferenced maps derived from one or several spatial databases. A demand for a WMS service defines an area of interest to be processed, for example, the streets of a city or the river basins in a particular region. As such, WMS is functionally similar to SOS. As a primary source of data, a PostGIS spatial database is employed. The WMS service used in the prototype was configured by means of the GeoServer server which also implements other web services defined by the OGC.

The database was initially populated with basic data regarding the São Carlos watershed which included data such as the boundaries of the watersheds, the contours, and the location of the river sources, among others. This database is also responsible for the storage of the data derived from the wireless sensor network. Information concerning the measurements of the sensors is also stored, such as the water gauge level and later the levels of pollution and turbidity, as well as information about the sensors themselves.

The development of the application was carried out by using the GeoExt API (Application Program Interface) as a base, i.e. a javascript open source library developed especially for creating geographic web application interfaces. The OpenLayers library was used together with the GeoExt API. We can regard this library as the main component of the client application. It is responsible for implementing the main functions of visualization, handling the geographic data and carrying out the integration with the OGC services.

RESULTS

Our approach was deployed with two sensor nodes in the city of Sao Carlos/SP in order to monitor two rivers that cross the city, as can be seen in the prototype interface of Figure 1. In this manner, data concerning the water level of the river can be displayed in real time by the application. Additionally, the web application also presents charts with the evolution of the water levels in the last hour for the selected sensor node (in the box above the map in Figure 1), and the evolution of the last 12 hours for the two monitored points (in the two boxes on the left of the map in Figure 1).

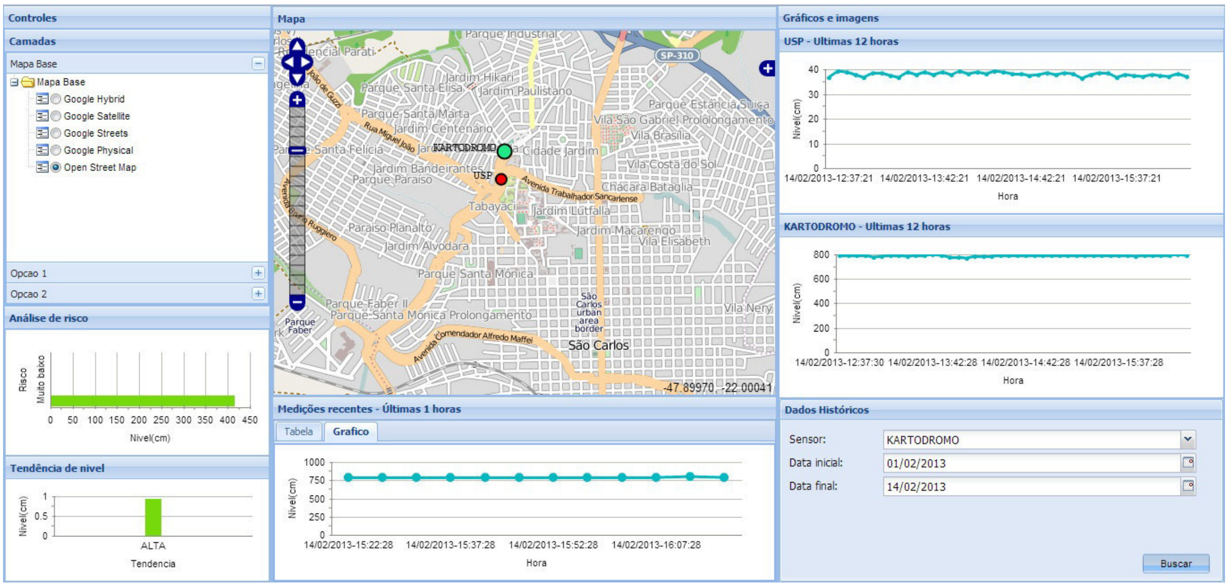

Figure 1 - Prototype Interface.

The objective of this study concerned mapping out the river levels in the town of São Carlos with the aim of determining the existence of flooding in critical regions. Among the challenges encountered, both in hardware and software development, the greatest challenge came from the wireless sensor network. Brazil has the characteristic of rivers of great length, thus hampering the use of some sensors. Initially, it was developed a prototype using Sunspot motes, however the prototype did not succeed to enable communication between a node (a mote located on the banks of the river) and base station, making the project unviable due to the characteristics of the Brazilian rivers.

Another disadvantage found in the use of Sunspot motes was the high battery consumption. Thus, we proposed the use of a new sensor that has a greater range and yet a lower consumption battery. In order to prolong battery life, a solar panel was employed to replenish the backup battery that is located inside the airtight box prototype, being benefited by the Brazilian tropical climate conditions.

The two sensor nodes installed in the city of São Carlos, are already collecting data regarding the water levels, which are being used by the developed application in an interoperable and flexible way, a characteristic that has been achieved by the reliance on the OGC standards.

Performance tests were conducted to check the efficiency of the server and the feasibility of using the SOS web service which took into account the response time to the request. Simple requests, using the operation GetCapabilites from a public SOS service found at the Internet, were made. These tests sought information about the most recent values with regard to temperature and water levels, which were returned in an XML file.

First of all, an observation was carried out involving the server of tests made available by terrestris GmbH & Co. KG (Terrestris, 2012), which disseminated data relative to the local temperature in all the towns and cities in Germany. It was verified that the average time for the reply to a test in a single observation was 697.75 milliseconds. Following this test, new measurements were employed, this time using the SOS 52North server that we implemented locally, within our internal network. From these new tests, we obtained an average time of 39.5 milliseconds for communication and 32.5 milliseconds for processing overhead.

When these results are examined, it is not possible to make a direct comparison between the two services because we do not know the details of how the implementation was made available by terrestris GmbH & Co. KG. In the case of the local tests, both the 52North server and the spatial database (PostGIS) are hosted in the same computer/server, which greatly reduces the communications overheads. In any case, the tests conducted showed that the implemented server performance is acceptable and the overheads imposed by the use of XML schemas via web services pay off in face of the gains obtained in interoperability.

CONCLUSIONS AND FUTURE WORK

This study summarizes our approach for providing a real world application of wireless sensor networks and geospatial services to monitor the river water level in the town of São Carlos in Brazil, as well as to use the data supplied by the sensors aimed at detecting floods. This kind of approach has become important owing to the constant occurrence of floods in Brazil, as well as technological advances in the detection of flooding in urban rivers, which can help to save many lives and give protection against material losses.

The next stage in this project is to install physical sensors at various points of the rivers in the town of São Carlos and gather a large amount of data to provide evidence of possible over flow points along the riverbed. As well as this, an approach will be adopted for the development of geospatial platforms to calculate the flooding risk at various points and thus alert the vulnerable community. This approach includes methods and techniques to identify the informational needs of a specific context and to provide a framework that is geared towards integrating the different sources of data. One of these sources in this project concerns data derived from citizens, the so-called voluntary geographic information, which can make a valuable contribution by supplying direct or indirect information, through the social networks sites etc.

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