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Development of a spatial decision support system for flood risk management in Brazil that combines volunteered geographic information with wireless sensor networks

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ABSTRACT

Effective flood risk management requires updated information to ensure that the correct decisions can be made. This can be provided by Wireless Sensor Networks (WSN) which are a low-cost means of collecting updated information about rivers. Another valuable resource is Volunteered Geographic Information (VGI) which is a comparatively new means of improving the coverage of monitored areas because it is able to supply supplementary information to the WSN and thus support decision-making in flood risk management. However, there still remains the problem of how to combine WSN data with VGI. In this paper, an attempt is made to investigate AGORA-DS, which is a Spatial Decision Support System (SDSS) that is able to make flood risk management more effective by combining these data sources, i.e. WSN with VGI. This approach is built over a conceptual model that complies with the interoperable standards laid down by the Open Geospatial Consortium (OGC) – e.g. Sensor Observation Service (SOS) and Web Feature Service (WFS) – and seeks to combine and present unified information in a web-based decision support tool. This work was deployed in a real scenario of flood risk management in the town of São Carlos in Brazil. The evidence obtained from this deployment confirmed that interoperable standards can support the integration of data from distinct data sources. In addition, they also show that VGI is able to provide information about areas of the river basin which lack data since there is no appropriate station in the area. Hence it provides a valuable support for the WSN data. It can thus be concluded that AGORA-DS is able to combine information provided by WSN and VGI, and provide useful information for supporting flood risk management.

1. Introduction

Recent floods have shown that such disasters can cause damage to the economy and citizens of a country (Kaewkitipong et al., 2012; Merz et al., 2012). This is particularly the case in Brazil, where frequent serious flooding accounts for 54% of the disaster events for the past few years (IBGE, 2014). In view of this, flood risk management has become a critical issue. Timely and accurate information can greatly assist the emergency agencies involved in flood risk management. However, the continuous monitoring of the potential risks of flood hazards requires precise estimates of the risks incurred that are based on the observation of rainfall and water levels in local regions (Jha et al., 2012).

Wireless Sensor Networks (WSN) have emerged as an alternative approach which can provide updated information for water resource management at a relatively low deployment cost (Albuquerque et al., 2013). Although this approach has been successfully employed for different situations (Lee et al., 2008; Hughes et al., 2011; Seal et al., 2012; Shukla and Pandey, 2014), it requires a considerable effort to ensure it works effectively (Patel and Kaushik, 2009). In addition, WSNs often fail to provide data from several parts of the riverbed since there is a lack of an appropriate station in what are called “ungauged areas”. Running parallel with this, another valuable source of information is Volunteered Geographic Information (VGI). This enables ordinary citizens who reside in high-risk areas, to provide information through various

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devices (e.g. smartphones) (Goodchild, 2007; De Longueville et al., 2010; Roche et al., 2011).

The combination of WSN and VGI can act as a mutual support system for achieving effective flood risk management. However, it raises challenges which are threefold: (1) dealing with distinct formats (e.g. photos vs numeric values) at different levels of measurements (e.g. water level gauges vs citizen's perceptions), (2) ensuring interoperability among data providers, and (3) conveying the integrated information in a single and understandable way. This paper therefore aims to tackle these challenges by presenting AGORA-DS, a Spatial Decision Support System (SDSS) that integrates the information provided by WSN and VGI, and is an aid to decision-making in flood risk management. AGORA-DS was based on a conceptual framework comprising the following: (a) the acquisition layer responsible for defining available data sources, (b) the integration layer designed to integrate the data and make them available in compliance with interoperable standards, and (c) the decision-support layer, the purpose of which is to provide a web-based decision support tool for visualizing the integrated information to support decision-making.

This paper is based on our previous work: Horita and Albuquerque (2013) set out a conceptual architecture for supporting decision-making by using different types of data sources. Degrossi et al. (2013) show the early results of our attempts to monitor urban rivers. Horita et al. (2014) display a geodashboard that processes data streams of WSN and makes them available to support decision-making. Degrossi et al. (2014) adopt and evaluate a crowdsourcing-based approach to obtain VGI for flood risk management. Thus, this paper both consolidates the results of our previous work and supplements this with the following novel contributions:

1. *Conceptual framework*: a definition of a conceptual framework for collecting and integrating heterogeneous data sources (i.e. WSN and VGI), and the visualization of integrated information. It employs interoperable standards to ensure the integration of information, and thus makes the framework flexible enough to support the inclusion of different elements.
2. *Real scenario*: lessons learned from the deployment and analysis of AGORA-DS in a real scenario of flood risk management in São Carlos, Brazil. The data provided by both a group of installed in situ sensors and volunteers in the field were used rather than data from simulated scenarios.

This paper is structured as follows. Section 2 first outlines the conceptual basis of this work. Following this, Section 3 describes AGORA-DS and sets out its conceptual framework. On this basis, Section 4 describes the deployment used for analyzing AGORA-DS. Section 5 discusses the lessons learned from this deployment and the results obtained. The limitations of this work are also described in this section. Finally, Section 6 summarizes our conclusions and makes recommendations for future work.

2. Background

2.1. Flood risk management

Since floods are the most common type of disaster that affects communities around the world, flood risk management is a necessary measure to minimize their effect. This kind of management seeks to reduce the social, economic, and environmental consequences of floods by means of a set of activities grouped into three phases: pre-flood planning, emergency management and post-flood recovery (Ahmad and Simonovic, 2006). In view of the many variables involved, information about the current state of rivers thus plays an important role in defining the current situation and supporting decision-making.

Nevertheless, three key issues must be addressed to ensure the effectiveness of flood risk management and that the right decisions are made by the emergency agencies: (1) the response time of official and emergency agencies must be fast, integrated and reliable because a delayed response based on erroneous data can have serious consequences (Ostermann and Spinsanti, 2011); (2) there may be a lack of detailed and updated information concerning the different variables in the affected areas (Tu et al., 2009), and (3) since there is a wide range of existing systems, there is no single standard that can ensure their interoperability (Baharin et al., 2009).

In order to tackle the second issue, Wireless Sensor Networks (WSN) (Xu et al., 2004) have been proposed to provide updated information at a relatively low deployment cost (Lee et al., 2008; Hughes et al., 2011; Seal et al., 2012; Shukla and Pandey, 2014). Due to advances made in wireless computing, sensing devices and small batteries, a wireless sensor network can be defined in terms of its low-cost and low energy consumption, regardless of external services. This makes it possible to monitor distinct variables of interest like the level of pollution in the river. This network generally consists of a range of sensor nodes installed in different locations, which are designed to gather and transmit specific data through short-range wireless interfaces to a base station (Khedo, 2013). To carry this out, the architecture of the nodes is equipped with low-power wireless networking technologies (e.g. ZigBee device) and simple sensors (e.g. for measuring the volume of rainfall).

2.2. Volunteered geographic information

The increase of interactions made possible by Web 2.0, the widespread use of devices equipped with GPS and the availability of broadband access to the Internet, geographic information has being produced by relatively unqualified people. This type of information, called Volunteered Geographic Information, has been of great practical value to complement existing geospatial datasets (Goodchild, 2007), owing to the potentially large number of volunteers who act as “sensors” (Poser and Dransch, 2010). In recent natural disasters, VGI has been used to support the activities of emergency agencies and government departments (Poser and Dransch, 2010; Yates and Paquette, 2011; Roche et al., 2011; Kongthon et al., 2012; Kaewkitipong et al., 2012; Triglav-Čekada and Radovan, 2013; Chae et al., 2014).

The volunteered information can be obtained through different collaborative activities, such as information sharing through social media (e.g. Twitter), collaborative mapping (e.g. OpenStreetMap,[1] Wikimapia[2]), and participatory sensing (e.g. citizen observatories) (Resch, 2013; Degrossi et al., 2014). In this study, it was decided to employ participatory sensing by means of a citizen observatory. This is because this platform seeks to gather specific and structured data rather than providing free-text content (e.g. Twitter) (Miorandi et al., 2013). A good deal of work has been carried out on the use of a citizen observatory for supporting disaster management (McDougall, 2011; Gunawan et al., 2012; Valecha et al., 2013; Hirata et al., 2013; Degrossi et al., 2014). However, neither of these works considered the question of integrating volunteered observations with other data sources nor the sharing of data by complying with interoperability standards.

[1] http://openstreetmap.org
[2] http://wikimapia.org