Computers, Environment and Urban Systems 56 (2016) 68–85

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

Towards multi-agency sensor information integration for disaster management

Farzad Alamdar [a,*], Mohsen Kalantari [b], Abbas Rajabifard [a]

[a] Centre for Disaster Management and Public Safety, Department of Infrastructure Engineering, The University of Melbourne, Australia
[b] Centre for SDI and Land Administration, Department of Infrastructure Engineering, The University of Melbourne, Australia

ARTICLE INFO

Article history:
Received 22 February 2015
Received in revised form 28 October 2015
Accepted 22 November 2015
Available online 4 December 2015

Keywords:
Multi-agency
Disaster management
Sensor information integration
In situ sensing
OGC Sensor Web Enablement
Sensor web services

ABSTRACT

Having access to real-time spatial information is central to the functioning of disaster management, and in particular disaster response. Existing spatially-enabled solutions for managing urban disasters provide limited support for time-sensitivity and urgency underlying emergency situations. These approaches mainly suffer from low temporal resolution and inability to source a broad range of required disaster data, together with insufficient support for automated operations. However, disaster management procedures, integrated with in situ sensing, promise an extensive range of real-time data and automated processes to acquire and manage disaster information. In this research, we study the process of integrating multi-agency in situ sensors for supporting disaster management. For this purpose, the research was adopted in Australia as the case study area in disaster management of a flood by emphasizing on the response phase. This paper first identifies the issues and existing requirements in the process of multi-agency sensor information integration and then proposes a standard-based approach to overcoming these integration issues. Afterward, based on the presented approach and identified requirements, a GIS-based software IDDSS-Sensor is implemented to provide the functions of standard-based access, as well as on-the-fly harmonization, integration and usage of multi-agency sensor information. We evaluate the applicability of our developed approach by applying it to the use case of supporting flash flood evacuation response.

1. Introduction

Disaster is a major challenge in today's world that causes loss of lives and devastating impacts on infrastructures and economies. In 2014, natural disasters caused 7700 fatalities and losses of US$110 billion worldwide (Munich, 2014). Amongst all disasters, flood occurring is the most common (Leskens, Brugnach, Hoekstra, & Schuurmans, 2014). In Australia, flooding counts for an average $377 million in damages annually (Middelmann-Fernandes, 2009).

Currently, the role of spatial information and its exchange between public safety officials is part of the research agenda (Tran, Shaw, Chantry, & Norton, 2009; Zlatanova, Li, Fabbri, & Zlatanova, 2007; Mansourian, Rajabifard, Valadan Zoej, & Williamson, 2006) and is acknowledged in the current practices for multi-agency incident management (VINE, 2013). Recently, attention has been turning towards sourcing and exchanging dynamic disaster information between responding agencies for increased situational awareness (Chen, Wang, Xiao, & Gong, 2014; Farnaghi & Mansourian, 2013).

In line with this demand, in situ sensing has emerged as a spatial data sourcing technology that provides the automated collection of varied information in (near) real-time (Alamdar, Kalantari, & Rajabifard, 2014; Wang & Yuan, 2010). The complications surrounding urgency and time-sensitivity underlying emergency decision-making could be handled by enabling sensor-derived situational awareness to be shared across responder organizations. However, it poses threefold challenges: (1) ensuring interoperability between sensor data providers and disaster management authorities, (2) dealing with existing sources of inconsistencies in sensor data, and (3) derivation of actionable emergency information from raw sensor observations. The goal of this study, therefore, is to tackle these challenges by presenting an approach based on OGC Sensor Web Enablement (SWE) with the following novel contributions:

1. Empirical study: The paper is grounded on an empirical case study on current processes for sensor information integration in the emergency management of Victoria, Australia.
2. Conceptual development: Definition of components for standard-based sensor data access, harmonization, and connection to realize the real-time integration of multi-agency sensor resources across emergency operation centers.
3. System implementation: Development of a GIS-based software tool that enables the integration of sensor information, and aids decision-making in flood response.

* Corresponding author.
E-mail addresses: farzada@student.unimelb.edu.au (F. Alamdar), mohsen.kalantari@unimelb.edu.au (M. Kalantari), abbas.r@unimelb.edu.au (A. Rajabifard).

http://dx.doi.org/10.1016/j.compenvurbsys.2015.11.005

This work builds on our earlier article: Alamdar et al., 2014 which set out a thorough survey of existing approaches to the state-of-the-art sensor monitoring research for disaster management.

The paper is structured as follows: Section 2 first provides a review of associated concepts, theories and related work. Next, section 3 outlines the results of the case study. Following this, section 4, presents the new approach for multi-agency sensor information integration and sets out its conceptual framework. On this basis, section 5 presents IDDSS-Sensor by describing the associated architecture, technologies and implementation results. Next, section 6 discusses the lessons learned from this deployment and future research considerations. Finally, the conclusion remarks are described in section 7.

2. Background and related work

The principle aim of this research is to improve the access, exchange and use of multi-agency in situ sensor data for supporting disaster decision making. In this section, we outline related work on sensor monitoring, with a special focus on SWE standards for sensor data exchange. Then, we discuss the related research on applying and integrating sensory information in emergency management. Finally, we provide an overview of the users of sensor-derived emergency information and their functional requirements.

2.1. From in situ sensors to real-time disaster information

At present, sensors turn into a very important source of spatial information (Liang & Huang, 2013; Liang & Huang, 2014). Significant live data on our environment (e.g., temperature, soil and water) and also its disasters (e.g., flood occurrence) and human activities during both normal and emergency situations (e.g., traffic and pedestrian behavior) can be observed by diverse types of sensors in the field. This method of data collection falls under the umbrella of in situ sensing, which is the collection of data either inside or in the proximity of a phenomenon (Teillet, Gauthier, & Chichagov, 2002). A series of computerized devices called in situ sensors, or simply sensors, gather this data. A sensor is an observing or measuring device which records environmental data such as rainfall, humidity, temperature, or even location (Duckham, 2013).

In the context of in situ sensing, integration of sensors and their observations for a common application (e.g., disaster management or environmental monitoring) has been targeted mainly through two broad research themes. As the first theme, research work in the (geo)sensor network domain emphasized on overcoming challenges related to constrained energy resources and bandwidth of the network of wirelessly communicating, spatially distributed in situ sensors (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002; Yick, Mukherjee, & Ghosal, 2008; Rawat, Singh, Chaouchi, & Bonnin, 2014). Thus, sensor network research largely deals with designing efficient and scalable protocols with the consideration of the network communication details, device layers, and heterogeneous sensor hardware. Unlike sensor network, sensor web (as the second research theme) hides the underlying sensor communication details and the heterogeneous sensor protocols (Bröring, Bache, Bartoschek, & van Elzakker, 2011a; Chen et al., 2014). Thus, sensor web can be considered as an inclusive and application-centered platform for connecting and integrating multisourced sensors to enable discovery, access, dissemination, and usage of sensor-sourcing information (Delin & Jackson, 2001; Wang & Yuan, 2010). As the major effort to realize the goals of sensor web, the Sensor Web Enablement initiative (SWE[1]) has been developed by Open Geospatial Consortium (OGC) and is designed as a suite of defined standards and web interfaces. The central objective of SWE standards is to enable interoperable web-based discovery, exchange and processing of sensor-derived data as well as task planning with hiding the heterogeneous sensor protocols (Jirka, Bröring, & Stasch, 2009b; Dìaz, Bröring, McInerney, Libert, & Foerster, 2013).

[1] http://www.opengeospatial.org/ogc/markets-technologies/swe.

Fig. 1, shows an overview of the architecture underpinning SWE standards and web interfaces. SensorML defines a schema for metadata description of sensors and sensor systems (e.g., description of identification, input and output of a pedestrian counting sensor). O&M specifies a schema for encoding sensor observations. For example, a pedestrian counting sensor has a result time (e.g., 2015–06-26 T14:30:00Z) and result (e.g., 500 counts) which is an estimated value of an observed property (e.g., number of people) for a feature of interest (e.g., Federation square). SWE Common defines encoding of low-level data building blocks that are used inside the elements of other SWE standards and web interfaces. TML, which is rarely used so far (Jirka et al., 2009b) also addresses encoding of senor observations and metadata, mainly for the application of data streaming. SOS, provides a standardized web service interface to enable web-based accessing and publishing of sensor data and metadata (e.g., SOS defines operations to register a new pedestrian counting sensor, insert or retrieve its observations based on spatiotemporal filters). SAS enables subscription to sensor alerts when certain criteria is met (e.g. receiving an alert if the total number of people observed by a pedestrian counting sensor goes beyond a threshold). SPS provides the ability to control sensors and change their measurement parameters (tasking a pedestrian counting sensor to collect data in finer resolution, if applicable). WNS supports the delivery of notifications between SWE web services and clients (e.g., notifying the generated SAS alert to the subscribed users).

2.2. Related work on integrating sensory information in disaster management

Applying and integrating sensory information in disaster management has gained attention in recent years as an efficient solution for providing live disaster information (Wang & Yuan, 2010; Bunker, Levine, & Woody, 2015). Multisourced sensor information integration concerns combining and processing sensor and spatial data sources to provide added-value information for a common application (Alamdar et al., 2014). Recent valuable research on multisourced sensor information integration applied to problems in disaster management and public safety has been made. Considering the metadata aspect of sensory information in flood monitoring, Chen et al., 2014 developed a sensor web node meta-model and a prototype system, called GeosensorNodeManager, that enables formal description of available node resources. This meta-model could facilitate the allocation of available nodes during flood monitoring tasks. Dìaz et al., 2013 emphasized on the registration and publication of sensor data into Geospatial Information Infrastructures (GIIs), and

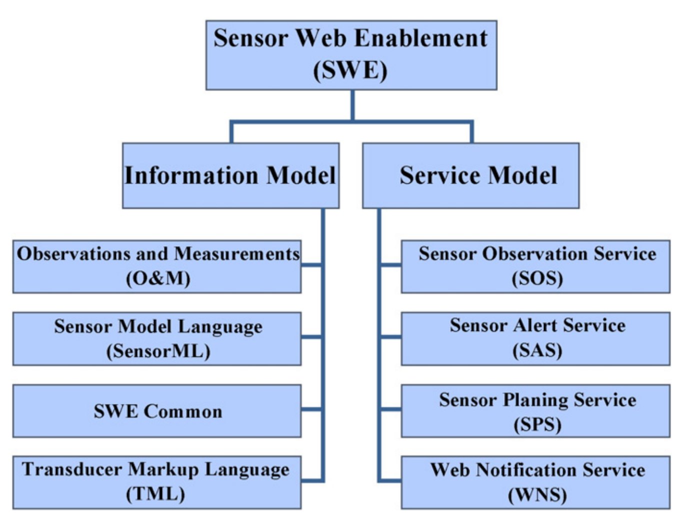

Fig. 1. Overview of Sensor Web Enablement architecture, adopted from Jirka et al. (2009b).