Enabling Spatial Intelligence Integrating Architectures of SDI and Sensor Web

Devanjan Bhattacharya*, Marco Painho†

Nova Information Management School, Universidade Nova de Lisboa

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Summary

Spatio-temporal aspects of data lead to critical information. Sensors capture data at all scales continually so it is imperative that useful information be extracted ubiquitously and regularly. Location plays a vital part by helping understand relations between datasets. It is crucial to link developmental works with spatial attributes and current challenge is to create an open platform that manages real-time sensor data and provides critical spatial analytics atop expert domain knowledge provided in the system. That is a two-faced problem where the solution tackles not only data from multiple sources but also runs data management platform, a spatial data infrastructure(SDI) as backbone framework able to harness sensor web(SW).

KEYWORDS: spatial analysis, spatial data infrastructure, sensor web, knowledge base, expert system.

1. Introduction

Everything happens somewhere and some-whence. Spatial and temporal aspects of data lead to critical insights into the information contained in it. Nowadays it is increasingly imperative to capture data at all spatial scales, local to global, and extract useful information from it ubiquitously and regularly. The research creates background for describing a spatially aware sensor web SmaCiSens, a system for smart city enhancements and interdisciplinary processes for sustainable development. It proposes a multidimensional distributed spatial platform using open source geo-datasets which involves web-geoinformatics for creating schema and interface for mapping under Open Geospatial Consortium (OGC) standards by interlinking models and datasets. At present, no web-enabled spatial sensor information system exists which can disseminate messages after events evaluation in real time. The research work formalizes a notion of an integrated, independent, generalized, and automated geo-event analyzing system making use of geo-spatial data under popular usage platform. Integrating SW with SDI enables to extend SDIs with sensor web enablement (SWE), converging geospatial and built infrastructure, and implement test cases with sensor data and SDI.

2. Background

With the advent of sensors for monitoring, data collection is ubiquitous are at unprecedented levels. The enormous volumes of data being collected constantly, create mounting challenges for optimal data processing and information retrieval. Furthermore, the spatial aspect of data is being largely underutilized in processing, although the importance of spatial decision-making is now widely accepted (Rössler et al., 2017). It has been proven that spatial analysis of data gives more meaning to the information extraction and hence enables easier assimilation of large volumes of data. Presently the systems that implement such processes are limited in effect by not utilizing all the data due to their standalone nature, offline or disconnected design, lack of spatial capabilities, unintegrated approach,

* dbhattacharya@novaims.unl.pt

† painho@novaims.unl.pt

and temporally disjoint (Giuliani et al., 2017; Jung et al., 2013). The solution could be addressed through integrating: data source, spatial data platform, data understanding, knowledge base, inferencing and visualization into a single, well-connected online real-time system. Such a spatial expert system(ES) with knowledge bases(KB) will not only serve the critical research of spatializing developmental works but do so to any research relying on real-time data capture and analysis with spatial domain of data being the unique enabler. Several important sources over the years have heavily stressed the need for developing a system capable of encapsulating the entire essence of geospatial studies in one platform which can be open, shareable, knowledgeable, and contributable globally.

Almost every decision that an individual or organization makes has some geospatial component. Sensor web(SW) and spatial data infrastructures(SDI) show great promise for building and maintaining a sustainable and changing society, which often needs to acquire spatial data through sensors and extract information using data analysis from SDI for better decision-making (Janowicz et al., 2010). The full potential of SW and IoT can only be reached with spatial intelligence integrated to them. The geospatial industry is also trying to ride the big wave and exploit the market. Research on the spatial capabilities enhancement of sensor web, in a limited manner, are reported in Liang and Huang, 2013. There have been activities that defined architectures and best practices for integrating sensor networks and observed data into existing and new SDI applications eg. Sensor Systems Anywhere (SANY, 2009), as a Framework Programme 6 (FP6) integrated project focuses on interoperability of in-situ sensors and sensor networks. An instance of utilizing sensor web with spatial knowledge was reported in Bröring et al., 2011 where a system was developed to provide a graphical user interface to sensor data and provisions for spatial reference to that data. The research in Maguire and Longley, 2004 reported a primitive system of sensor and web mapping was discussed that worked on web mapping interfaces.

SmaCiSENS can have a real edge over the currently under development projects of similar kind in terms of impact on urban development, hazard management and mitigation, digital mapping, location based services, core services and much more. Geo-visual platforms discussed in (Bhattacharya and Painho, 2017; Nativi et al., 2013) integrated sensors with SDI for creating 3D city view. But the work only applied to a few specific sensor datasets. The generalized integration of sensor web and SDI has been reported by Jazayeri et al., 2015 and the papers elaborate on the underlying logics. A geosensor web concept has been discussed in Liang and Huang, 2013 with SDI in background and the development aspects from this theory have been put together by Jazayeri et al., 2015; Bhattacharya and Painho, 2017, setting the tone for SmaCiSENS. Further, the semantic requirements of a spatial system have been suggested in Taylor and Parsons, 2015. A detailed deployment of enhanced SDIs is presented in Giuliani et al., 2017 where the need for scalability of ontologies to spatial datasets is proven. In another related publication, the interlinking of open geodata sets has been described (Overpeck et al., 2011) and the functional and usable enhancements are proven. According to Laurini 2017; Bhattacharya and Painho, 2017 the main reason such a system as SmaCiSENS has not been achieved yet is the difficulty to merge spatial geometry and topology inherently with traditional analysis and create an effective spatial inference engine. But through this research work the solution is demonstrated in creating algorithms and ontologies utilizing geometry, topology, and location arithmetic and shown that SmaCiSENS can be the system to address all the challenges.

3. Methodology

The methodology of development of SmaCiSENS is modular in structure (Figure 1). The overall architecture depends on the creation of knowledge bases for natural hazards (or any event) to deduce the specifics of the occurrence. The methodology is that the input module of the system implements extraction, based on legend matching, of information about causative factors from thematic maps, satellite images, and GIS layers. Understanding module addresses expert knowledge rules (qualitative approach) in expert module, which conducts pixel-based reclassification of input (compatible to KB), results in evaluation of intensity/effect of hazard(any situation) on ratings of causative factors (deterministic method) out from Output module and communication to user is achieved through Communication module which also gives feedback to improve inputs and geospatial information improvement, since GIS module has bi-directional data flow. The interactive graphical user interface (GUI) allows for data visualization, manipulation and sharing (Figure 2).

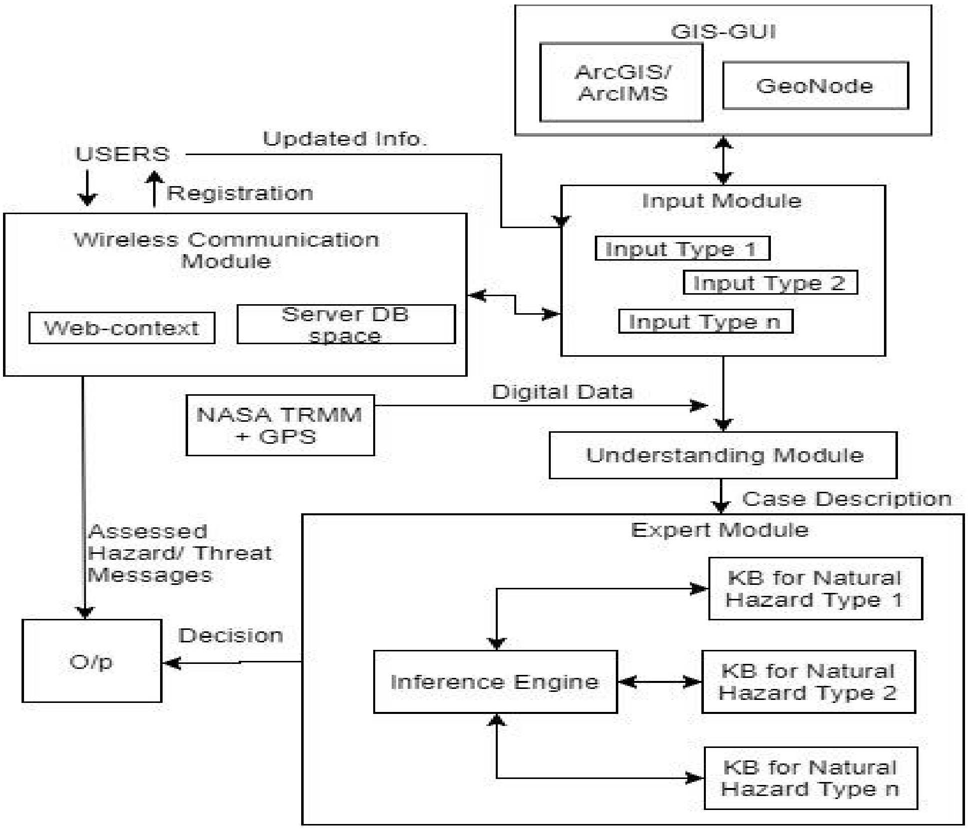

Figure 1 Schema SmaCiSENS modular architecture & data flow.

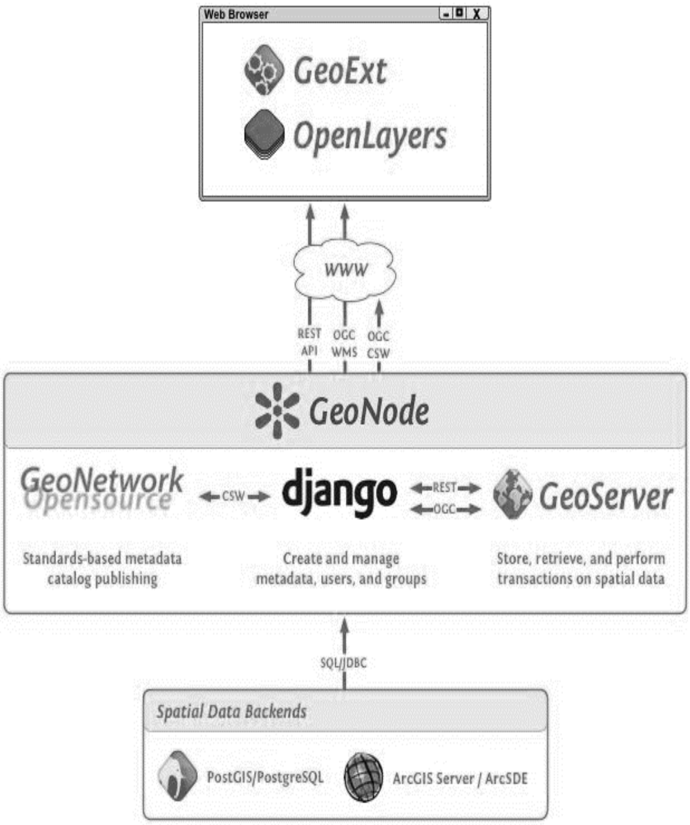

Figure 2 The Geonode, architecture used in Figure 1

The elements of Sensor Web Enablement (SWE) services could be understood as a service for retrieving sensor 'observation' data and meta-information, the so-called 'Sensor Observation Service', a service for sensor planning and executing tasks, called the 'Sensor Planning Service', a service that allows users to subscribe to specific alert types, known as the 'Sensor Alert Service', a service that facilitates asynchronous message interchange between users and services, and between two OGC-SWE services, called the 'Web Notification Service' (WNS). And that of web mapping (SDI) services: Web Map Service (WMS); Web Feature Service (WFS); Web Coverage Service (WCS); Web Map Context (WMC); Catalogue; Metadata. It is necessary to have a one-to-one correspondence between the elements of Sensor Web and SDI. A possible environment for establishing such interfaces could be GeoServer and GeoNode which provide an OGC compatible data store that can speak WMS, WFS, WCS and others in common formats like GML, GeoJSON, KML and GeoTiff. It can be connected to different spatial backends including PostGIS, Oracle Spatial, ArcSDE and others. The main research is on the inclusion of spatial components of geometry and topology with conventional analysis. Through the inclusion of SDI, spatial KBs, and spatial inference engine the goal of a spatial expert system can be achieved. The framework would work on open technologies such as GeoNode, GeoServer, Apache Kafka/Storm/Hadoop, Apache CloudStack, Open Street Map, PostgreSQL, PostGIS, Java, QGIS, TeraData, Presto, SPARQL, Python, CKAN, RDF, OWL and MongoDB to manage the top level, middle level and lower level architecture (Figure 3). This architecture makes a distributed spatial system possible where the location knowledge is advanced by utilising databases and ontologies (Figure 4).

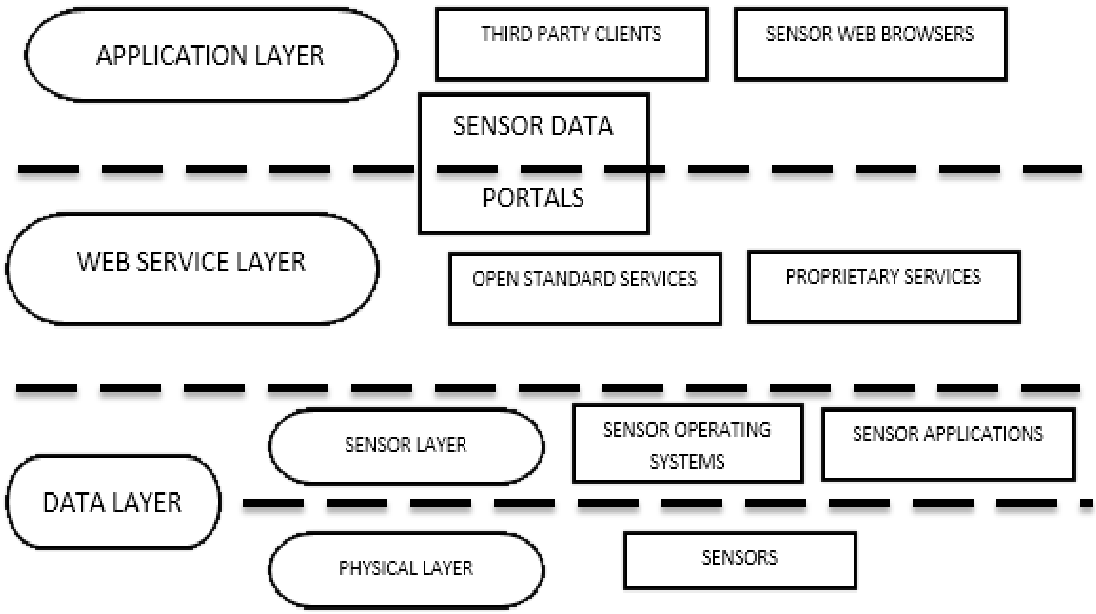

Figure 3 Capturing sensor web for SmaCiSENS.

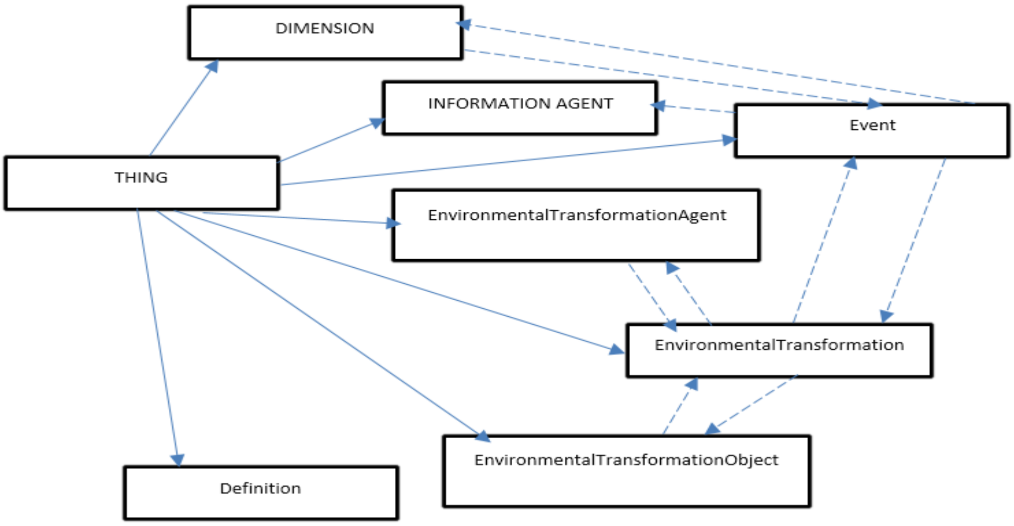

Figure 4 Sample ontology for Things (IoT).

The **topological** and **geometric** matching of big open data has been achieved in a moderately non-trivial case as reported in Laurini 2017; Bhattacharya and Painho, 2017. Additionally the ontological representation of natural phenomenon for expert systems has been developed for specific cases. The object-oriented ontological framework has been planned to be hybrid of object-based and rule-based.

4. Results

The joining of geospatial datasets and knowledge bases is required to utilize the complete set of information available in each of them. There are many open source geospatial datasets available such as GeoNames, Open Street Map, Natural Earth and to get a comprehensive dataset with the union of all available information it is important that such datasets are linked optimally without redundancy or loss of information.

5. Conclusions

SmaCiSENS can deliver an integrated sensor web and SDI which can solve a lot of challenges that stand-alone, disconnected, case-specific, and customized systems lack. SmaCiSENS addresses smarter living conditions for citizens and better management of resources for administrators and industries by spatially enabling the new data sources coming up. Expected users will be scientists developing systems like EU INSPIRE directives, OGC, ISO, public users and other agencies. The next level of capability for both SDI and sensor web would be to evolve into a new realm of a location enabled and semantically enriched Geospatial Web or Geosemantic Web but additionally with spatial analytics capabilities. The SDI has the capacity to integrate with distributed computing and database platforms and enable the Geospatial Web with capabilities of data democratization. Hence in conclusion, it is of pressing importance to geospatial studies to integrate SDI with Sensor Web. The concept of SmaCiSENS has to keep evolving to help overall development.

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7. Biography

Devanjan researches on geospatial technologies for sustainable development, planning and management of resources. A background in information technology and geomatics engineering his interests range from smart cities geo-informatics to SDIs and big geodata towards opening up smart cities by citizen participation, open data initiatives and collaborative development, using an open city toolkit.

Marco's research interests include Geographical Information Systems and Science, (Spatial) Decision Support Systems, Data Integration, Spatial Analysis, (Geographical) User Generated Content, Information Infrastructures, New Technology Implementation GIS Education and Distance Learning (e-learning). In terms of applications currently working on land use, transportation, smart cities, public participation and planning problems.

References

Bhattacharya D and Painho M (2017). Smart Cities Intelligence System (Smacisys) Integrating Sensor Web With Spatial Data Infrastructures (SENSDI), *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.*, IV-4/W3, 21-28, https://doi.org/10.5194/isprs-annals-IV-4-W3-21-2017.

Bröring A, Echterhoff J, Jirka S, Simonis I, Everding T, Stasch C, Liang S, Lemmens R (2011). *New generation Sensor Web Enablement. Sensors*. http://doi.org/10.3390/s110302652

Giuliani G, Nativi S, Obregon A, Beniston M and Lehmann A (2017). Spatially enabling the Global Framework for Climate Services: Reviewing geospatial solutions to efficiently share and integrate climate data & information. *Climate Services*. http://doi.org/10.1016/j.cliser.2017.08.003

Janowicz K, Schade S, Broring A, Kessler C, Maue P and Stasch C (2010). Semantic enablement for spatial data infrastructures. *Transactions in GIS*, 14(2), 111–129. Retrieved on 19/05/2017 http://doi.org/10.1111/j.1467-9671.2010.01186.x and http://carsten.io/tgis09_sel.pdf

Jazayeri M A, Liang S H L and Huang C Y (2015). Implementation and evaluation of four interoperable open standards for the internet of things, *Sensors (Switzerland)*, 15(9), 24343–24373.

Jung C T, Sun C H and Yuan M (2013). An ontology-enabled framework for a geospatial problem-solving environment," *Comput. Environ. Urban Syst*., 38(1), 45–57.

Laurini R (2017). Geographic Knowledge Infrastructure: Applications to Territorial Intelligence and Smart Cities, *1st Edition, iSTE Press, Elsevier*, p. 312. https://www.elsevier.com/books/geographic-knowledge-infrastructure/laurini/978-1-78548-243-4

Liang S H L and Huang C Y (2013). GeoCENS: a geospatial cyberinfrastructure for the world-wide sensor web. *Sensors (Basel, Switzerland)*, 13(10), 13402–13424. http://doi.org/10.3390/s131013402

Maguire D and Longley P (2004). The emergence of geoportals and their role in spatial data infrastructures, *Comput. Environ. Urban Syst.*, 29(1), 3-14.

Nativi S, Craglia M and Pearlman J (2013). Earth science infrastructures interoperability: The brokering approach, *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens*., 6(3), 1118-1129.

Overpeck J T, Meehl G A, Bony S and Easterling D R (2011). Climate Data Challenges in the 21st Century. *Science, 331*(6018), 700–702. http://doi.org/10.1126/science.1197869

Rössler O, Fischer A M, Huebener H, Maraun D, Benestad R E, Christodoulides P, Vlachogiannis D (2017). Challenges to link climate change data provision and user needs - perspective from the COST-action VALUE. *International Journal of Climatology*. http://doi.org/10.1002/joc.5060

SANY (2009). Sensors Anywhere (FP6 EU Project), http://cordis.europa.eu/project/rcn/79757_en.html (accessed: 15/05/2017).

Taylor K and Parsons E (2015). Where Is Everywhere: Bringing Location to the Web. *IEEE Internet Computing*. http://doi.org/10.1109/MIC.2015.50