

Article

Augmented Smart Cities Integrating Sensor Web and Spatial Data Infrastructure (SmaCiSENS)

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Abstract: 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). The paper proposes development of such a globally shared open spatial expert system(ES), SmaCiSENS, a first of a kind geo-enabled knowledge based(KB) ES for multiple fields, smarter cities to climate modeling. SmaCiSENS is integration of SW and SDI with domain KB on data and problems, ready to infer solutions. The paper describes an architecture for semantic enablement for SW, SDI; connect interfaces, functions of SDI and SW, and sensor data application program interfaces (APIs) to better manage climate modeling, geohazard, global changes, and other vital areas of attention and action.

Keywords: spatial data infrastructure; sensor web; geographical information system; smart cities; knowledge based system; expert system; spatial technologies

1. Introduction

Everything happens somewhere and some-when. 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. For the information to have an impact, it should be extracted in real-time or as near to real-time as possible. It is where location plays a vital part by rendering meaningful ways of understanding relationships between datasets quickly. The benefits of associating all developmental works with spatial attributes is universally acknowledged now, hence the next big leap will be to research a platform that manages real-time sensor data and provides critical spatial analytics. Both the aspects are size intensive and time consuming so an automated, compartmentalized yet integrated solution is the optimal way forward. 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. Spatial systems are needed for real time analysis and information on events and developments through Open Source Geographical Information System (OS-GIS) platform. Location is involved with everything, hence a spatial system is vital for better urban information management and spatial data infrastructure(SDI) creation. This also benefits when huge databases are created and consulted regularly for region planning at different scales through satellite images and maps of locations. There is need for spatially referenced data creation, analysis, and management. The paper

describes existing state-of-the-art towards development of a system with sensor-web(SW) access utilizing geomatics for sustainable societies. There has been a need to develop automated integral spatial systems to sense and categorize events and issue information that reaches users directly. 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. The previous works in this domain either focused on SDI and described an application, or on sensor web describing its application, mainly suggesting the development of such ideas but have not created an integrated system generalized enough for multi-case use. Most such theories have put forward specific instances of usability and hence the research has stopped at that. The current work describes the research gaps that could be overcome by the development of a generalized system SmaCiSENS and the broader research benefits arising out of the endeavor. The aim is to create a generalized location enabled platform for use-cases analysis in smart cities environments ranging from automated natural hazard monitor webGIS with internet-SMS warning, climate monitoring, to urban design, intelligent transportation systems, disaster management SDI.

2. Background

Systems have been proposed to handle the seemingly infinite and continuous data being generated but have fallen short of universal adoption due to several reasons, apart from lacking domain knowledge hence not being decisive, being offline or disconnected, case specific, temporally disjoint, and unintegrated. Further, to be fully accepted as a system the solution should provide decision-making information in least supervised manner. It should have some degree of autonomous functionality. With the advent of digital initiatives and information technology (IT) implementations like internet of things (IoT) and sensors, administrations today are faced with a challenge of large volumes of unstructured data coming from multiple disparate sources which are difficult to make sense of. Traditional systems report problems but are not capable of "showing them", which adds to the troubles of the administration in a situation where they are flooded with high volume data constantly. In many cases by the time administration has figured out the exact location along with an action plan, the ground situation would have already changed.

With the advent of sensors for monitoring, data collection is ubiquitous and is at unprecedented levels. The enormous volumes of data being collected constantly, create mounting challenges for optimal data processing and information retrieval [1]. Furthermore, the spatial aspect of data is being largely underutilized in processing, although the importance of spatial decision-making is now widely accepted [2-3]. 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 [4]. 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, and temporally disjoint. For example, in spatial data processing the major hurdles are that the different research groups globally are processing their data in silos, most of the time repeating same processes at each location, creating similar metadata each time, duplicating data, thereby falling behind the rushing stream of more incoming data [5-6]. 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 [7-9].

Spatial data are dramatically increasing in volume and complexity, just as the users of these data in the scientific community and the public are rapidly increasing in number [10-11]. A new paradigm of more open, user-friendly data access is needed to ensure that society can reduce vulnerability to spatial data variability and change, while at the same time exploiting opportunities that will occur [12-13]. The burgeoning types and volume of spatial data alone constitute a major challenge to the spatial research community. As a result, spatial scientists must not only share data among themselves, but they must also meet a growing obligation to facilitate access to data for those outside their community and, in doing so, respond to this broader user community to ensure that the data are as useful as possible [14]. Although research scientists have been the main users of these data, an increasing number of resource managers need and are seeking access to spatial data to inform their decisions, just as a growing range of policy-makers rely on spatial data to develop spatial change strategies. With this gravity comes the responsibility to curate spatial data and share it more freely, usefully, and readily than ever before [2,15].

Almost every decision that an individual or organization makes has some geospatial component. Almost any piece of information stored in a database has a location attribute. Sensor web(SW) and spatial data infrastructures(SDI) show great promise for building and maintaining a sustainable and changing society [16], which often needs to acquire spatial data through sensors and extract information using data analysis from SDI for better decision-making. The full potential of SW and IoT can only be reached with spatial intelligence integrated to them [17-18]. The geospatial industry is also trying to ride the big wave and exploit the market [19-20]. Moreover the concept of geo-data democratization is gaining momentum and is being described as the next big disruption [21-22]. But the long-term solution has eluded everybody so far and only case specific systems are being designed. Hence the motivation in SmaCiSENS is to develop a system using the core spatial technologies of SDI integrated with SW and IoT through standard architectures and utilising expert domain KBs.

To study a system designed on SDI, spatial KBs and SW, one has to survey each of them separately since hardly an integrated system exists [8, 23]. Considerable research and development has been carried out in SDI in past years [15, 24-25]. For example, Global Earth Observation System of Systems [26], enviroGRID [27], and COPERNICUS [28] provide high quality spatial data to users in user-friendly geo-visualization platforms. The Infrastructure for Spatial Information in Europe, INSPIRE [29] adopts service technologies for building its spatial information infrastructure. Other systems are high-level middleware services and domain-specific services for problem-solving and scientific discovery in infrastructures. For example, the Group on Earth Observation (GEO) Model Web initiative proposes to provide environmental models as services and integrating distributed models in infrastructures. Data provenance is added into SDI to capture and share the derivation history of geospatial data products, which is important in evaluating the quality of data products. Others propose the ontology approach for geospatial resource discovery in SDI. The Open Geospatial Consortium (OGC) is leading and coordinating the efforts of international organizations and enterprises to develop interoperable geospatial services. A series of standard-based interface specifications are already available, including Web map services (WMS), Web feature service (WFS), Web coverage services (WCS), catalogue services for the Web (CSW), and Web processing service (WPS).

Research on the spatial capabilities enhancement of sensor web, in a limited manner, are reported in [30-32]. There are some ongoing activities that are defining architectures and best practices for integrating sensor networks and observed data into existing and new SDI applications eg. Sensor Systems Anywhere, SANY [33], 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 [34] 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 [35] reported a primitive system of sensor and web mapping was discussed that worked on web mapping interfaces. SmaCiSENS goes much ahead of such efforts by combining various research threads into

one system having semantic KB robustness for a variety of data formats and sources, generalized interfaces for connectivity to spatial functions, a comprehensive and extensive SDI framework, and real-time data capture and processing.

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. Moreover, the ever-increasing repository of data are held in silos and are not shareable. The apprehension of losing data integrity also hinders the process of sharing. Typically, the fault is put on lack of easy tools to do that. Hence, we are looking at a two-faced problem where the solution would have to tackle not only data from multiple sources but also provide data management platform. Such a system would invariably need a spatial data infrastructure (SDI) as its backbone framework. And it should be able to harness the sensor web. Essentially the system would call for an integration of Sensor Web(SW) and SDI. Both SDI and SW are web-enabled so by the logic of extension it should be possible to connect SDI and sensor web. With the inclusion of domain knowledge base (KB) about the data and problems the system becomes ready to infer solutions. And the solution not only helps with administration, the situation holds true with many other areas of immediate attention and action, like climate modeling, geohazard management, global changes that are taking place, all these and more, have huge spatial implications that could be understood quickly with location intelligence through a geo-enabled expert system(GES). The best solution is implementation of a spatial knowledge based expert system (SKBES).

Geo-visual platforms discussed in [31] 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 [36-38] and the papers elaborate on the underlying logics. A geosensor web concept has been discussed in [30] with SDI in background but the discussion is theoretical and the development aspects from this theory have been put together by [38-39] setting the tone for SmaCiSENS. Further, the semantic requirements of a spatial system have been suggested in [31]. A detailed deployment of enhanced SDIs is presented in [40] 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 [41] and the functional and usable enhancements are proven. A proof of concept funded by NASA has described a geospatial sensor web architecture [32] but it has not been fully developed yet, pointing to the importance of the vision which has been picked up by this proposal addressing SmaCiSENS. Distributed architectures for socio-economic spatial studies have been proposed by [42-44] but a developed system has not been realized yet. Several schemas for cyberinfrastructure have been reported [45-46] but the development is still to be done. According to [8] 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.

The research questions that have been discussed through the present work are: i) how to build open source spatial ontologies for spatial phenomenon using causative factors ii) how to connect ontologies to intelligent inferencing logics iii) how to build specialized knowledge bases for a generalized spatial KBES iv) how to apply the system to automate procedures viz. urban and natural v) how to integrate sensor web(SW), other data sources and spatial data infrastructure(SDI) with open source technologies. On completion SmaCiSENS will deliver: i) integrated system working with sensor web and SDI (ii) automated decision support in real time for a) urban events b) natural events iii) generalized KB for spatial systems iv) algorithms for automated data processing, storage, estimation of spatial conditions, knowledge creation and maintenance v) new ontologies and spatial inferencing schemes for perpetuating expert knowledge. SmaCiSENS aims to address these challenges through developing a framework that houses data, metadata, understanding of the data,

knowledge to be applied on the data, and output from the data. SmaCiSENS would enable a distributed spatial framework that targets to deliver spatial decisions to start with but would administer spatial functionalities to a variety of social needs.

3. Methodology

The methodology of development of SmaCiSENS is modular in structure (Fig. 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.

Open-Source Geographical Information System (OS - GIS) and distributed architecture based platform such as GeoNode allows 3-dimensional (3D-GIS) development. To develop on an open source platform is extremely vital when huge databases are to be created and consulted regularly for region planning at different scales particularly satellite images and maps of locations. There is a big need for spatially referenced data creation, analysis and management. Some of the salient points of SmaCiSENS are that GeoNode is an open source platform facilitating the creation, sharing, and collaborative use of geospatial data (Figure 2). The project aims to surpass existing spatial data infrastructure solutions by integrating robust social and cartographic tools; at its core, the GeoNode is based on open source components GeoServer, GeoNetwork, Django, and GeoExt that provide a platform for sophisticated web browser spatial visualization and analysis.

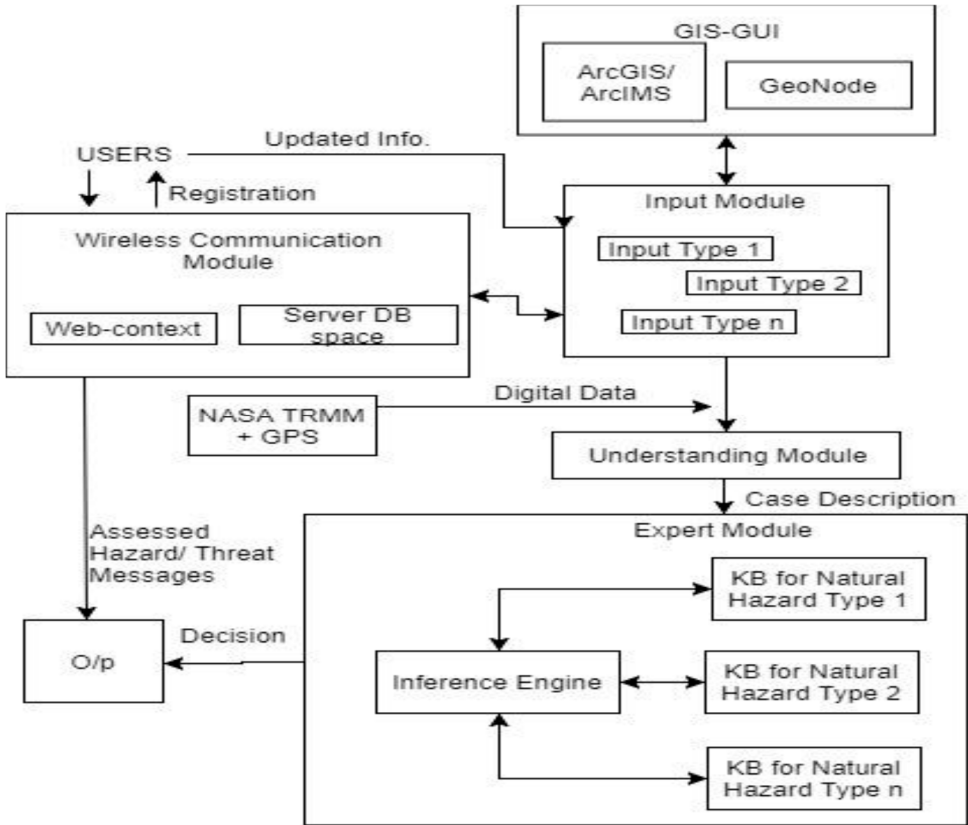


Fig. 1: Schema SmaCiSENS modular architecture & data flow.

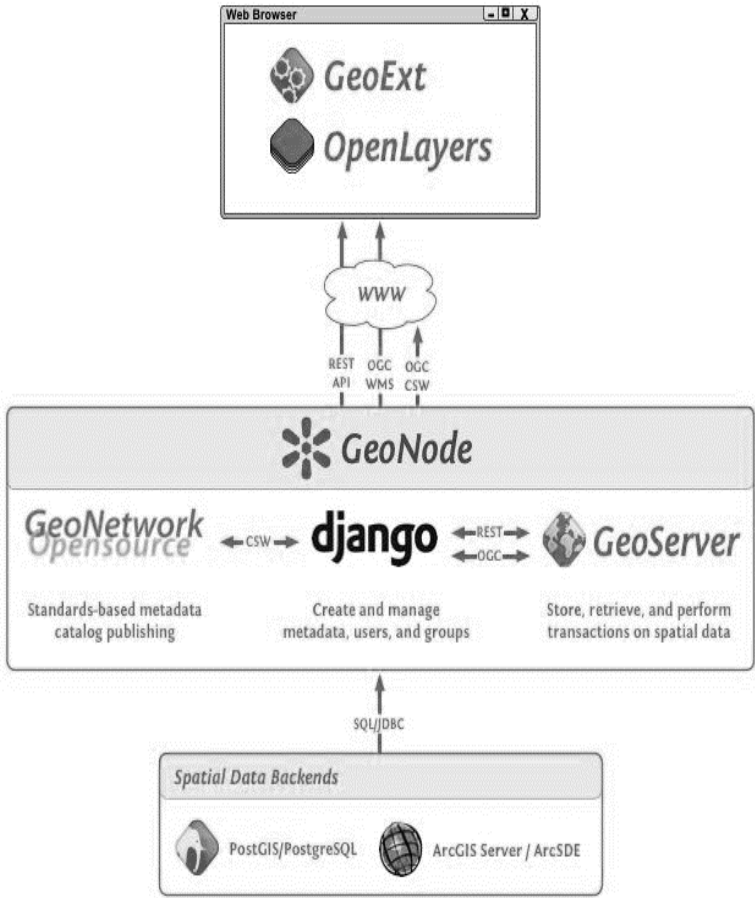


Fig. 2: The Geonode, architecture used in Fig. 1

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' (SOS);
- a service for sensor planning and executing tasks, called the 'Sensor Planning Service' (SPS);
- a service that allows users to subscribe to specific alert types, known as the 'Sensor Alert Service' (SAS);
- 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 Catalog, GeoNetwork, provides a standard catalogue and search interface based on OGC standards. It is used via the CSW interface to create and update records when they are accessed in GeoNode. It talks to the other components via HTTP and JSON as well as standard OGC services [36-38]. The integration of sensor web and SDI in open source domain could be achieved possibly by setting up one to one correspondence between their services through functions calling and methods calling.

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 (Fig. 3). This architecture makes a distributed spatial system possible where the location knowledge is advanced by utilising databases and ontologies(Fig. 4).

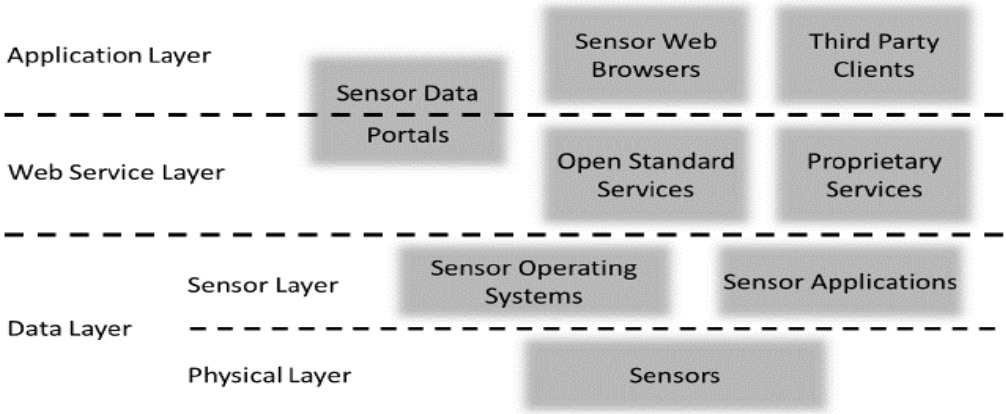


Fig. 3: Capturing sensor web for SmaCiSENS.

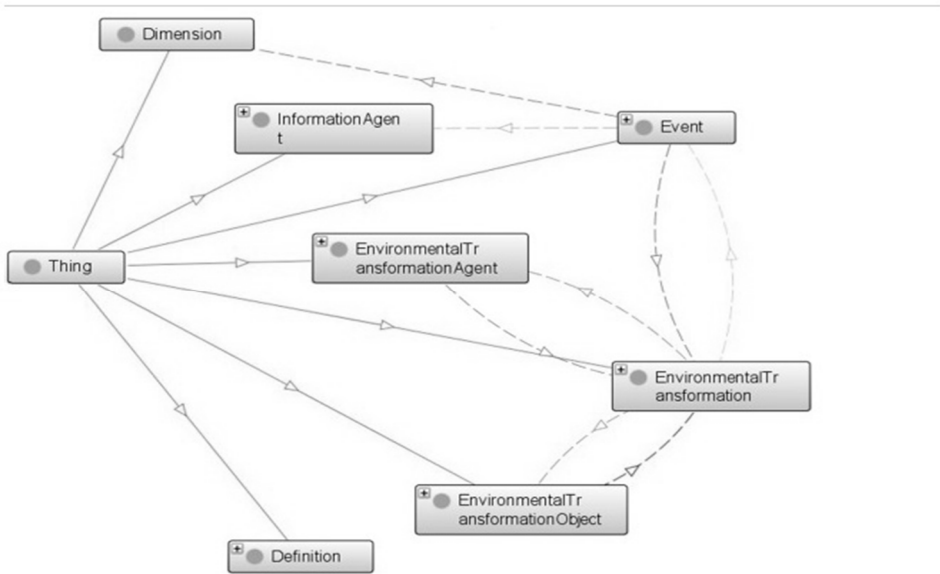


Fig. 4: Sample ontology for Things (IoT).

The **topological** and **geometric** matching of big open data has been achieved by the PI in a moderately non-trivial case as reported in [41]. 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 as reported by Pantazis [42-44]. The feasibility analysis behind SmaCiSENS involves significant works on the spatial data analysis algorithms [36-38] which benefit from the semantic logic being robust and research through SmaCiSENS has to proceed in similar directions. Also related works on user generated spatial data [39] and crowd sourced VGI prove the need for integrated platform for spatial analysis. The developmental research work under the proposal draws methodologies from the following previous works and delivers functionalities such as: integrating in a single platform multiple spatial data sources with analytics capabilities [36-38]; maintaining a spatial knowledge base with inferencing capabilities [41]; integrating sensor web with spatial data infrastructure [38]; providing a platform for visualizing and testing different models [39]; distributed processing of spatial big data [41].

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. One of the essential aspects of digital mapping and online visualization of maps is the prioritized ranking of geolocations with respect to their attributes and this facility is available as rank columns in Natural Earth data tables which need to be merged with other datasets for creating a complete and exhaustive mapping example. The online mapping systems facilitate many geospatial datasets which are used, created, edited and maintained including the use of GeoNames as the layer for populated places. Many of the geolocations on digital maps are not classified for importance because of the lack of additional information such as population or administrative level. A way to give an importance scale to the names is by linking the GeoNames to other datasets (OSM, natural earth). OpenStreetMap data provides a limited number of place

classifications (such as region, town, village). For the best cartographic results we need classes that are a little more opinionated about how they rank cities. Questions such as "Which of the labels should be visible" and "how much should this label be emphasized" are important decisions that need to be made in cartographic design. To do this the present research is to join additional information from Natural Earth, GAUL, SALB, GADM etc. The challenges faced include geometry searching, matching, buffer determination, local regional naming text inclusion and accuracy. This has been achieved by the current research work where presently GeoNames, Natural Earth and Open Street Map data tables have been merged with the union of all their attribute columns resulting in a complete geospatial dataset with place accuracy of atleast 95% for any given country dataset. The data tables at global level consist of hundreds of thousands of rows with each row depicting a geolocation. The geometry, name and geo-id complete and fuzzy searching and matching around a buffer of 50 km took a minimum of 30 secs to maximum 1 minute in a commodity computer with 2 GHz, 2 GB memory, according to size and complexity of the query run for a country which could have a list of points ranging from a dozen to several hundreds. The future aim is to ultimately do this for global datasets to create an all-encompassing geodata bank having such information as administrative, political, ecological details from important databases as GAUL, SALB, GADM etc.

5. Discussion

SmaCiSENS will deliver the current state-of-the-art with respect to sensor web data utilization and spatial data infrastructure (SDI) applications for developmental activities in smart cities. Further it is seen that singly as a technology sensor web as well as SDI each is stagnating on their own. The need at present is to explore possibilities of merging the two so that each can feed on the strengths of each other and synergize their respective fields. For the future smart cities this could be a huge advantage as we look towards harnessing the potential of ubiquitous sensor data through intelligent apps. The apps would get a ready framework in SmaCiSENS for data sources as well as spatial processing platform with cloud, virtualization and data federation capabilities. It is evident that within a short time, the vast majority of all geospatial content will be from sensor networks and systems, with the volume of available sensed content orders of magnitude larger than at present. SmaCiSENS poses a very big challenge but it is high-gain as well. The provision of a fail-safe process is also there, just in case, where we develop SmaCiSENS on the specific applications dataset only.

Optimal decision making relies not only on the ability to fuse and apply core geospatial information, but also the ability to discover, access and apply real time information from sensors and sensor networks. A gamut of information about the environment - land, air, water, weather, climate and natural and man-made risks can be harnessed by seamless and rapid access to sensors. In addition, sensors are critical components of building, transportation, utility and industry infrastructure. The ability to harness and render this information in a location context is a major challenge. Until recently though, there were no facilitating standards to make it easier to discover, access and integrate this information. Therefore, a consistent set of encoding and interface standards are mandatory for adapting and integrating sensor networks into an SDI application. Both, SDI (web mapping) standards and sensor web enablement standards from OGC, have to meet at a common ground and connect together. The integration of sensor web and SDI in open source domain could be achieved possibly by setting up one to one correspondence between their services through functions calling and methods calling.

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. 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 integration can

be done through merging the common OGC interfaces of SDI and Sensor Web. Through SmaCiSENS, Sensor Web and SDI are going to keep expanding in the next decade. Sensors are going to be so ubiquitous that similar to the world wide web the addition of vast number of sensors will keep happening like new data sources of present internet. The concept of SmaCiSENS has to keep evolving to help overall development.

6. Conclusions

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. Currently the vast capacity of spatially referencing newer sources of data and information is not being done. SDI concept has hit a roadblock towards further development. One very smart and efficient way forward is to integrate SDI with new data sources sensors that are coming up and creating a sensor web of spatially oriented information. The results are to be published in reputed open journals and international conferences. The methodologies employ open source techniques. Open licensing is the way to future development. The project is data intensive so interactions with data providers and sources is prominent. There must be meaningful interactions. The results of data processing and infrastructure building will be of interest to current and future stakeholders so that has to be formulated according to the university rules. Expected users will be scientists developing systems like EU INSPIRE directives, OGC, ISO, public users and other agencies.

SmaCiSENS can have very attractive market and research and academic scope in spatial developments. Applicable to virtually all activities of commerce and governance. Sensor Web and SDI are going to keep expanding in the next decade. It is envisioned that sensors are going to be so ubiquitous that like the WWW the addition of vast number of sensors will keep happening like new data sources of present internet. The concept of SmaCiSENS has to keep evolving step by step in the years to come to help overall development of a nation. The future scope is immense for a system such as SmaCiSENS what with various applications such as defense application of analyzing different sensor data; health applications of medical sensor data; and last but not the least, spatial change studies globally.

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