A semantic data model for sensory spatio-temporal environmental concepts

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ABSTRACT

Nowadays, the well-known Resource Description Framework (RDF) forms a rather general method for web resources' conceptual description or even for generic information modeling. However, RDF's capabilities are challenged once used to effectively represent non-thematic metadata, e.g, in the form of spatial and temporal objects deriving primarily from sensor information. In addition, Wireless Sensor Network (WSN) is considered today to be a widely adopted platform, related to environmental monitoring and decision making applications. Specifically, exclusive subjects, such as environmental degradation and optimized agriculture, provide a scope of applied research on the basis of multilevel semantic data analysis. Observations and sensors are the core of empirical science and their implementation (i.e., the increasing volume of data, heterogeneity of devices, data formats and measurement procedures) produce a large volume of unsupervised data. Thus, the prevailing growth of sensing systems has currently led to the development of defined interoperability among standards on web semantics. In particular, Semantic Sensor Network (SSN) ontologies prospect on modeling the capabilities and properties of sensors, monitoring procedures and observations. Furthermore, the dynamically evolving natural phenomena require proper conceptualization of environmental change and monitoring agents. Consequently, this paper describes an inaugural attempt to create a conceptual framework of spatially and temporally-enabled environmental variables for sensing systems.

KEYWORDS

semantics; ontology model; sensors; environmental monitoring;

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1 INTRODUCTION

In principle, environmental monitoring implements procedures of knowledge extraction through Earth and Sensor Observation techniques. Subsequently, a fundamental factor of empirical science monitoring consists of an explicit representation of physical events revealing the causality of physical events [1]. On the other hand, "machines" - under the generic auspice of computer science - support and preserve acquisition and management of information onto accessible semantic agents [22].

The goal of integrating the task of monitoring, physical computing, IT and knowledge representation has been served in the past by SSN ontology and it's many variations. Developed initially by the W3C semantic sensor network incubator group (SSN-XG) and based on an OWL 2 ontology, SSN describes sensors and observations as capabilities, measurement processes, observations and deployments [5]. SSN was developed with the purpose of storing and accessing sensor-related data, equipped with syntactic interoperability and semantic compatibility. Particularly, it has adopted sensors and sensing systems assisted by semantic technologies for managing, querying and combining sensors and observation data [5].

Ontology models related to monitoring applications facilitate data discovery and retrieval along with network analysis and interoperability. Apart from operational tasks, environmental monitoring requires structures that accommodate the complexity of spatial coverage and temporal frequency pertained to physical variables. Complex natural phenomena bare spatio-temporal characteristics that determine their consequence on a given physical system. Therefore, spatio-temporal evolution of the phenomena is optimally tracked by semantic inference [9] through identifying the response phase of the event management cycle.

Information related to environmental conditions bares particular composition and operates within a known time and location. Therefore, continuous recordings are a pre-requisite to a sensing system that captures physical parameters. The variability of climate and temporal changes can though be detected and concluded on how the ontological context of every natural element are changing through temporal steps. Natural phenomena offer a conceptual framework for semantic study, especially through the correlation of accompanied variables (i.e., time, location etc).

In this direction, IoT applications offer variability and customization mainly via WSN platforms. WSN capabilities allow for data acquisition and semantic processing [3] with higher spatial and temporal resolution due to their distributed operation (sensor nodes and base stations). Therefore, a common terminology for monitoring services is essential, in order to facilitate the intricate patterns of dynamic natural phenomena [20]. Additionally, operational and monitoring services with time relevant structure are indispensable factors of machine interpretable data models [9].

This work captures a initial data model based on a already deployed monitoring system that describes environmental monitoring as an

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observation derived from spatio-temporal recordings. The proposed ontology is focused on the recording of physical parameters of physical systems [1] in order to capture a series of snapshots on varied spatial and temporal frames through monitoring particular aspects of the environment. The model is based on a structure operating within an OWL[2] framework. This describes parameters, sensor's operating conditions, general environmental factors and specific recordings relevant to a broad aspect of monitoring criteria.

The rest of the paper is structured as follows: In Section 2, we present related research work concerning various concepts of semantic ontologies. Then, in Section 3, we present in detail the proposed model of environmental monitoring. Finally, a short discussion regarding the potential implementation of the aforementioned concept within a "smart viticulture" paradigm, together with drawn conclusions and future prospects of the proposed framework are presented within Section 4.

2 RELATED WORKS

In the framework of our research study, logical conclusions drawn from temporal information form a supplemental semantic dimension for environmental applications. Thus, time as a factor on Semantic Web data structures is mainly introduced as temporal annexes to OWL and Description logic, encoding methods on temporal data models and preservation tools on graph versions [22].

Koubarakis and Kyzirakos [12] focused on representation methods of temporally varied thematic and spatial information. Their main contribution is bounded in the use of "constraint" elements for querying and reasoning spatio-temporal data. Specifically they formally defined their data model (*stRDF*) and query language (*stSPARQL*) as extensions of existing protocols and presented the according semantics. Their work demonstrates that their RDF and SPARQL extensions can be incorporated within current work related to sensor network ontologies under perception of the Semantic Sensor Web. Subsequently Kyzirakos et al [14] presented the open-source geospatial semantic DataBase Management System (DBMS) named *Strabon*. The system is able to store linked geospatial data through stRDF and stSPARQL by evaluating large amount of data and allowing compatibility with PostGIS[1].

Sensor functionality within the discovery of system's available assets by describing a spatio-temporal model for objects and processes is captured by Ibrahim et al. [11]. The authors based their model on the SSN ontology and identified factors that lead to environmental reasoning on the basis of real world variability. Additionally, the produced model enabled the optimal utilization of a WSN through network's dynamic management of both operation and role assignment.

Nikolaou et al. assess the subject of managing time related linked geospatial data through *Sextant* web-based tool [17]. The tool is capable of exploring spatio-temporal data along with managing and producing thematic maps compatible with Open Geospatial Concortium - OGC[2] and standards and GIS applications. Their concept presents interoperability between several geospatial platforms and file formats (e.g., SPARQL, KML, GeoJSON etc).

An approach to ontological modeling that concerns change detection on RS images was proposed by Ghazouani, Messaoudi and Farah [8]. They proposed a conceptual framework that contains ontologies on the basis of spatial, temporal and semantic relations between elements on satellite imagery. Hence, spatio-temporal objects could be recognized in order to produce better understanding on geospatial phenomena through a specific time frame. Additionally, the authors implemented a multilevel approach on representation methods, which consists of change detection, geographic processes and conceptual ontologies.

Semantic Sensor Web (SSW) allows the description of sensor data with rich semantic context. Al Rasyid et al [21] implemented a web platform that incorporates physical readings (Gasses microparticles) into a semantic web platform. In addition, they deployed a Restful service API[3] to obtain data from varied sources and thereinafter stored in RDF/OWL form. Their work allows accessibility and observation of the data by users by implementing web technologies and ontology modeling. The visualization and analysis of statistical data on a geographic map is implemented by Mijovic et al. by representing spatio-temporal information within a predefined semantic vocabulary [16]. More precisely, authors deployed the OWL Time ontology that explicitly defines the exact time delimiter and provides additional temporal information. Furthermore, they introduced the RDF Data Cube Validation component in order to evaluate the correspondence of the produced maps with the W3C Standards. In summary, spatio-temporal analysis may be combined with SPARQL endpoints into single statistical map layers.

The concept of inter-connected IoT nodes is assessed by Le-Phuoc et al. with the visualization platform *Graph Of Things -GoT* [15]. GoT is a graph-based platform that provides representation and semantic capabilities on sensors, data and observations. Furthermore, the platform is a "Live Knowledge Graph" that correlates monitoring data streams on the purpose of implementing an efficient exploration and discovery methodology on IoT data. Additionally, GoT employs existing RDF and Linked Stream data models through semantic infrastructures.

The work of Hu et al [10] is related with the study of monitoring harmful algal blooms (HABs) in aquatic ecosystems. They proposed a "Web-based system for near-real-time tracking of red tides caused by the toxic *dinoflagellate Karenia brevis*" by employing an interface with three type of satellite-imagery and numerical data products combined from different sources. More specifically, near-real-time monitoring of algae biological processes in a user-friendly methodology superimposed on a web portal based mainly on algorithmic development.

A different approach on spatio-temporal semantics has been introduced by Kurte et al. [13]. They presented a methodology of capturing spatio-temporal changes during flooding disasters. The authors proposed the *Dynamic Flood Ontology - DFO* through the use of Remote Sensing (RS) imagery to track evolution on land use at the region of interest. Accordingly, the evolving area during the event is classified as dynamic "flood inundation status" and "land cover" properties.

Another aspect of functional management of WSN concerned the

[2]https://www.w3.org/OWL/
[1]http://postgis.net/
[2]http://www.opengeospatial.org/
[3]Application Program Interface

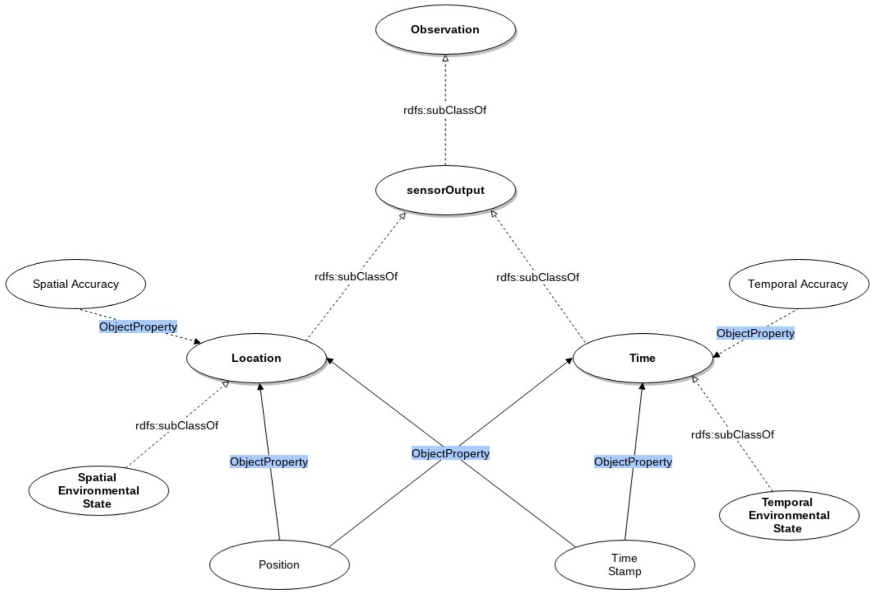

Figure 1: Overall ontology model

study of D'Anniello et al. [6]. They introduced a middle-ware between users and physical devices in order to define sensor readings and adjust quality requirements accordingly. This "virtualized quality aware sensor network" contains represents virtual and physical nodes and recordings by a semantic layer that, also, includes the system evaluation processes. Specifically, the assessment is implemented by defined association rules for readings' estimation to compensate for failed recordings and missing data.

Duy et al[7] proposed a model for environmental related streaming data among cross-domain knowledge exploiting the SSN's framework. They mainly dealt with heterogeneity of sensory data through a "light-weight" ontology and a RDF modal for streaming data. In particular a set of identification URIs have been presented that support several data types and deployed with real conditions on top of a Graph Store server. The authors scientific contribution is a novel architecture that describes the transformation of data from raw state to semantically enriched. This enhances the re-usability of sensor data and information with the added benefit of conglomerating monitoring information with different factors of Metadata.

Assessing information and within semantic web is a subject studied recently by Nouira, Chentiti-Beclhadi and Braham [18]. They particularly proposed an assessment analytics architecture by introducing an ontological model in order to track and annotate their related data. By using web services and semantic web technologies the authors managed to form an architecture based on three layers: a) Learning context, b) Assessment data and c) Semantic. Furthermore, their theoretical ontological model operated on the basis of structuring logical formalism by performing logic rules that support inference mechanism.

The aforementioned works presented the notion of temporal and spatial variability in relation to semantic ontology modeling for natural phenomena. The decisive element on each approach is the provided method to which information is treated for advanced reasoning. Furthermore, network schemes are describing the according ontologies and concepts, in addition to system operation and observation. On the contrary, we propose an elementary concept on the basis of event evolution divided in two semantic layers, location and time, that is ordained in the basis of environmental system. Moreover, the graph is taking into consideration qualitative parameters of a sensing system in the form of accuracy.

3 MODELING ENVIRONMENTAL MONITORING

The herein proposed model combines analytic environmental monitoring and spatio-temporal conjecture within a sensor network framework. Environmental parameters are assessed dually as static and dynamic suggesting their local and temporal characteristics. The general conception depicted in Fig. 1 separates sensor recordings among Location and Time, which subsequently produce the Spatial and Temporal state of the environment. Each observation contains the Sensor Output that consists the sum of recordings, along with sensing technical specificities described as accuracy (spatial and temporal). The output represents the given location (i.e., Latitude and Longitude) and time accompanied by a set of captured physical parameters. The main purpose of this ontology is to present a novel conceptualization of an integrated environmental monitoring system.

The effect of natural phenomena is optimally captured within a given temporal resolution [4]. These variations are affiliated with natural event development, therefore recording variables are dependant of their distinctive temporal identifier (i.e., time-stamp). The variables are classified into particular fields of environmental systems, taking into consideration their specific characteristics (Fig. 3). Particularly, each recording is considered as a Temporal Environmental State captured on a given time interval. Furthermore, each State contains three sub-classes including the environmental

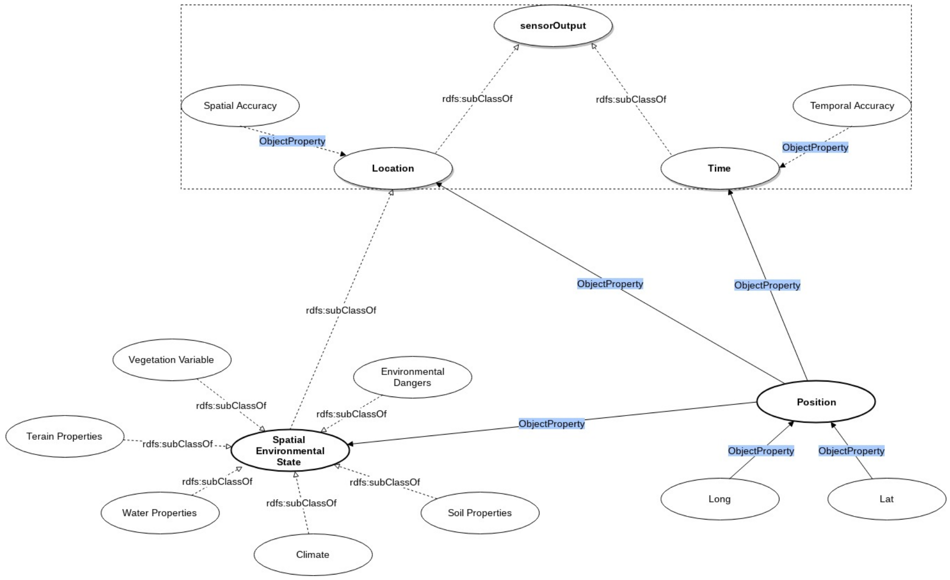

Figure 2: Model's spatial aspects

systems (Aquatic, Terrestrial and Atmospheric) and subsequently by their respective sensor measurement capabilities. The proposed model is quite flexible and can be adjusted to the required research framework, i.e., one or more of its sub-classes may be altered accordingly.

Natural elements preserve process dependant characteristics, thus require contrasting approaches in relating to the scientific inquiry in place. Therefore, the environment is segregated into climatic, solid earth and life bearing systems, each of these are recognized by their particular characteristics. Successively, environmental research requires specific classification due to existing particularities on natural processes and monitoring methodologies. Hence, on the purpose of specialized environmental observation we established a set of subordinate categories that describe the dynamically observed environmental state (Fig. 3). These are atmospheric, aquatic and terrestrial, and each contains further distinctive subclasses that describe processes and quantities.

Apart from event development through time, every location bares specific properties regarding the general conditions of the specific environmental system. These properties are designated as the aquatic, soil, climatic, vegetation, geomorphological features of a given position the sensor is located or been on the time of recording (Fig. 2). Moreover, spatially relevant variables produced by stationary sensing nodes are used in the purpose of further correlation between the general environmental state and real-time recordings. In relation to this representation model, a system of specialized recording equipment is deployed in the field [23]. The devices are operating interactively with model design and creation under the scope of systemic integration and are capable of producing customized real world data.

4 FUTURE WORK AND CONCLUSIONS

It should be clear by now that our current research attempt focuses on the first step of a broader goal, i.e., the one of efficiently utilizing sensory spatio-temporal environmental concepts through an integrated semantic data model to achieve meaningful and qualitative better raw data handling. In order to demonstrate the model's efficiency, we plan to apply it on a viticulture data optimization task; the latter is currently deployed on site with the aid of state-of-the-art meteorological stations and soil sensors implemented with the aid of Raspberry Pis microprocessors[4]. The main scope of the particular application will be to collect microclimatic features and parameters on vineyards for the purpose of their quality assessment. In this framework we shall utilize various web, computer, sensors, communication system and software components and the overall system will be designed to collect a small sample of local weather data through a network of connected weather stations and soil sensors from selected vineyards. Thus, the application of the aforementioned model will produce intelligent farming knowledge in the direction of optimized, smart viticulture activities.

Still, in its current form this paper presents a preliminary ontology model for environmental monitoring that identifies the system's measurement capabilities under the scope of spatial and temporal observations. The herein presented model described functional parameters and physical concepts related to natural systems and their processes. Furthermore, its technical parameters are considered on the basis of sensor accuracy and is divided into a dynamic (temporal) and a static (spatial) environmental state. In conclusion, the proposed model in the form of a graph manages to successfully describe environmental monitoring as a dynamically evolving process with several variables and assumptions. A further future development of the model is planned in order to portray classes, relations and instances in detail, among the integrated monitoring

[4]http://raspberrypi.org

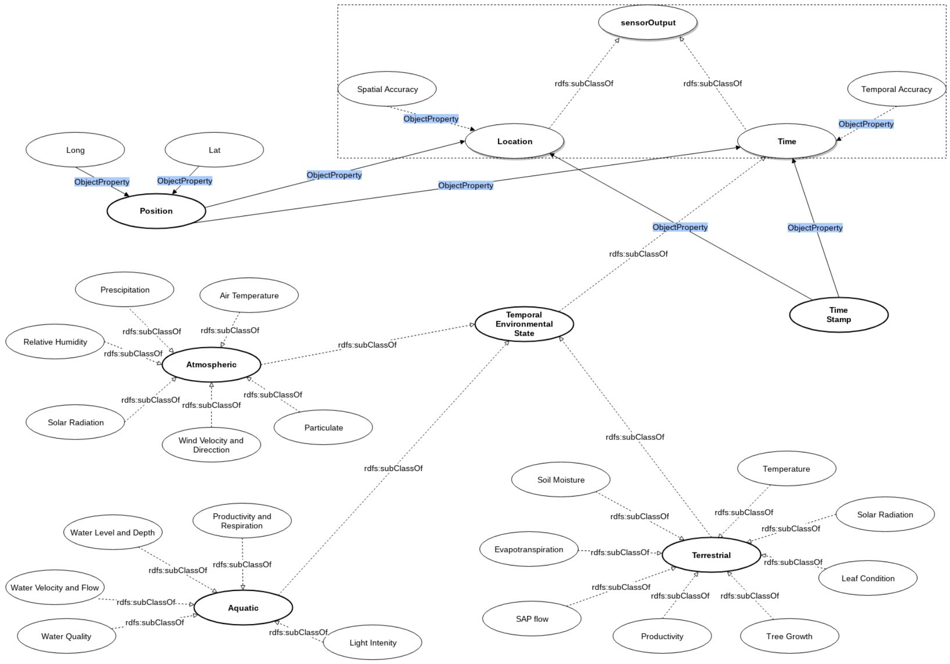

Figure 3: Model's temporal aspects

domain [19]. Furthermore, the research will be driven by existing standards on the direction of implementing a common platform on automated environmental monitoring. Thus, the proposed system will evolve in accordance to the specifications of inference engines [2] on the purpose of automated environmental assessment.

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