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# A Universal Ontology for Sensor Networks Data

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**Abstract –** *In this paper, we present our work towards the development and evaluation of an ontology for searching distributed and heterogeneous sensor networks data. In particular, we propose a two layer prototype ontology that utilizes the IEEE Suggested Upper Merged Ontology (SUMO) as a root definition of general concepts and associations and two sub-ontologies: the sensor data sub-ontology and the sensor hierarchy sub-ontology. The proposed ontology was implemented using Protégé 2000 and eventually evaluated using the RDQL language (RDF Data Query Language). The performance analysis demonstrated the ability of the ontology-based search to improve both the precision and recall rates and enhance the interoperability between different sensor networks domains through the use of the universal SUMO ontology.*

**Keywords –** *sensor networks data, SUMO, ontology design, IEEE 1451, semantic representation.*

## I. INTRODUCTION

Sensor networks have gained a significant research attention in the last decade. They deploy large number of heterogeneous sensing nodes for capturing environmental data. The ability to search, task, control, and fuse data collected from heterogeneous sensors can significantly facilitate the discovery of added value knowledge that is unreachable using classical information retrieval techniques [1-2]. Furthermore, integrating higher and lower-level sensors (such as video cameras complemented by temperature and luminance sensors) could reveal additional knowledge about a target event with an increased confidence in a hypothesis.

Therefore, heterogeneous sensors (either wired or wireless), with vastly different capabilities such as temperature, acceleration, GPS, light, pressure, magnetic field, radiation and acoustic measurements, are pending integration. In this paper, we extend our design, initially proposed in [3], and implement a universal ontology to retrieve ALL-and-ONLY relevant sensor data. The envisioned goal is to adopt a standard upper ontology (SUMO) that will promote data interoperability, information search and retrieval, automatic inference, and extendibility. Different domain sensor networks can define their own ontologies and link them through the upper SUMO ontology.

The remainder of the paper is organized as follows: section 2 presents the rationale of the present work and highlights existing related work. In section 3, we provide a brief overview of the methods and infrastructure used in the prototype ontology. Section 4 discusses preliminary evaluation of the current implementation and possible future avenues for this research.

## II. RELATED WORK

Several researchers have investigated the theory of semantic web and ontologies yet little attention has been paid to semantic representation of sensor networks data. The idea of using ontology-driven information system for sensor networks was introduced in [2]. The authors presented how to capture the most important features of a sensor node that describe its functionality and its current state. The ontology includes a description of main features of sensor nodes such as CPU processing power, memory, power supply, and radio and sensor modules.

Few attempts were made to build ontology-based sensor networks nodes (for example [4] and [5]) to manage network routing behavior. For instance, the researchers in [4] define an ontology that integrates high level network features for customizing routing behavior. The developed ontology describes the network topology and settings, sensor description, and data flow. There is no mention of sensor data. Subsequent work like [6] is an effort in the direction of facilitating semantic service-oriented sensor information systems. The notion of ontology used in this research was to capture information about physical entities and their corresponding relationships.

One of our references for collecting sensors features was the IEEE 1451 standard [7]. As a matter of fact, IEEE 1451 is a family of proposed standards that provide generic interface between a transducer and external network protocol. The standard uses Transducer Electronic Data Sheet (TEDS) to capture sensor characteristics, such as transducer identification, calibration, correction data, and manufacturer-related information. A semantic web compatible ontology, named OntoSensor, was developed in [8] using a well known ontology editor, Protégé [9]. OntoSensor includes knowledge models for the data acquisition boards, sensing elements, and processor/transmitter units. The concepts and associations defined in OntoSensor are instantiated in distributed repositories that are updated by the base stations of the network.

## III. THE PROPOSED ONTOLOGY

The proposed universal ontology, as shown in Figure 1, comprises four components: the SUMO ontology, the Sensor Hierarchy Ontology (SHO), the Sensor Data Ontology (SDO), and Extension Plug-in Ontologies (EPO). Notice that the SHO and SDO ontologies reference and extend the SUMO ontology to facilitate automatic data fusion and inference in distributed and heterogeneous sensing environments.

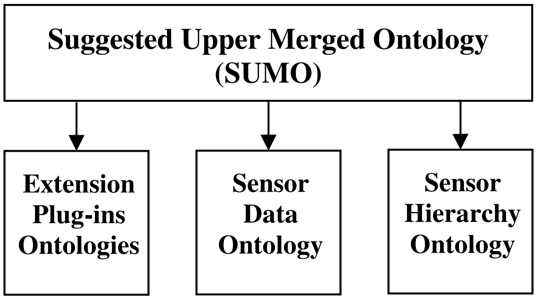

Figure 1. Proposed universal ontology

### *A. The SUMO Ontology*

The SUMO ontology was created by merging publicly available ontological contents into a single, comprehensive, and cohesive structure [10]. Using a common standard ontology implies shorter development cycles, easier and faster integration with other contents, and more stable and robust knowledge systems. The SUMO ontology comprises low-level details ontologies for various domains such as computing services (networks, systems, and services), finance, geography, time, economy, and transportations, among others.

### *B. The Sensor Hierarchy Ontology (SHO)*

Currently the SHO includes knowledge models for the transducer (sensors and actuators) elements, data acquisition units, and data processing and transmitting units. It contains a hierarchy of transducer classes and describes its attributes and capabilities. The data model for a given transducer contains meta-data such as the measurement and/or output range, accuracy and type, as well as physical properties and calibration methods. A snapshot of the current implementation of the transducer SHO is shown in Figure 2.

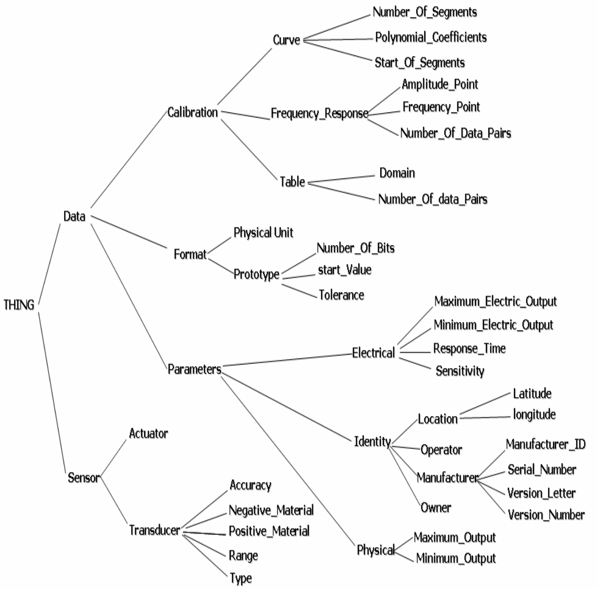

Fig. 2. Taxonomy for the *Sensor Hierarchy Ontology (SHO)*

### *C. The Sensor Data Ontology (SDO)*

The goal of the SDO ontology is to describe the dynamic and observational properties of transducers data that goes beyond just describing individual transducers. The ontological model describes the context of a sensor with respect to spatial and/or temporal observations. Furthermore, the SDO utilizes the notion of virtual transducer as a group of physical ones to provide abstract measurements/operations. For instance, a temperature sensor, a humidity sensor, and a wind speed sensor may collectively monitor weather as “weather sensors”.

### *D. The Extension Plug-ins Ontologies (EPO)*

To extend the capabilities and behavior of the proposed universal ontology, the EPO plug-ins allow developers to integrate domain-specific ontologies with the universal ontology. Each plug-in ontology should implement the knowledge representation for a particular domain of sensor data and networks and establish the connection with the SUMO ontology. This enables interoperability and knowledge sharing among sub-ontologies in the ontology architecture.

## IV. IMPLEMENTATION AND DISCUSSION

The SUMO ontology can be freely downloaded from [5], and is available in KIF, OWL, LOOM, and Protégé formats. It currently includes 965 terms and 3742 assertions. We have used the Protégé SUMO version since our sub-ontologies were implemented using protégé. Protégé is an ontology development tool that is used to build and edit the ontology. As per validation, we have used the RacerPro reasoner because of its strong reasoning capabilities and interoperability with protégé. RacerPro automatically computes an inferred class hierarchy (called asserted ontology) based on the description of classes and relationships. If both class hierarchies match, then the ontology is consistent and valid (usually referred to as subsumption test).

To instantiate the SHO ontology we used the WordNet lexical reference system [6], developed at Princeton University. WordNet is essentially a large lexical database where English words are grouped into distinct sets of cognitive concepts. On the other hand, the SDO was instantiated using random sensory data collected from sensors databases.

Currently, we are in the process of evaluating the semantic-based search approach using two measures: recall rate and precision rate, defined as shown in equations (1) and (2), respectively. It is worth mentioning that a search system should attempt to maximize both precision and recall rates. Next, we plan to compare the performance of this approach against traditional syntax-based search.

$$\textbf{\textit{Recall Rate}} = \left( \frac{\textbf{\textit{Number of relevant items retrieved}}}{\textbf{\textit{Total number of relevant items}}} \right) \qquad (1)$$

$$\textbf{\textit{Recall Rate}} = \left( \frac{\textbf{\textit{Number of relevant items retrieved}}}{\textbf{\textit{Total number of items retrieved}}} \right) \qquad (2)$$

To compute the recall and precision rates, we are using RDQL language to query the knowledge base and find out relevant results. We are currently testing with three queries to judge the knowledge base, as shown in Figure 3. For example, query 2 retrieves all entities that have both a sensor as well as actuator functionality. A simple ontology for traffic modeling and analysis was developed whereas the pollution ontology was integrated through the SUMO universal ontology via EPO.

The scenario used to proof-concept the semantic based approach assumes that a network of traffic, pollution, and weather sensors are collocated in the same physical area (the city of Ottawa in our example). This data is heterogeneous in the sense that it belongs to different domains. The ontology approach helps in utilizing low level sensory data and mapping them to a high level query. For instance, one possible source of pollution is the existence of high traffic. Therefore, given that the pollution concept is mapped to the traffic concept through the relationship “a_result_of”, the search for high polluted areas will be enhanced by searching for traffic sensors as well. A portion of an actual running query is shown in Figure 3.

```
SELECT ?Locname
Through
        SPO(?Sensor, http:// www.Owl
       ontologies.com/Sensors.owl
       #Traffic :a_result_of, “apr”)
       Operation at locathost:traffic
       Interval 1000
Through
       SPO(?Sensor, …)
Where (?trafficlevel > 50),
        (?pollutionlevel>20) …
```

Figure 3.A sample RDQL query used to measure recall and precision rates

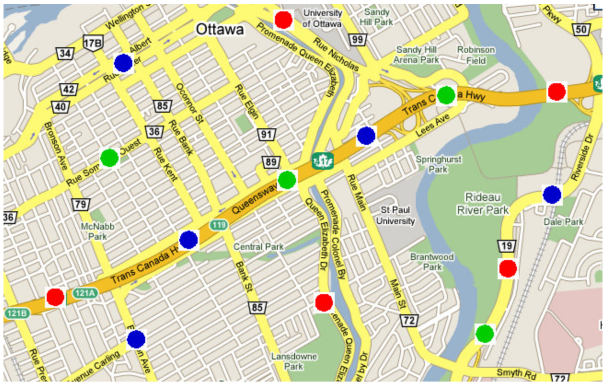

Figure 4. Map of Ottawa. Red dots represent traffic sensor, blue dots represent pollution sensors while green dots represent weather sensors

The results of querying the simulation model showed that ALL the highly polluted places were retrieved with the assist of traffic sensory data. Therefore, this demonstrates the effectiveness of the ontology approach for heterogeneous sensory data integration to answer higher level queries.

## V. CONCLUSION AND FUTURE WORK

The semantic representation of sensor networks data is an exciting vision that maximizes the quality of search engines. Increasing the precision and recall rates is a necessary prerequisite for automatic search, retrieval, and processing of sensor data. This paper is step further towards defining a universal ontology for describing concepts and relationships of the sensor networks units and data. The benefits of our work are to maximize the precision of searching sensor data by utilizing the semantic information.

As for future work, we are planning to perform more comprehensive performance analysis by considering real life scenario(s). Moreover, in order to support semantic web services, we plan to investigate building a functional ontology that describes operations on sensor data. This effort will be a further step in the direction towards enabling semantic web services to access and process sensors data.

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