

Semantic Information and Sensor Networks

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ABSTRACT

Embedded Networked Sensing involves untethered, networked devices tightly coupled to the physical world, to monitor and interact with it. Raw sensor observation can be annotated with semantic metadata to provide interpretation and context for it. In this paper, we discuss what, why and how of semantic sensor data and semantic sensor networks. Specifically, we explore (i) benefits of augmenting sensor data with semantics, (ii) domain-specific and spatio-temporal problems to be addressed, (iii) role of knowledge representation and reasoning (Semantic Web technology), and (iv) standardization efforts underway to make sensor-related data and sensor observations widely available.

Categories and Subject Descriptors

I.2.4 [Artificial Intelligence]: Knowledge Representation Formalisms and Methods

General Terms

Management, Design, Standardization

Keywords

Semantic Sensor Network, Semantic Web, Sensor Web, Ontology, Spatio-Temporal Reasoning.

1. INTRODUCTION

Embedded Networked Sensing involves untethered, networked devices tightly coupled to the physical world, to monitor and interact with it [1]. To understand the role and impact of sensor data, it should be situated in its environment. For example, a temperature measurement taken inside an engine and one taken inside a person have vastly different implications. Thus, to assimilate the full impact of sensor data, contextual information in terms of location, time, and domain themes are necessary. To emphasize the need to integrate spatio-temporal reasoning with sensor data, consider bridging the gap between a seismic sensor data with latitude/longitude and time of observation, and a query that requests the number of earthquakes in California last year.

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SAC'09, March 8-12, 2009, Honolulu, Hawaii, U.S.A.

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2. BACKGROUND AND RELATED WORK

One of the fundamental obstacles to deploying large-scale Semantic Sensor Networks is lack of standards. The Sensor Web Enablement Working Group of the Open Geospatial Consortium has begun addressing this with specifications for sensor data, devices and services [3]. Observations & Measurements (O&M) encodes observations and measurements. Sensor Model Language (SensorML) describes sensors systems. Sensor Observations Service (SOS) requests, filters, and retrieves observation and sensor data. Sensor Planning Service (SPS) provides the facility for requesting user-driven acquisitions and observations. Sensor Alert Service (SAS) allows alert publish/subscribe from sensors.

These standards provide models for the expression of simple concepts such as location coordinates, timestamp, and sensor specification. However, to provide the ability for rich semantic reasoning over the sensed data, more expressive annotations are necessary. Integration with ontologies would provide the benefit of additional annotations for abstract concepts, such as temporal relationships, geographic region, and domain-specific themes.

3. DISCUSSION OF PROBLEM

We develop a conceptual model of the Semantic Sensor Network and discuss the queries that can be posed to and about them.

3.1 Conceptual Model for Semantic Sensor Network

We propose a model of the Semantic Sensor Network (SSN) by describing its constituents (sensors, context, domain model) and their relationships. The model elucidates the scope of SSN.

Primitive sensors measure some physical quantity (temperature, pressure, etc). They can be described by specifying sensor details (accuracy, range, etc.) and observation details (magnitude and unit of measure). Composite sensors can be defined in terms of primitive sensors.

A space-time context can be provided by associating each observation with spatial and temporal coordinates. These are explicitly specified for primitive sensors and their observations, while they can be derived for composite sensors. Thematic context can be provided to synthesize real-world state (phenomenon / event of interest) from sensor observations.

3.2 Querying Semantic Sensor Network

A SSN database can be queried to retrieve information about the structure and the nature of sensors, their observations and locations, as a function of time. Sensor data can be made more

intelligible (such as in the context of a decision support system) by enabling symbolic queries with natural space- and time-related vocabulary, such as references to geographical locations, relative vs. absolute instants and intervals, etc., and by aggregation queries for synthesizing information, such as average, maximum, etc. In a number of situations, it may be necessary to trigger an alert when a specific real-world state is reached or is prevailing. For instance, an observer may wish to be notified of temperatures above 100F.

The long-term vision is to be able to develop a system that can relate and reason with various entities and events, and potentially predict future occurrences of events or involvements of entities, by representing and reasoning with entities (organizations, persons), events (themes), space and time. For example, ‘How many car bombs were exploded by Hezbollah near Tel Aviv in the last three months?’

3.3 Methodology

In order to build and use a SSN, we provide a high-level plan for long-term research and development for sensor data acquisition, dissemination and processing using Semantic Web and Web Services technologies. For initial experimentation, we define a simple logic- and rule-based sensor data representation and reasoning system, described by the following applications.

(1)Catalog Web Services: O&M, SensorML, and SOS are the applicable standards. (2) Discover Web Services (i.e. how to find and task the sensors): SOS and SPS. (3) Sensor Data Fusion: This requires a domain model to map raw heterogeneous sensor data into real-world events and generate events of interest. (4) Sensor Data in Context: Integrate space and time information with sensor data. (5) Data Collection Application: SOS services with additional semantic annotations could be used in this application. (6) Alert Monitoring Application: SAS applies here. (7) Time Ontologies: The general problem of representing and reasoning with time is very complex, so it will be important to develop progressively expressive, tractable subsets. OWL-Time [4] may apply. (8) Geography/Space Ontologies: Spatial coordinates can be represented using longitude and latitude or geographical locations. Similarly to the time, representing and reasoning with space is very complex. The W3C Geospatial Incubator Group [5] is examining such issues. (9) Natural Events: Without proper space-time context, the significance of a specific sensor data is unclear. (10) Object Tracking Application: Entity registration in various perspectives of the same world state is an important task.

These diverse applications help outline the general requirements of a robust SSN architecture. It includes temporal and spatial relationships of the sensor data to provide context. It supports higher-level reasoning. It allows the fusion and aggregation of sensor data to build composite sensors that support more abstract types of readings. It enables performing expressive queries and/or registering alerts over the state of sensed world. Finally, it uses standards and models from the realm of web services.

A SSN will incorporate annotations from a range of ontologies. Ontologies that deal with concepts such as time and spatial regions can be classified as domain-independent, as their constituent concepts have a very wide range of applicability and should be fairly standard across web services, allowing the interoperation of the SSN with other services, (e.g. GIS lookup

and transformations). Thematic ontologies are highly domain-dependant and will need to be defined for the application to which the SSN is being tasked. A semantic representation of Situation Awareness is important to the basic objective of most any SSN; making it a priority in the architecture of SSN allows the sensor data to be used in support of data fusion and decision support.

Towards this end, we have begun work on a prototype application which makes use of semantic relationships to provide a rich user-interface with which to examine the sensor readings in time and space [2]. The prototype provides support for semantic time queries over intervals (e.g. within, overlaps, contains) and embeds semantic model reference annotations into SensorML documents.

Currently, we are refining the implementation of an SOS service, backed by an ontology modeled after the O&M and SensorML specifications. We are using collected measurements from temperature, wind, precipitation, and pressure atomic sensors as our base observations. From this, we make use of domain models, to infer higher-level phenomena and features. All readings are placed within a rich temporal and geospatial context which may be queried via the SOS requests. We are working towards a means to insert new atomic sensors and observations, and to automatically infer new composite sensors and readings. All of this will be available via SOS service, allowing sensors to register and insert observations that are automatically annotated.

4. FUTURE TRENDS

Semantic service composition is still maturing and therefore lacks standardized tools, which presents some difficulties. Another challenge lies in identifying and handling errors in the face of tampering, unreliable network connections, and battery-powered platforms. To support richer alert and monitoring systems, we need logic rules and inferencing. Currently, the Rule Interchange Format and Semantic Web Rule Language are under development, but have not yet gained wide acceptance.

5. CONCLUSION

Given the exploratory nature of our research task, we are currently implementing the outlined plan to systematically apply Semantic Web and Web Services technologies in Semantic Sensor Networks. Pursuing a service-oriented architecture and leveraging semantics, SSN will allow us to richly interact with the physical world, from smart homes to battlefield situation awareness.

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