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SEMANTIC IMPLEMENTATION AND PERFORMANCE EVALUATION OF CONTEXT AWARE SERVICES IN AN INDOOR ENVIRONMENT CONTROL SYSTEM

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ABSTRACT: This paper focuses on the modelling and development of a semantic sensor service provider and semantic GIS service provider module for a Semantic Internet-of-Things System based on context aggregation and location of an Indoor Environment. Due to the diversity of the large volume of data produced by Internet-of-Things devices, the issue of interoperability rises. Semantic technologies are used in many studies for overcoming issue of interoperability. In this study, we have built ontologies that act as a semantic repository for storing the sensor and location information. To offer sensor data storage services we have designed a semantic sensor service provider module whereas GIS service provider module is designed for storage and provision of an indoor location data. To retrieve this data from the ontologies we have used SPARQL and DotNetRdf API. Pellet based reasoning on the sematic ontologies have been implemented to enable data manipulations using SPARQL. Finally, Performance analysis based on the comparison of SPARQL and SQL based data manipulation has been performed showing that the average execution time for SPARQL based data manipulations is much better than that for SQL based data manipulations.

Keywords: Application Programming Interface (API), Geographic Information System (GIS), Hyper Text Transfer Protocol (HTTP), Structured Query Language (SQL) and Simple Protocol and RDF Query Language (SPARQL).

INTRODUCTION

The vision of the Internet of Things (IoT) is to connect devices all over the Internet to share and exchange data in order to provide useful services to people. According to Cisco's predictions there will be more than 50 billion devices connected to the Internet by 2020 (Evans, 2011; Royer, 2013). These devices will generate huge amount of data to be acquired by many services and application in areas such as smart homes, smart grids, healthcare, and environmental monitoring. These devices are of heterogeneous nature, producing data in various different formats and requiring different protocols to communicate. This makes interoperability one of the most fundamental requirements to support various tasks such as object addressing, tracking and discovering as well as information representation, storage and exchange (Barnaghi *et al.,* 2012).

Recently, different semantic technologies such as ontologies, semantic annotations, linked data and semantic web services have gained popularity specifically in the connected devices domain. Applying semantic technologies to the things on IoT will make its data unambiguous and transparent for both the users and the applications using it. It also provides efficient data access and integration, resource discovery, reasoning and knowledge extraction. The different semantic web technologies such as ontologies, semantic annotations, semantic web services and linked data can be used for fulfilling the goals of IoT. The proposed system is a hybrid system that utilizes both semantic and database technologies to collect, store and provide environmental context information.

The sensing devices connected to the system are registered in the sensor ontology; they are used to collect the data from the area and send it to the application layer. The semantic GIS provider module uses the GIS ontology to store the location information of the indoor environment that is monitored by the sensors. The sensor and its location information is bonded together in the application layer, from where the users can retrieve this data. The rest of the paper is structured as follows: Section 2 presents the related work of the study, Section 3 shows the design of the semantic sensor service provider and the semantic GIS service provider ontologies. Both the figures show actual ontologies as rendered by Protégé. The section discusses the concepts used in the ontology in detail. Section 4 provides a performance analysis based on comparison of SPARQL and SQL queries used by the system. Finally, the conclusion section gives an overview of what is already discussed, and the future work of this study.

MATERIALS AND METHODS

The idea of the internet of things is emerging fast and it is changing the world with it. The devices connected to the internet are huge in number and it is providing a tremendous amount of opportunities. However, due to the interoperability gap between the devices and the applications there is a growing challenge to its potential. This is causing the major disconnection between the physical and the virtual world, as a lot of effort is required to search, understand and integrate the information produced by these devices in a useful way. To bridge the gap between the devices and the applications, many researchers have been using semantic technologies. These technologies provide a knowledge framework that allows the devices and the applications to understand the data being produced and exchanged.

The traditional paradigm of the IoT service model offers raw data that does not carry any aggregated annotations and thus need specialized knowledge and manual effort to build smart applications (Gyrard *et al.*, 2016). Several studies have made use of semantic technologies in order to provide sensor data with more meaningful representation. OntoSensor (Compton *et al.,* 2009) is a repository reusing concept and relation definitions from SensorML (Botts *et al.*, 2006). The authors have presented an approach to deploy a framework for translation among different domain ontologies by using upper level ontologies. The work in (Desai *et al.*, 2015) has proposed a gateway and an IoT architecture based on semantic web to approach the interoperability issue between IoT based systems.

The gateway is located between the physical level sensors and the cloud based services providing translation between widely used CoAP (Bormann *et al.*, 2012), MQTT (Hunkeler *et al.*, 2008), XMPP (Kirsche and Clauck, 2008) protocols. This enables seamless semantic integration between these levels. The Semantic Web Enablement established by the Open Geospatial Consortium includes specifications such as Observation and Measurement (O&M), Sensor ML, Transducer Markup Language (TML) and Sensor Observation Service i.e. SOS . The O&M includes standard models and XML schemas for encoding observations and measurements from a sensor. The Sensor ML includes standard models and XML schema for describing sensor systems and processes. TML includes a conceptual model and XML schema for describing transducers, and finally the SOS is a standard web interface for requesting, filtering and retrieving sensor system information (Botts *et al.*, 2006).

The SemSoS (Henson *et al.*, 2009) is a critical element of the SWE; it proposes ontology models for sensor domain and sensor observations, with semantics annotated to the sensor data thus making it machine understandable. Furthermore, W3C's SSN ontology (Compton *et al.*, 2012) is developed to describe the capabilities and properties of sensors, the act of sensing and the resulting observations. Similar studies for representing sensor observations include Sensor Data

Ontology (SDO) (Eid *et al.*, 2007), Sensei O&M (Villalonga *et al.*, 2010) and SensorML. In (Eid et al., 2007) the authors have developed ontology for searching the distributed and heterogeneous sensor data. They have a root ontology SUMO (Kuraoka and Batres, 2003) that defines the general concepts and two sub ontologies i.e. SDO and SHO and extension plugin ontology (EPO). The SDO and SHO ontologies reference and extend the SUMO ontologies. These ontologies offer automated fusion of data generated by disparate sources of sensing environments.

Currently most of the work in IoT targets a single domain; however, using cross-domain applications can reduce a lot of development, and maintenance costs. A smart IoT system is required to publish its output as well as describe device information in a well-understood format with added metadata and machine process able formats. This will not only address cross-domain and interoperability issues but also make the devices accessible in multiple applications.

RESULTS AND DISCUSSION

This study of context aggregation for location based indoor environment control is conducted through a semantic IoT system for indoor environment monitoring. It is an enhanced sub-system of its predecessor IoT enabled indoor environment control system with service-oriented architecture and conventional data storage.

The system consists of multiple modules that interact with each other to exchange sensor and location information. The conventional data storage limits the capabilities of the system as data queries based on semantics cannot be fully implemented. The enhanced system can be used in multiple domains as we have equipped it with semantic storage and inference capabilities at each module. The new implementation consists of added annotations that provide machine understandable meanings of the data produced by the devices connected to the system. A semantic repository annotates meaningful information with the data that arrives at these layers. An ontology has been created using Protégé (Knublauch *et al.*, 2004) in order to share and manipulate data among all the modules in the system. To retrieve and store data in the ontology dotNetRdf API (Vesse, 2009) is used. It is a powerful and easy to use API for working with RDF (Klyne, 2004), SPARQL (Quilitz and Leser, 2008) and semantic web. Pellet Reasoner (Sirin *et al*., 2007) has been used for semantic reasoning and query generations. The ontology models enable interoperability by annotating the information collected from the devices with semantics. These semantic repositories in the system are a key solution for the devices to convey their contexts as useful information.

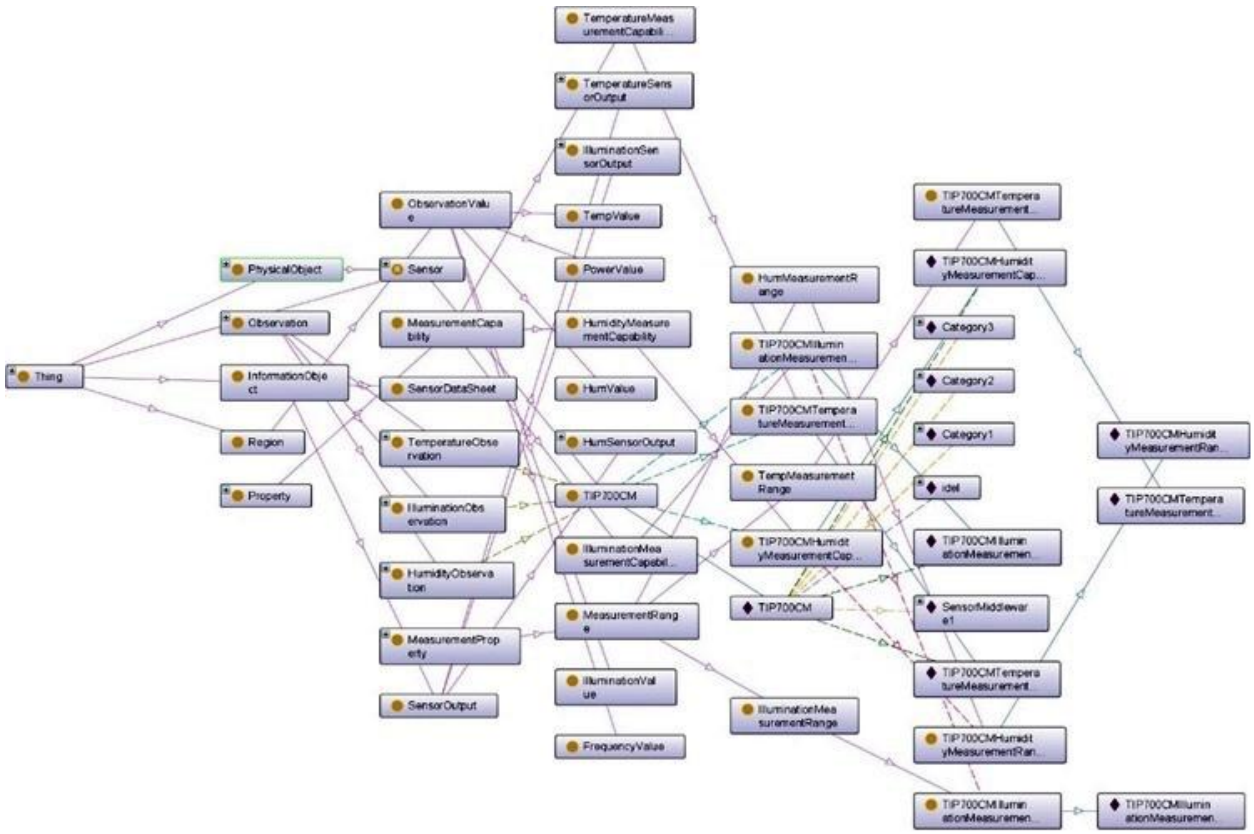

Figure 1 Semantic Sensor Service Provider Ontology

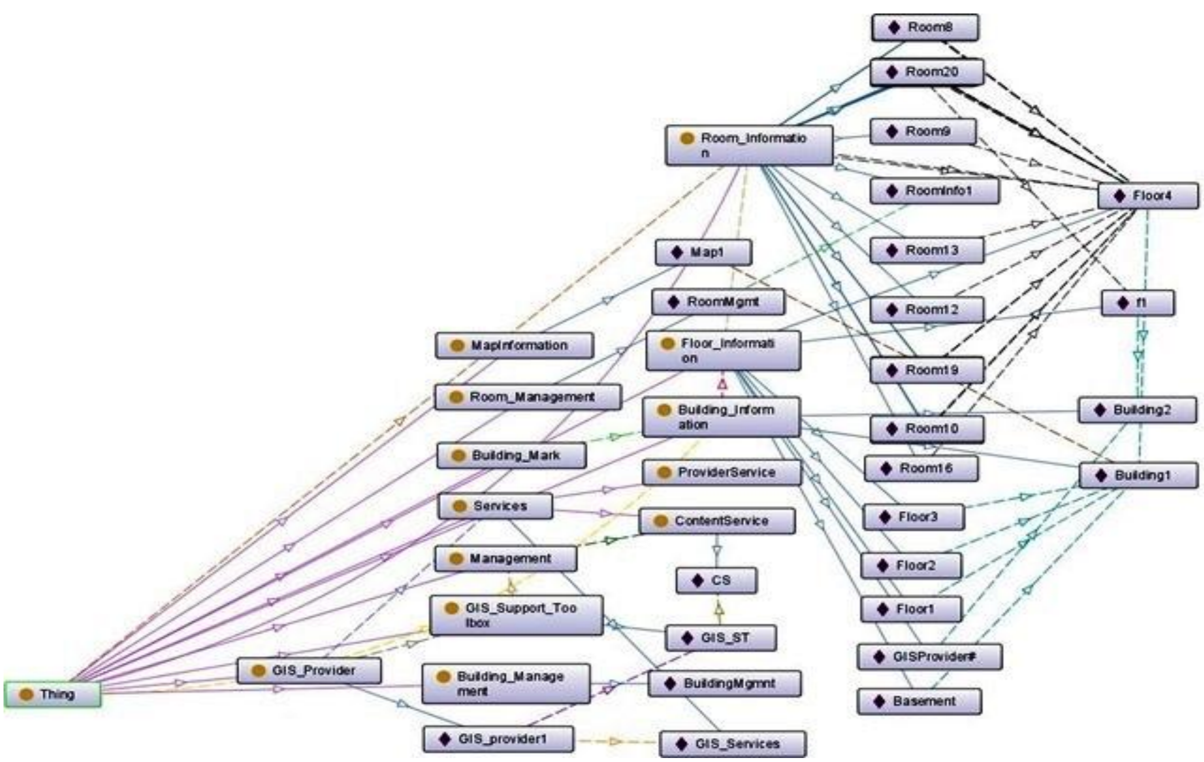

Figure 2 GIS Service Provider Ontology

In this paper, we have focused on two of its modules i.e. the semantic sensor service provider and semantic GIS service provider. Figure 1 shows the protégé generated graph for the Sensor Service Provider ontology. It shows relationship between classes, subclasses, equivalence and object properties. Semantic IoT indoor system requires storing and representing the sensor information so it may semantically query the data for the monitoring of various environmental attributes. The ontology encompasses all information related to a sensing device such as the type of observations it can generate, measurements, range of outputs etc. This information in semantically related and can be reasoned upon to generate more information.

Semantic sensor service provider stores real time sensor data in the database, whereas the information related to the sensors such as sensor properties, categories and the relationships between them is stored in the ontology. The reason for using database for storing real time sensor data is the possible decrease in system performance with the growth of ontology size. Figure 3 shows a SPARQL query that is used by the system to insert sensor information to the ontology.

The experiments shown in this section analyses the efficiency of performing SPARQL queries versus SQL queries as the system was previously developed using database technologies. Both of these languages give the user access to create, combine, and consume structured data. SQL does this by accessing tables in relational databases, and SPARQL does this by accessing a web of Linked Data. The comparison of SPARQL and SQL queries for adding new sensor information to the sensor service provider repository.

Ten iterations are taken at random resource utilization level of the host system. The difference between the two queries has been recorded in terms of min, max and average time in milliseconds for the 10 iterations. For the SPARQL query the min time in milliseconds taken for adding iteration is 16ms, max time taken is 874 msec and average time taken is 227.65 msec. Whereas the min time taken for an SQL query to add an iteration is 65 msec, the max time taken is 976ms and the average time taken is 555.45 msec. The graph shown in figure 5 describes the comparison results for SPARQL and SQL update queries. The update query takes the data updated from the user interface and updates the entry in the service provider repository.

The comparison of the two queries is based on the min, max and average time taken in milliseconds to update iteration. The minimum time taken in milliseconds by the SPARQL query to update an iteration is 104 msec, the max time taken is 776 msec and the average time taken is 227.88 msec. Whereas the min time taken in milliseconds to update an iteration using SQL query is 16 ms, the max time taken is 920 ms and the average time taken is 272.66 ms. Query comparison based on the min, max and average time taken in milliseconds from 10 iterations of both type of queries. The min time taken in milliseconds by SPARQL add query is 41 msec, the max time taken is 54 msec and the average time taken is 47.6 msec. Whereas the min, max, and average time taken by the SQL add query is 46 msec, 972 msec, and 459.8 msec respectively.

Floor information is a sub-part of the building information which specifies locations inside a building. The minimum time taken by a SPARQL query to add floor information to the semantic GIS service provider repository is 48 ms, the max time taken is 73 msec and the average time taken is 54.9 msec. Whereas the min, max and average time taken for a SQL query to add floor information to the semantic GIS service provider repository is 30 msec, 973 msec and 419.6 msec.

Conclusions: The work presented in this study addresses the issue of interoperability in IoT systems. This paper has provided a semantic web approach to the issue by modelling and developing ontologies for different modules in the proposed system. The data at each layer is annotated with semantic description which makes it more meaningful for the rest of the system components using it. This study focuses on annotating the sensor data and the location information, which is provided to the application layer for further use. Users can query the application layer directly for sensor and location information. Reasoning is performed on the ontology to infer high level abstractions from the sensor and location information. Finally, the performance analysis of the system is performed by comparing SPARQL and SQL queries which proves that SPARQL query response time is much better than SQL. Future work includes publishing the ontologies online and connecting to other related knowledge bases. This will help make the system smarter by deducing new information from the connected knowledge bases.

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