SensXplore: A Tool for Sensor Discovery using Semantics with Focus on Smart Metering

Sounak Dey, Ranjan Dasgupta, Arpan Pal, and Prateep Misra

Innovation Labs, Kolkata,
Tata Consultancy Services Ltd, India
{sounak.d,ranjan.dasgupta,arpan.pal,prateep.misra}@tcs.com
http://www.tcs.com

Abstract. Sensor capability discovery, services discovery and selection of right sensor as per application requirement is very important aspect for sensor systems. Structured semantic representation of the same in an ontology would be helpful for manufacturers, application developers and sensor deployment users. This paper describes an online tool called "sensXplore" which uses such ontology as a backbone to serve the aforesaid purpose.

Keywords: Sensor, Interoperability, Discovery, Tool, Ontology

1 Introduction

Present day cyber-physical systems (CPS) are becoming more and more dependent on sensors. With frequent use of sensors, there come challenges to be solved with respect to sensor data semantics, sensor capabilities exploration, tasking, discovery etc. Based on user classification and technology, SSN XG Report [1] has clearly divided the challenging use case sets in four broad categories: 1. Data Discovery and Linking, 2. Device discovery and Selection, 3. Provenance and Diagnostics and 4. Device Tasking and Operations. As the names suggests, first category is more focused on sensor data semantics and relation discovery while the second one is related to sensor services and capabilities exploration and selection of sensor as per application requirement. Third category is an extended subtle set of second category and last one relates to low level commands and operation.

Though data semantics and discovery is a very important topic with respect to CPS, but sensor device and capability discovery (category 2) is more important for those who deploy sensors in a system. Exploring capabilities and fitness of a sensor with respect to a particular application is important as this will decide the system performance and reliability. Moreover quality and usefulness of data, way of tasking and operation of system, scalability of system etc. are dependent on the kind of choice of sensor is made before deploying.

So those who are responsible for selecting and deploying sensors for a particular use case need to understand and search different capabilities and factsheets of sensors and evaluate performance of sensor under given constraints, from different manufacturers following specification standards defined by various standard bodies. All these are highly variable over time so one deployment cannot entirely help next deployment. So a reinvention process is waiting every time a new deployment comes. If the deployment goes wrong then that also creates problem for application developers who use data from sensors.

Taking example of smart meters (henceforth energy sensor), it has been seen that there are many standards like DLMS/COSEM, ANSIC12 etc. which meter manufacturers generally follow but there is huge variation in terms of capability of such meters for e.g. measurement parameters (while some meter measures values of active energy, reactive energy, some others gives energy only), measurement precession (some meter measure values up to multiple decimal points), communication protocol followed (there are different protocol like Modbus, MBus, serial port, optical port, zigbee etc.), data storage and analytics capacity (some has data storage chips built in) and so on. Before deployment of a meter one has to go through all these details and have to decide the best meter that fits the requirement. Also manufacturers do not have a common platform to describe their meters so that it can be used by those who will deploy meters in households.

Thus, it is obvious that there is a requirement for a common knowledge base which can hold details of sensors as provided by manufacturers (its specification, accuracy, factsheet, performance under constraints etc.). Again that knowledge base should be semantically searchable by sensor deployment users. Also it should help explore sensor services. Application developers should also use the same knowledge repository.

Looking at the nature of the problem, an obvious way to address the problem is using ontology as a data and knowledge representation technique and using it as a semantic tool to enrich both sensor data and metadata. Though there are many top level approach for describing sensors, it has been observed that OntoSensor [2] goes close to cover all the aspect of a sensor. Taking OntoSensor as a starting point, the ontology has been extended for energy sensor and created one example ontology which carries modularized approach to describe sensor hierarchy, sensor data representation, sensor functionalities and some sensor domain specific representations. All these have been discussed in our earlier work [3] and have been implemented for energy sensors.

Based on this ontology, a tool named "sensXplore" has been made which have an interface for manufacturers to enter details of their sensors and an interface for sensor deployment users who can select and provision the sensor at per requirement and finally one query interface which will enable users and application developers to search sensor capabilities, services, data semantics etc.

2 Related Works

2.1 Ontology Selection

To capture metadata, fact sheets, capabilities etc. of sensors there needs to be a semantic knowledge base which will hold all these details in a structured way in an ontology so that sensor deployment team can search a sensor easily and efficiently based on given constraints and requirements.

Prior art search says that there is no such ready comprehensive knowledge base or interface which can be used for sensors or at least for meters. There are some ontologies like SWAMO, CSIRO, SDO, OntoSensor etc. Of them, CSIRO lacks a clear hierarchy of sensors, SWAMO lacks clear category separation and top classes are a bit mixed up, SDO focuses only on data though and have very limited resource to work with. Of all these sensor ontologies, OntoSensor found to be a good starting platform for this requirement as it inherits Suggested Upper Merged Ontology (SUMO) [4] by IEEE and also ISO 19115 standard in some its relations. For e.g. "Sensor", "Platform" and "Event" concepts of OntoSensor extend the "Measurement Device", "Transportation Device" and "Process" concept of IEEE SUMO respectively. Also it incorporates some concepts of SWE OGC standard for sensor description language SensorML [5].

2.2 Tool Requirement

In absence of what proposed in section 2.1, stakeholders of CPS face many practical problems as discussed here.

Manufacturers, while releasing a new sensor of some category, have to describe its metadata, fact sheet, capabilities etc. in their own way in absence of a standard description tool. Having a standard tool backed by a stable ontology, which can even be modified by experts as and when required on manufacturer's request, would be a nice tool. In absence of standard tool, when user of such sensors want to deploy them into practical fields then they need to check out every individual sensor's metadata sheets separately to understand its capabilities, precession etc. This can again be reduced by a tool that will help selecting sensors by categories, types, capabilities, way of functioning, communication protocols etc.

Last section consists of developers who use services of a CPS and query sensor data and metadata, analyze them and produce meaningful inference or actions. A meaningful semantic query tool will help their need to much extent.

3 Proposed Ontology Design and Implementation

Energy sensor has been selected and used as an example for which OntoSensor has been extended into much more details for some classes defined there. Also this richer ontology is divided into some logical modules (as shown in Fig. 1) like sensor hierarchy (SHR), sensor functionalities (SFR), sensor data (SDR) and sensor data exchange (SDER). There is also a placeholder (DSR) for keeping domain specific information.

Meters can be classified and divided into hierarchy based on any of (1) measurand (2) sensor material (3) application (4) cost (5) accuracy (6) output signal etc. In our case, measurand has been taken as the key feature based on which meter has been categorized in SHR (Fig. 2a).

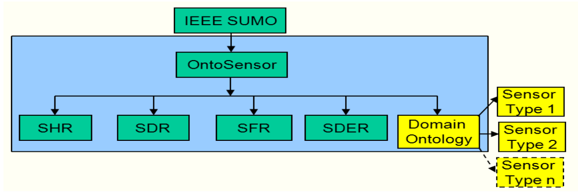
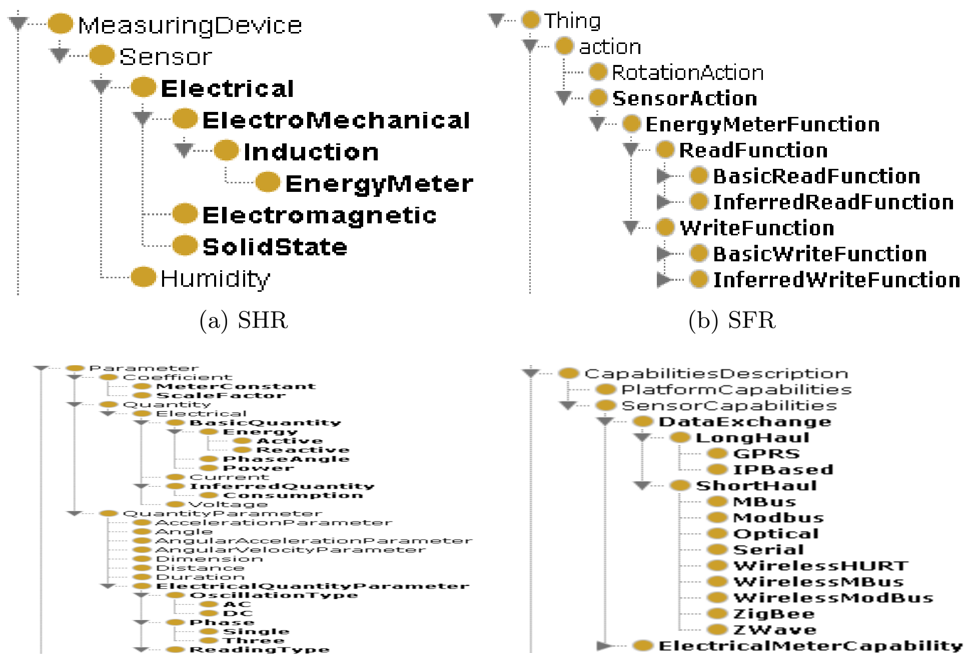


Fig. 1: Logical modules in ontology

All functional capabilities and services provided by meters (like "Reading-Data", "SendData" etc.) are captured under SFR (Fig. 2b). This inherits from "action" concept of OntoSensor and provides a good platform for API service exposure for meters.

SDR (Fig. 2c) represents data and basic parameters as measured by meters like "power", "voltage", "current" etc. This tree starts frm OntoSensor concept called "Parameter" and "Quantitiy".

SDER (Fig. 2d) starts from OntoSensor concept of "CapabilitiesDescription" where all types of communication protocol relevant to meters are listed.



(a) SHR (b) SFR

(c) SDR (d) SDER

Fig. 2: Different modules of ontology

Meter specific concepts are logically parked into DSR placeholder. This can be spread across all above four logical divisions. Concepts like "MeterConstant", "UserConsumption", "three-phase meter" falls under this category.

This model can be followed for any other type of sensor and that sensor can be semantically described using this model.

4 Tool Design and Description

Based on the requirements as specified in section 2.2 and taking sensor ontology described in section 3 as a backend platform, a tool "sensXplore" has been designed and implemented. This is our second contribution. Sensor example for both ontology and tool is electric meter. Architechture diagram for the tool is given in Fig. 3.

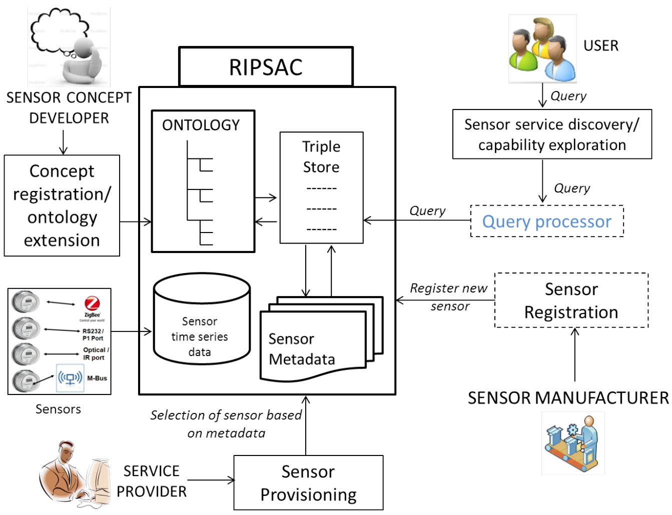


Fig. 3: Architechture of sensXplore

The tool is hosted in RIPSAC (Real Time Integrated Platform Analytics and Services for City) [6] which is our proprietary platform for sensor based intelligent systems. This tool is capable to cater needs of sensor manufacturers (in this case, meter manufacturer), sensor based service providers (here, utility service providers who install meters at households) as well as query makers (who in this case are utility service providers, consumers and data researchers).

There are three modules in the tool. Purpose and uses of these modules is explained below. A details description of how to use the tool with proper screenshots is given in Appendix.

Sensor Registration: This module is meant for sensor manufacturers. As ontology already holds details knowledge base of a type of sensor, its hierarchy, general factsheets of that type of sensor, other details like capabilities, working range, accuracy, data communication protocols and interdependencies of these parameters, manufacturers will only have to select the right position from sensor hierarchy (this is where their sensor fits) and select the features, capabilities or semantic categories relevant to their sensor and will register the new sensor in the CPS. In this way interoperability in terms of sensor definition would be there. Also higher level semantics can be embedded with metadata level for future processing. In future this work can be extended to accommodate modification in sensor feature set or hierarchy in ontology against manufacturer's suggestions subject to a proper review by domain experts.

Sensor Provisioning: When sensors are registered and are ready to be deployed by CPS enablers then they can select correct sensor by searching its feature, performance, capabilities etc. and deploy and activate the sensors in actual fields. To elaborate with an example, when multiple electric meters are registered in the system by multiple makers, electric supply company can search for best meter that fits their requirement and can deploy and provision it to households by attaching customer details with the meter id and defining a space for data storage from that meter. All these can be done without knowing much intricacies of standard, format etc. followed by manufacturers.

Sensor Discovery: Once the sensor is registered and provisioned in the system then the obvious requirement will be gathering time series data and using them to analyze and answer complex queries. Another angle of requirement will be to query the sensor itself about its factsheet, metadata, capabilities etc. to help establish the reliability of data. This module focuses on second angle and just puts a pointer to data for the former part. Queries here may be meter centric (like "retrieve all the AMIEnabled meters whose firmwire can be upgraded") or customer centric (like "find all customers having IPbased meters"). In future, this module will look into handling more complex semantic queries. For example, semantic queries like "Find high consumption customers in a particular area during peak load time in Summer" contains different semantic terms like "High Consumption", "Peak Load", "Summer" etc. These terms are defined either in the base ontology or some other ontology that have been imported and reused. This knowledge base and interrelations and defined set of rules in the system will finally help infer the final output of the query.

5 Future Scope:

More structured approach for ontology creation can be done usign SSN philosophy which revolves around concepts like stimuli, feature of interest, observation etc as explained in [1]. Also a Query Processing unit would be introduced which will help break down categories of queries, translate natural language queries into standard sparql queries, make a query plan etc.

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Appendix:

Online Link of sensXplore:

"sensXplore" tool is publicly available in the link:
http://ripsac2.web2labs.net/ontologyUi/

User Manual of sensXplore:

Step 1: On going to this link, there will be a prompt for username and password. User will have to enter username = "tcs" and password = "tcs" for further progress into the demo of the tool.

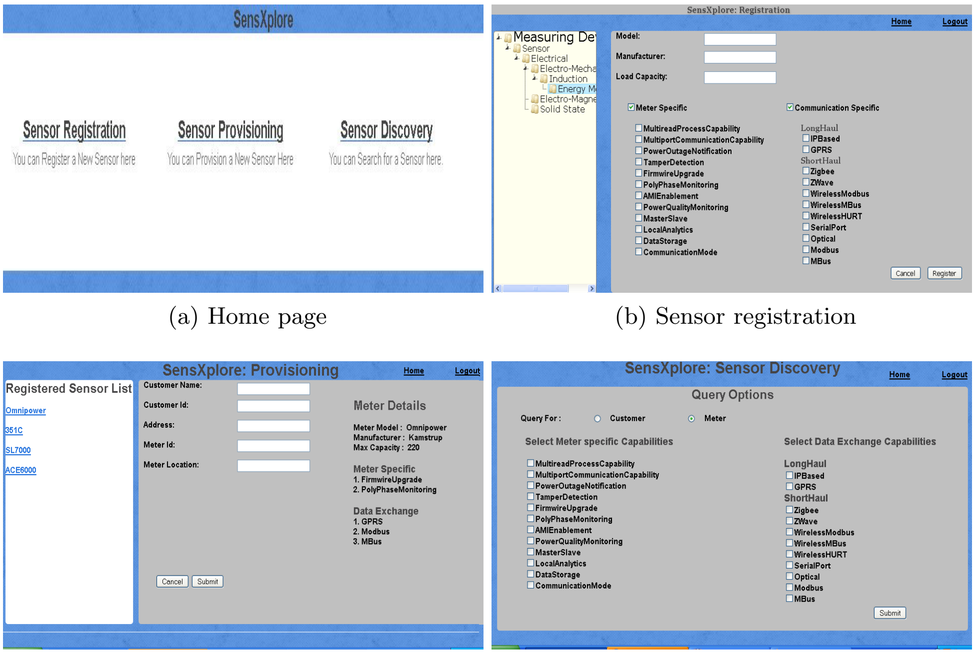
Step 2: on successful log in, demo user will see a homepage as shown in Fig. 4a. There are three options to choose from namely "Sensor Registration", "Sensor Provisioning" and "Sensor Discovery".

Step 3: On clicking Sensor Registration link, screen as shown in Fig. 4b will appear. This screen is for use of manufacturers. They will search the tree in the left pane to find out desired sensor type from the hierarchy of sensors. On selecting one type of sensor, text boxes on the right hand side will be enabled and user have to enter sensor model name, maker name, load capacity and have to select what capabilities the sensor has from the list of checkboxes. When done with data entry and selection, user will press "Register" to register the sensor.

Step 4: Now going back to homepage in Fig. 4a, user will select "Sensor Provisioning" link. This screen is as shown in Fig. 4c. It is for use of sensor deployment users. User will select one of the registered sensors from the left pane. Upon selecting the sensor, the capabilities and type of that sensor will be populated in right portion of the screen and user have to enter customer name, address, id, location (in "latitude longitude" format eg. "88.25 22.78") and sensor id. Upon data entry, user will press "Submit" and the sensor will be provisioned for that customer id.

Step 5: Again on going back to homepage (Fig. 4a), user may select "Sensor Discovery". This screen as shown in Fig. 4d is for sensor service and capabilities explorers. User will use checkboxes to choose from sensor capabilities and query can be done based on customer id or sensor id. On clicking "Submit", output will be shown. Also queries like "which customer has which meter" can be done from this screen.

Note: Pressing the "Cancel" buttons in all screens will stop whatever operation was being done in that particular screen and will take back users to home page (Fig. 4a). Pressing "Home" button will take user to same home page. Pressing "Log Out" from any screen will log out user from the system.



(a) Home page (b) Sensor registration

(c) Sensor provisioning (d) Sensor discovery

Fig. 4: sensXplore Screens