Sensor Information Representation for the Internet of Things

Jiehan Zhou[1], Teemu Leppänen[1], Meirong Liu[1], Erkki Harjula[1], Timo Ojala[1], Mika Ylianttila[1], and Chen Yu[2]

[1] University of Oulu, Oulu, Finland
{firstname.lastname}@ee.oulu.fi
[2] Huazhong University of Science and Technology, Wuhan, China
yuchen@hust.edu.cn

Abstract. Internet of Things integrates wireless sensor networks into the Internet, and paves the way to help people live seamlessly in both physical and cyber worlds. In a synergizing Internet of Things application, various types of sensors will communicate and exchange information for achieving user tasks across heterogeneous wireless sensor networks. This application needs an information representation for uniformly developing and managing sensor data. The information representation thus accelerates data integration and increases Internet of Things application interoperability. In this paper, we present an overview on existing technical solutions for representing sensor information.

Keywords: Internet of Things, sensor ontology, semantic Web, Web of Things.

1 Introduction

The Internet of Things (IoT) accelerates and facilitates the user to operate with information and communication technology through connecting wireless sensor networks. These wireless sensor networks act much the way nerve endings do in the human body. The sensors can be massively distributed in the living environment, and can be responsible for perceiving changes in the surroundings, while transmitting the data to the sink node. Sensor networks can also be responsible for receiving and executing commands from the central node. Wireless sensor networks can involve various application domains such as home automation, logistics, factory systems, or medical domains. In a synergizing application, wireless sensor networks commonly communicate and exchange information across domains (Figure 1). Interoperability and efficient sensor data transfer become crucial issues for realizing the Internet of Things.

Ontology methodology is often used to address application interoperability in distributed systems. An ontology is a description of the contents or parts of a system, and of how they relate. Design of ontologies serves to enable knowledge sharing and re-use [1]. An ontology is also regarded as a data model that defines the primitive concepts, relations, and rules comprising a topic of knowledge, in order to capture, structure, or enlarge the explicit or tacit topic knowledge to be shared between people, organizations, computers, or software systems [2]. From the viewpoint of a data

P. Herrero et al. (Eds.): OTM 2012 Workshops, LNCS 7567, pp. 515–524, 2012.

model, an ontology is an hierarchical arrangement of metadata. As the Internet of Things has received widespread attention in the academia and industry, a number of researchers have studied and developed ontologies for specifying sensors. For example, the OntoSensor ontology [3] was intended as a generic knowledge base of sensors for query and inference. Avancha and Patel [4] designed the sensor node ontology for addressing wireless sensor network adaptivity. Neuhaus et al. [5] proposed a semantic sensor network ontology to describe sensors in terms of their capabilities and operations.

To accelerate and realize the vision of an Internet of Things, we proposed the Mammoth project,[1] funded by Tekes — the Finnish Funding Agency for Technology and Innovation. This project aims to facilitate information exchange and synergic performance between IoT things and people via global, massive-scale M2M (machine-to-machine) networks, and to provide M2M automatic metering, embedded web services, universal control of electricity or water utilities, etc. However, in the project initiation stage, we need a specification standard for describing sensors and data.

To meet the requirement for specification standards, this paper presents the requirement analysis of a synergizing IoT scenario, and overviews the state-of-the-art on information representation for the Internet of Things. The remainder of this paper is organized as follows: Section 2 briefly discusses the background of the Internet of Things, examines a typical synergizing IoT scenario, and analyzes requirements for representing sensor data. Section 3 reviews the state-of-art on information representation for the Internet of Things. Section 4 discusses the interesting research topic of semantic service composition, which is followed by conclusions.

2 Representing Sensor Information

2.1 Internet of Things (IoT)

As NIC defines the IoT concept,[2] "*IoT refers to the general idea of things, especially everyday objects, that are readable, recognizable, locatable, addressable, and/or controllable via the Internet — whether via RFID, wireless LAN, wide-area network, or other means.*" This definition specifies key characteristics for IoT things: such things must be addressable, controllable, and use the Internet as the major means of interaction with other IoT things.

We describe the IoT concept in this paper from four perspectives: IoT things, IoT networks, IoT service systems, and IoT controls. IoT things refer to everyday objects, which are context aware, able to perceive, and able to extract information on their surroundings with the help of RFID (Radio-Frequency Identification) and sensor technology. People manipulate IoT things via IoT networks. For example, IoT sensors help monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, humidity, or pollutants. These sensors cooperatively pass their data through the IoT network to an IoT things of server. The IoT network is a part of the Internet, and an extension of the Internet as an ubiquitous network. The IoT network

[1] http://www.mediateam.oulu.fi/projects/mammoth/?lang=en

[2] http://www.dni.gov/nic/PDF_GIF_confreports/disruptivetech/appendix_F.pdf

consists of smart everyday objects. These objects transmit data and exchange information with each other. Analogically, if the Internet is the artery for information exchange, then the Internet of Things is the capillary network for that information exchange, and its control system. The IoT network is ubiquitous, and has networking capabilities to support various classes of applications/services that require "any services, anytime, anywhere and any devices" operation. IoT networking capability should support human-to-human, human-to-object (e.g., device and/or machine), and object-to-object communications. IoT service systems refer to computer programs responsible for logics management, data processing, and storage for any purpose.

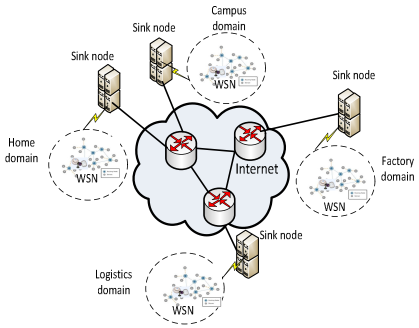

Fig. 1. Internet of Things with a synergizing application

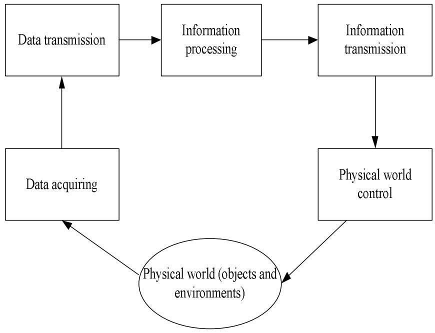

Fig. 2. Information flow in an IoT application

Figure 2 illustrates information flow in an IoT application. To guarantee the information flow across heterogeneous sensor and network domains involves the questions of how to describe sensors as processing units, and how existing sensors can be composed to integrate. The next section will examine a synergizing scenario, and investigate the requirements for designing a sensor ontology.

2.2 A Synergizing Application and Requirement Examination

Take a synergizing application as an example of a smart-course schedule system.[3] Imagine everything as connected. Let us say a professor at the university is not feeling well, and calls in sick. The automatic system for the school sends an alert to all the students in the class, and cancels the class. Furthermore, this information is passed on to a system that adapts my agenda. It calculates the new time to my next class, which is two hours later, taking the transport timetable into account. The system could also re-set my alarm clock to wake me up later, and adjust the heating system and coffee machine.

In the above synergizing example, sensors are distributed across the university, the student dormitory, and the city travel system domains. The sensor involves different types of data, whether small and static, or big and dynamic. Fusion of data from multiple sensors leads to the extraction of knowledge that cannot be inferred from using individual sensors alone. There are still several impediments to data sensing in IoT. The network is limited by the lack of a well-developed common language for

[3] `http://www.youtube.com/watch?v=kq8wcjQYW90`

describing sensors, attributes, etc. This limits data fusion because different networks use different terminologies. The lack of integration and communication between these networks often isolates important data streams, or intensifies the existing problem of too much data and not enough knowledge. These systems need comprehensive sensor ontologies to establish a widely accepted terminology of sensors, properties, capabilities and services. It is necessary that the context terminology is commonly understood by all participating devices. Sensor ontology (i.e. representation scheme) is what facilitates the data fusion and increases interoperability, as well as providing contextual information essential for observations. An effective representation scheme must meet the following set of requirements:

- The scheme needs to be generic and extensible. Sensor nodes are extremely dense, and produce huge amounts of data. This data must be efficiently searched to answer user queries.
- The scheme needs to describe sensors' technical information, e.g. their temporal resolution. The scheme needs to describe how to access to the sensor. This is required not only for data retrieval, but also for sensor control or reconfiguration.
- The scheme needs to describe the location of a sensor, in particular, the location of the sensor with regard to the feature it is observing.
- The scheme needs to describe the physical sensor information regarding power source, consumption, batteries, etc.
- The scheme needs to describe operational information on process and results. A sensor may have a number of operations, with result information given in terms of inputs and conditions, accuracy, latency, resolution, effect, and the behavior description of the sensor.
- The scheme needs to be extensible, and to include larger macro instruments.

3 Information Representation for IoT Sensors

Many researchers have realized the problem of semantic integration of sensor data, and have tried to address the issue using semantic web technologies. This section presents a review on existing efforts or schemes for representing sensor data. Table 1 overviews the schemes developed for representing sensor data, with a brief description of each.

Table 1. Schemes for Representing Sensor Data

Name	Description
W3C SSN ontology (W3C)	Ten modules, consisting of 41 concepts and 39 object properties, built on four perspectives of sensor, observation, system, and property.
Ontology for adaptive sensor networks [4]	Networks involving the main concepts of processor CPU and memory, power supply, and radio or sensor modules.
Sensor network modeling frameworks [6]	Ontology describing the network topology and settings, sensor description, and data flow.

Table 1. (*continued*)

Ontology for sensor-rich information systems [7]	A UML-based representation for a vehicle/human detection ontology.
Sensor data ontology [8]	An initial class taxonomy which includes two main concepts: data and sensor.
Sensor data's pedigree ontology [9]	A refined pedigree ontology consisting of concepts regarding sensor, system, human, setting, software, InfoSource, report data, etc.
SensorML (Sensor Modeling Language)	A language that aims to describe the geometric, dynamic, and observational properties of dynamic sensors.
OntoSensor [3]	A system that includes definitions of concepts and properties adopted from SensorML, extensions to IEEE SUMO, references to ISO 19115, and constructs of the Web Ontology Language (OWL).
W3C Efficient XML Interchange (Efficient XML Interchange)	An IoT system that exploits the EXI format to mitigate the size and parsing complexity of the XML, while maintaining most of its capability.
DPWS (DPWS)	Defines a minimal set of implementation constraints to enable secure Web Service messaging, discovery, description, and eventing on resource-constrained IoT devices.
CESN ontology [10]	Core concepts are the physical sensor, Sensor*;* the *PhysicalProperty* that a *Sensor* can measure; and the measurement that a sensor has taken, *physicalPropertyMeasurement*.
CSIRO sensor ontology [5]	Organized around four core clusters of concepts: Feature, Sensor, Sensor Grounding, and Operation Model and Process.
WTN ontology [11]	Ontology based on OWL-S, and focused on the following aspects: services, manufacturer's view, bridging axioms, and syntactic description.

At the heart of semantic web technology is the concept of ontology. An ontology is defined as an explicit and formal specification of a conceptualization system [12]. There are four types of ontologies, namely top-level, domain, task, and application ontologies. At a broad level, Sheth et al. [13] classified ontologies according to the three types of semantics associated with sensor data – spatial, temporal, and thematic, in addition to ontological models representing the sensor domain. The many advantages of sensor ontology design include: a) classification of sensors according to functionality, output, or measurement method, b) location of sensors that can perform a particular measurement; collection of data spatially, temporally, or by accuracy, c) inference of domain knowledge from low-level data, and c) production of events when particular conditions are reached within a period. The efforts made to date concerning semantic sensor information representation are as follows.

The W3C Semantic Sensor Network Incubator group (the SSN-XG) [14] produced an SSN ontology to describe sensors, observations, and related concepts. SSN does not describe domain concepts, time, locations, etc. as these are intended to be included from other ontologies via OWL imports. The SSN ontology is organized into ten modules, consisting of 41 concepts and 39 object properties, directly inherited from 11 DUL (DOLCE-UltraLite) concepts and 14 DUL object properties. The SSN can describe sensors, the accuracy and capabilities of sensors, and observations or methods used for sensing. Also, concepts for operating and survival ranges are included. A structure for field deployments also describes deployment lifetime and sensing purpose of the deployed macro instruments. The SSN ontology is built on four main sensor perspectives: a sensor perspective (with a focus on what it senses, how it senses, and what is sensed), an observation perspective (with a focus on observation data and related metadata), a system perspective (with a focus on systems of sensors, deployments, platforms, and operating or survival conditions); and a feature and property perspective (focusing on what senses a particular property or what observations have been made about a property). The SSN ontology is currently used in a number of research projects, where its role is to describe sensors, sensing, the measurement capabilities of sensors, the observations that result from sensing, and the deployments in which sensors are used. The ontology is OWL-based, and covers large parts of the SensorML and O&M standards, omitting calibrations, process descriptions and data types.

Avancha et al. [4] described an ontology for adaptive sensor networks in which nodes react to available power and environmental factors, calibrate for accuracy, and determine suitable operating states. The sensor node ontology consists of the main concepts of processor CPU and memory, power supply, and radio or sensor modules. Five types of sensors are deployed in the sample network, namely vibration sensors, pressure-pad sensors, acoustic sensors, radioactive sensors, and sight optical sensors.

Jurdak et al. [6] defined an ontology that integrates high-level features to characterize sensor networks for customizing routing behavior. The ontology describes the network topology and settings, sensor description, and data flow. The two closely related topology features are location-awareness (i.e. whether or not the sensors are aware of their relative locations), and sensor deployment (i.e. the process by which the sensors are deployed). The network setting describes the communication media used, the transmission technology, operating environment, etc. The sensor description features routing protocols, memory size, battery lifetime, processor technology, etc. The data flow features data acquisition approaches such as time-driven, event driven, or demand-driven acquisition.

Enabling scalable sensor information access helps to define an ontology and its associated sensor information hierarchy in order to interpret raw data streams. Liu and Zhao [7] presented a UML representation for a vehicle/human detection ontology used for describing the data that can be provided by a sensor information system. Using this ontology, multiple end-users can simultaneously interact with a sensor-rich information system, and query the system for high-level events without dealing with raw signals.

To enable scalable and precise sensor information searches, Alamri et al. [8] defined an ontology that associates sensor information taxonomy for searching and interpreting raw data streams. The initial class taxonomy includes two main concepts: data and sensor. Data could be calibration, format, or parameter information. The sensors could be actuators and transducers. The experimental evaluation of this ontology is limited to validating the ontology's logical inconsistencies, and comparing the performance parameters of a search engine when utilizing the ontology as compared with traditional searching.

The pedigree or provenance of sensor data describes how the data was collected, and what it contributes to. It is extremely important to take data pedigree into consideration when performing level one fusion (i.e. attempts to combine data collected from multiple sensory sources into a single cohesive description). Matheus et al. [9] made efforts to develop an initial pedigree ontology for level-one sensor fusion, in which the highest level concept is "information object," represented by the InfoObject class. Associated with the InfoObject is its pedigree, which is represented by a class called InfoObjectMetaData. The refined pedigree ontology consists of concepts regarding sensor, system, human, setting, software, InfoSource, and report data etc. at the high level. The design and development of this pedigree ontology is based on a naval operation scenario examination.

The SensorML [15] aims to describe the geometric, dynamic and observational properties of dynamic sensors. This language goes beyond just describing individual sensors. Different sensor types can all be supported through the definition of atomic process models and process chains. Within SensorML, all processes and components are encoded as application schema of the Feature model in the Geographic Markup Language (GML) Version 3.1.1. This specification allows sensor providers to describe *in situ* what a sensor can observe, with what accuracy, etc. The language also introduces the notion of virtual sensors as a group of physical sensors that provide abstract sensor measurement.

The OntoSensor [3] was intended as a general knowledge base of sensors for query and inference. This system includes definitions of concepts and properties adopted in part from SensorML, and partly from extensions to IEEE SUMO, references to ISO 19115 and from constructs of the Web Ontology Language (OWL). OntoSensor adopts classes and associations from SensorML to create specific sensor profiles, and also extends IEEE Sumo concepts. In addition, the implementation of OntoSensor references the ISO 19115 constraints.

Considering means of reducing overhead, the W3C Efficient XML Interchange Working Group has developed an encoding system that allows efficient interchange of XML Information Set documents [16]. A major design decision in EXI is to use XML schema information for the encoding. Both endpoints must use the same schema files to generate the EXI grammar [17]. The IoT exploits the EXI format to mitigate the size and parsing complexity of the XML, while maintaining most of its capability for enhancing data with context information. EXI can reduce up to 90% of the original XML message size, thus carrying a rich set of information in very small packets. However, highly resource-constrained IoT devices are not capable of parsing and processing schema sets during runtime [18]. Hence the EXI grammar must be generated and integrated in the nodes at compile time, as described by Käbisch *et al.* [19].

The Devices Profile for Web Services (DPWS) is chosen as a suitable subset of web service protocols for machine-to-machine communication. DPWS defines a minimal set of implementation constraints to enable secure Web Service messaging, discovery, description, and eventing on resource-constrained IoT devices [20]. In addition, DPWS is fully aligned with Web Services technology, and includes numerous extension points, which allow for seamless integration of device-provided services in enterprise-wide application scenarios. In DPWS, service discovery can be done via multicast communication instead of querying a central service registry such as UDDI [17]. Research has also shown that DPWS can provide real-time capabilities [21].

To model IoT hardware used in the Coastal Environmental Sensor Networks (CESN), Matt et al. [22] developed the CESN sensor ontology to describe the relationships between sensors and their measurements. The CESN ontology [10] provides concepts about sensors and their deployments as seen by middleware responsible for database persistence. The core concepts in the CESN sensor ontology are the physical sensor devices themselves, *Sensor;* the *PhysicalProperty* that a *Sensor* can measure; and the measurement that a sensor has taken, or *PhysicalPropertyMeasurement*. The ontology is unconcerned with the sensor network's logical or physical topology, or with issues of intermediate aggregation within the sensor network. The ontology has a local knowledge base of facts describing particular CESN instrument deployments as instances of classes defined in the ontology. Moreover, the ontology has a collection of rule sets which represent the domain-specific knowledge and hypotheses of scientists. The main concepts found in the CESN sensor ontology are similar to the terminology described in SensorML.

A semantic sensor network would allow the network and its components to be organized, queried, and controlled thorough high-level specification. Neuhaus and Compton [5] developed the CSIRO sensor ontology for describing sensors and deployments. The CSIRO ontology is organized around four core clusters of concepts: those which describe the domain of sensing (feature), those describing the sensor (Sensor), those describing the physical components and location of the sensor (SensorGrounding), and those describing functions and processing (OperationModel and Process)—both processing on a sensor, and processing that can create a sensor from any number of data streams. CSIRO ontology does not serve to organize all concepts of sensing, but instead provides a language to describe sensors in terms of their capabilities and operations.

Undertaking research into simplifying the configuration and maintenance of wireless transducers (i.e. sensors and actuators) for wireless transducer networks (WTNs), Horan [11] summarized the requirements for transducer capability descriptions. Basically, the functionality of a device should be described in terms of its syntax and its semantics. The device and its description should be closely linked, the description should be machine-interpretable, and an *a priori* agreement on standards is insufficient. Further, Horan used the OWL-S as a basis for designing a framework for the exploitation of capability description focusing on the following aspects: services, manufacturer's views, bridging axioms, services provided by a class of devices, devices provided by themselves, and syntactic descriptions.

Other efforts have been made to describe the capabilities of sensor devices. Composite Capability/Preference Profiles (CC/PP) [23] are focused on describing the physical capabilities of a device such as its memory, CPU, etc. This standard is based on an extensible language, and it targets larger devices such as mobile phones and PDAs. TEDS [24] provides a similar description of transducers to SensorML, which provides a hardware description of the physical device, rather than of its functionality. A TEDS contains the information to identify, characterize, interface, and properly use the signal from an analogue sensor. The national marine electronics association standard 0183 [25] has become a standard protocol for interfacing navigational devices, for example Global Positioning System receivers. TinySchema [26], which is a schema for describing the attributes, commands, and events in TinyOS.

4 Conclusion and Discussion

The Internet of Things integrates wireless sensor networks with the Internet, and paves the way for people to live seamlessly in both the physical and cyber worlds. Those wireless sensor networks serve much like the nerve endings in the human body. The IoT requires information representation for uniformly developing and managing sensor data in wireless sensor networks. Thus it accelerates data integration and increases interoperability in sensor-intensive IoT applications. This paper discusses a generic Internet of Things structure, and examines requirements for designing information representation schemes for sensor nodes. The paper reviews the state of the art in sensor information representation for the Internet of Things. This work initiates the study of semantic information representation for the Mammoth project.

An interesting topic for future research concerns semantic service composition. This is an important technology for shifting the Internet of Things to the Web of Things. Semantic services are composed by connecting their inputs and outputs with compatible semantics. The connections between input and output of services could be implemented based on publish-subscribe mechanisms. The benefit of semantic service composition is that it makes automation compose services possible, and allows adaption to resource changes.

Acknowledgement. This work was carried out in the Mammoth project funded by Tekes — the Finnish Funding Agency for Technology and Innovation.

References

1. Gruber, T.R.: A Translation Approach to Portable Ontologies. Knowledge Acquisition 5(2), 199–220 (1993)
2. Zhou, J.: Pervasive Service Computing: Community Coordinated Multimedia, Context Awareness, and Service Composition. Dissertation, Acta Universitatis Ouluensis. Series C 399, University of Oulu, Finland (2011)
3. Russomanno, D.J., Kothari, C.R., Thomas, O.A.: Building a Sensor Ontology: A Practical Approach Leveraging ISO and OGC Models. In: The 2005 International Conference on Artificial Intelligence, Las Vegas, NV, pp. 637–643 (2005)
4. Avancha, S., Patel, C., Joshi, A.: Ontology-Driven Adaptive Sensor Networks. Mobile and Ubiquitous Systems: Networking and Services. In: The First Annual International Conference on MOBIQUITOUS 2004, pp. 194–202 (2004)

5. Neuhaus, H., Compton, M.: The Semantic Sensor Network Ontology: A Generic Language to Describe Sensor Assets. In: AGILE Workshop: Challenges in Geospatial Data Harmonisation (2009)
6. Jurdak, R., Lopes, C.V., Baldi, P.: A Framework for Modeling Sensor Networks. In: Workshop on Building Software for Pervasive Computing, OOPSLA (2004)
7. Jie, L., Feng, Z.: Towards Semantic Services for Sensor-Rich Information Systems. Broadband Networks. In: 2nd International Conference on BroadNets 2005, vol. 2, pp. 967–974 (2005)
8. Alamri, A., Eid, M., El Saddik, A.: Classification of the State-of-the-Art Dynamic Web Services Composition Techniques. Int. J. of Web and Grid Services 2(2), 148–166 (2006)
9. Matheus, C.J., Tribble, D., Kokar, M.M., Ceruti, M.G., Mcgirr, S.C.: Towards a Formal Pedigree Ontology for Level-One Sensor Fusion. In: 10th International Command & Control Research and Technology Symposium (2005)
10. CESN Sensor Ontology (2008), http://www.cesn.umb.edu/sensor/cesn.owl
11. Horan, B.: The Use of Capability Descriptions in a Wireless Transducer Network. SMLI Technical Report (2005)
12. Zhou, J., Gilman, E., Riekki, J., Rautiainen, M., Ylianttila, M.: Ontology-Driven Pervasive Service Composition for Everyday Life. In: Denko, M., Obaidat, M.S. (eds.) Pervasive Computing and Networking. Wiley (2010)
13. Sheth, A., Henson, C., Sahoo, S.S.: Semantic Sensor Web. IEEE Internet Computing 12(4), 78–83 (2008)
14. W3C, http://www.w3.org/2005/Incubator/ssn/ssnx/ssn
15. Sensor Modeling Language, http://www.opengeospatial.org/standards/sensorml
16. Efficient XML Interchange, http://www.w3.org/TR/exi/
17. Moritz, G., Golatowski, F., Timmermann, D., Lerche, C.: Beyond 6LoWPAN: Web Services in Wireless Sensor Networks. IEEE Transactions Industrial Informatics 99, 1–1 (2012)
18. Bui, N., Zorzi, M.: Health Care Applications: A Solution Based on the Internet of Things. In: Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies, pp. 131:1–131:5. ACM, New York (2011)
19. Käbisch, S., Peintner, D., Heuer, J., Kosch, H.: Efficient and Flexible XML-Based Data-Exchange in Microcontroller-Based Sensor Actor Networks. In: IEEE 24th International Conference on Advanced Information Networking and Applications Workshops (WAINA), pp. 508–513. IEEE Press, New York (2010)
20. DPWS, http://docs.oasis-open.org/ws-dd/ns/dpws/2009/01
21. Cucinotta, T., Mancina, A., Anastasi, G.F., Lipari, G., Mangeruca, L., Checcozzo, R., Rusina, F.: A Real-Time Service-Oriented Architecture for Industrial Automation. IEEE Transactions on Industrial Informatics 5(3), 267–277 (2009)
22. Calder, M., Morris, R.A., Peri, F.: Machine Reasoning about Anomalous Sensor Data. Ecological Informatics 5(1), 9 (2010)
23. Composite Capability/Preference Profiles. Composite Capability/Preference Profiles, W3C Working Draft (July 28, 2003), http://www.w3.org/TR/CCPP-struct-vocab
24. IEEE Standard for a Smart Transducer Interface for Sensors and Actuators Transducer to Microprocessor Communications Protocols and Transducer Electronic Data Sheet (TEDS) Formats. [IEEE 1451.1] (approved September 16, 1997)
25. National Marine Electronics Association (USA): Standard 0183, Standard for Interfacing Marine Electronic Devices, Version 3.01 (January 1, 2002)
26. TinyOS TinySchema: Managing Attributes, Commands and Events in TinyOS, Version 1.1 (September 2003), http://telegraph.cs.berkeley.edu/tinydb/tinyschema_doc/index.html