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SIGHTED: A Framework for Semantic Integration of Heterogeneous Sensor Data on the Internet of Things

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Abstract

Sensors are embedded nowadays in a growing number of everyday life objects. Smartphones, wearables, and sensor networks together play an important role in bridging the gap between physical and cyber worlds, a fundamental aspect of the Internet of Things vision. The ability to reuse sensor data integrated from multiple heterogeneous sources is a step towards building innovative applications and services. In this paper SIGHTED, a sensor data integration framework, is proposed exploiting semantic web technologies and linked data principles. It provides a layered structure as a guideline for integrating sensor data from various sources supporting accessibility and usability. DotThing, a demo platform, is implemented as an instantiation of SIGHTED framework and evaluated. Smartphones and sensor nodes are connected to DotThing showing the ability to query and reuse integrated sensor data from multiple sources to create more flexible horizontal applications. DotThing implementation also demonstrates the need for adding a semantic layer to existing IoT cloud-based platforms, like Xively, that generally lack such layer resulting in proprietary vertical solutions with limited data integration and discovery capabilities. DotThing makes use of vocabularies from existing ontologies on the linked data cloud providing a unified model to annotate data and link it to existing resources on the web.

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1. Introduction

The Internet of Things (IoT) still does not have a widely accepted definition. IoT initially considered RFID tagged physical objects. The vision grown to cover distributed sensor networks, sensor-enabled devices and generally smart objects collaborating to support services that allow interaction with physical world. IEEE IoT Initiative recently released a document to establish a common definition of IoT[1]. According to IBM Center for Applied Insights, International Data Corporation (IDC) estimated that 212 billion sensor-enabled objects will be available by 2020, 30 billion of them will be connected to networks[2]. Although there is a progress in sensor-enabled devices abstraction, applications are still immensely coupled to sensor deployments in a vertical approach. Integration of sensor data from two various systems for reuse in unintended application is still not a trivial task. This tight-coupling is a result of heterogeneous sensor data representation formats, and absence of sensor data context and sensed value meaning except for a specific proprietary application. Sensor data true potential is unexploited in such vertical perception

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of data. A vital step towards the success of the IoT vision is the reuse of data collected from widely distributed heterogeneous sensor-enabled devices. In this horizontal approach applications can use data in an integrated way regardless the technical aspects of each system. Sensors in such case represent an essential way to collect data from their environment fetching states of real-world things by generating context data. This contributes to mapping physical world's people, places and things to cyber world bridging the gap between two largely disconnected worlds. Evolution of IoT and expansion of internet-connected sensor-enabled devices has resulted in massive amounts of data raising the need for huge data storage and computing power. This resulted in the emergence of IoT cloud-based platforms like Xively[1] and OpenSensors.io[2] for storing data to be used by proprietary applications. This approach requires prior knowledge of the used devices, software development environments and platforms' libraries and APIs.

Since most of sensor data on the web depends on heterogeneous models, data needs to be made available homogeneously to allow integration from wide variety of sources. A unified machine-understandable representation of world knowledge is required to put things into common semantic context. An approach to achieve data integration from various sensor deployments is adding a semantic layer annotating sensor data according to ontology concepts preferably applying linked data principles[3]. A considerable aspect for evolving IoT is building scalable distributed web-accessible sensor data platforms. Data collection context should be in computer-interpretable fashion to facilitate discovery and access to data using standard methods. The needed mechanisms are mostly supported by semantic web technologies. Resources can be explicitly annotated with semantic metadata encoding the meaning of their capabilities and measurement values to be interpreted by machines without human intervention. This facilitates the creation of intelligent applications and supports decision making and reasoning mechanisms. Efforts are still slow-paced towards creating generic, dynamic and scalable open platforms supporting reuse of such huge data bridging data silos.

A framework for Semantic InteGration of HeTerogeneous SEnsor Data (SIGHTED) is proposed as a reference to collect and provide uniform access to heterogeneous sensor data of multiple sources based on semantic web and linked data principles. DotThing platform is instantiated based on SIGHTED layered structure to publish integrated semantically annotated sensor data to be consumed by programs. The remainder of this paper is organized as follows: Section 2 discusses background and related work. Section 3 explains proposed SIGHTED framework. Section 4 presents proposed DotThing platform and results of initial performance evaluation and Section 5 concludes the paper.

2. Background and Related Work

2.1. Internet of Things Heterogeneity and The Semantic Web

Things in the context of IoT can be divided into three main classes. The first includes devices attached to objects for identification. The second class includes sensors and actuators to provide external access to object's properties and functions. The third class is for embedded sensor-enabled devices like wearables and smartphones with embedded access to their properties and functions mostly over the internet. Regardless the way in which things are connected to IoT, they should be uniformly discoverable and integrated with network infrastructure and its existing services which requires interoperability at multiple levels. IoT smart environments are growing in numbers and varieties of connected devices vendors. Developers should be able to build applications based on heterogeneous data independent of hardware and software capabilities. Communication and networking of smart objects within the IoT have been in research focus with some efforts of standardization[4,5,6]. Less focus is given on the application level to provide integrated web-accessible data in a unified way after data is collected from such multiple heterogeneous environments.

Open distributed platforms are needed to support such integration and to provide context and enhance knowledge extraction from sensor data. The Semantic Web[7] is an extension of current web in which the meaning of information is made explicit using ontologies. It can be considered as a huge distributed knowledge base of machine-understandable data. Semantic annotation of sensor data can be described as adding semantic tags to raw data to represent concepts, properties and relationships based on an ontology to describe the metadata associated to sensor data in a meaningful standardized way. This allows programs to automatically process information meaning integrating and relating heterogeneous data. It also allows reasoning capabilities by implicitly inferring logical consequences and new facts about sensor data where ontology languages encode domain knowledge and inference rules. Semantic web extends

[1] http://xively.com/
[2] http://www.opensensors.io/

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