Interoperability and sensor integration for smart farming

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Abstract:

Nowadays, many organizations and private companies, throughout the world have been actively investigating new ICT technologies for agriculture. They are from many different industries and economic sectors, ranging from finance, engineering, food retailers, to industry associations and groups of small farming suppliers. Due to the diversity and heterogeneity of the stakeholders, one of the main problems is interoperability of IoT 'Internet of Things' nodes. Interoperability is the ability of multiple systems with different hardware and software platforms, data structures, and interfaces to exchange data with minimal loss of content and functionality. In this paper, we will present our approach to solve the interoperability by considering the current state-of-the-art through a smart farming use case. Section 2 presents the related work on interoperability lied on metadata. In section 3, we present our contribution on the implementation of metadata based on SensorML illustrated by a use case: smart irrigation system. To validate our proposal, an example of integration of temperature sensor using SensorML standard into W3C semantic web stack is designed and implemented and an assessment and discussion will be dressed in section 4. Section 5 concludes this work and we will present some perspectives.

Keywords: Wireless sensor network; Interoperability; metadata; Semantic data; SensorML; Smart farming and IoT.

1. Introduction

The world population is expected to reach 9.8 billion in 2050 according to the United Nation report [1]. How to produce sufficient and high quality food to feed appropriately this increasing world population by using least planet resource with the climate change is an open research issue. Since the beginning of 20th century, like the development of the industry, the agriculture has been advancing continuously from agriculture 1.0 to agriculture 3.0 (precision agriculture) by adopting new technologies such as GPS and satellite image processing. To face the climate change and save scarce resources such as water (agriculture consumes 70% of the world's fresh water supply [2]) and arable lands, a new agriculture practice need to be invented (IoT Cloud based disruptive farming). Nowadays, many research institutes and private companies worldwide investigate all the new technologies (e.g., STT enumerates 20 technologies [3]), which can be used to increase agricultural and livestock yield by using least resources to preserve the environment and the biodiversity. IoT and cloud technologies are considered unanimously as the key technologies to drive agriculture 3.0 to the new disruptive agriculture or smart farming 4.0 [4]. Due to the diversity and heterogeneity of the ecosystem of players, it is very complex to develop generic standard applications for smart farming. The scope of the smart farming is very large ranging from big business, finance, engineering, chemical companies, food retailers to industry associations and groups through small suppliers of expertise in all the specialized areas of farming [2]. Therefore, interoperability is a key issue to make user-friendly large scale smart IoT cloud platform deployment a reality. Interoperability is the ability of multiple systems with different smart object 'IoT node' hardware and software platforms, data structures, and interfaces to exchange data with minimal loss of content and functionality [1]. A smart object is an object connected to the real physical world, capable of detecting event or sensing sensory data issued from physical world, of making interpretation and decision. Due to the lack of standard, until now smart objects were built with its own proprietary system, following a cloud computing architecture (Figure 1).

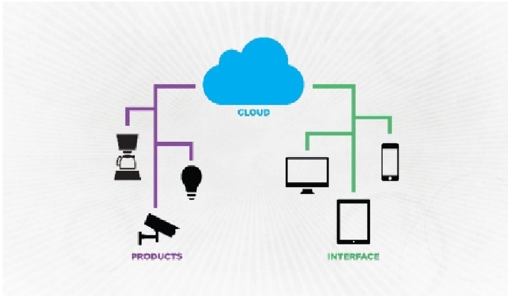

Figure 1. Smart objects connectivity architecture

Smart farming involves diverse actors such as consumer, farmer, cattle, plant and unmanned autonomous technologies such as robots. Therefore, to develop large-scale IoT deployment for smart farming 4.0 application, interoperability is the key issue. In this paper, we will investigate the interoperability of smart objects for smart farming 4.0 applications by focusing on metadata model. It is very difficult to achieve the interoperability for all applications, so we limit our survey on the interoperability for smart farming application. In general, a smart object has the following workflow and functional layers from hardware to web services:

- Heterogeneous sensors: multi-scalar sensors
- Multi-support local server/edge router: sensory data collection
- Metadata,
- Semantic data,
- Knowledge database, big data and ontology
- Web services: decision support system, search and extract relevant data.

For the basic physical level, interoperability of smart objects is solved by adopting wireless multi-support edge routers or local servers, which enables to collect sensor data by ZigBee, Wi-Fi, BLE etc. The modeling of the sensor data to use or share by different services is an open research issue. Metadata is the cornerstone to overcome this problem.

2. Related works

Describing a smart object with metadata allows it to be understood by both humans and machines in ways that promote interoperability. There are several types of metadata and the main challenge is to define metadata suitable for smart farming. Metadata is structured information that describes, explains, locates, or otherwise makes it easier to retrieve, use, or manage an information resource. There are three main types of metadata [1]:

• *Descriptive metadata* describes a resource for purposes such as discovery and identification. It can include elements such as title, abstract, author and keywords.

• *Structural metadata* indicates how compound objects are put together, for example, how pages are ordered to form chapters.

• *Administrative metadata* provides information to help manage a resource, such as when and how it was created, file type and other technical information, and who can access it. There are several subsets of administrative data.

Many current metadata schemes use SGML (Standard Generalized Mark-up Language) or XML (Extensible Mark-up Language) [2]. SGML is a superset of both HTML and XML and allows for

the richest mark-up of a document. However, useful XML tools are becoming widely available as XML plays an increasingly crucial role in the exchange of a variety of data on the Web.
Currently, some standards are proposed:

- IEEE Suggested Upper Merged Ontology 'SUMO' was created by merging a number of existing upper-level ontologies. SUMO focuses on semantic search and ontologies. These ontologies encompass content created by Sowa, Guarino et al., Allen, and Smith, as well as more concrete ontologies from the repositories at Stanford KSL and ITBM-CNR [8].
- OGC '*Open Geospatial Consortium'* SWE 'Sensor Web Enablement' suite of standards include: *Observations & Measurements* (*O&M*), *Sensor Model Language* (*SensorML*), *Sensor Observation Service* (*SOS*), *Sensor Planning Service* (*SPS*), *PUCK Sensor communication* protocol, and SensorThings, which is specifically designed for IoT and is currently in the finalization stage [5]. **W3C:** Web of Things, an initiative and vision from W3C's, focuses on the role of Web technologies for a platform-of-platforms as a basis for services spanning IoT platforms from microcontrollers to cloud-based server farms. Shared semantics are essential for discovery, interoperability, scaling and layering on top of existing protocols and platforms [12]. For this purpose, metadata is used and can be classified into: things, security and communications, where things are considered virtual representations (objects) for physical or abstract entities (Figure 2).

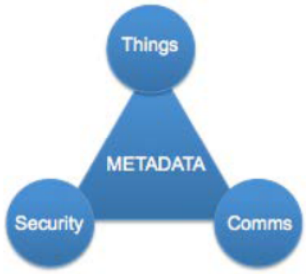

Figure 2. Metadata classification

W3C wants to make it easier for developers to create services that span platforms and enable an open market of services: RDF 'Resource Description Framework', OWL 'Web Ontology Language', and SPARQL.

W3C semantic web stack is clearly defined and supported by AIOTI (Figure 3) [11 , 12, 13].

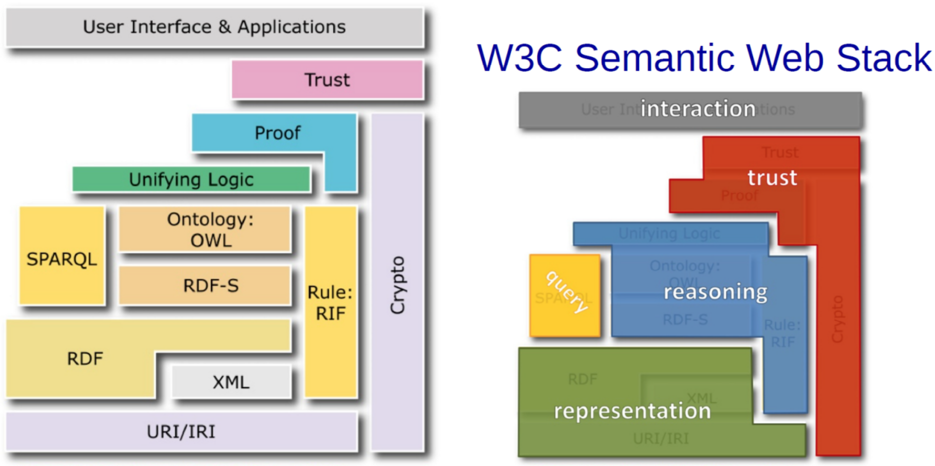

Figure 3. W3C semantic web stack [13]

Our work will focus on the development of a core metadata for smart farming application. Therefore, our implementation is in the representation layer particularly: XML 'eXtensible Markup Language' and RDF.

3. Integration of SensorML into W3C semantic web stack

3.1. Hybrid platform: edge, fog and cloud

In rural area, the QoS of wireless network is not as good as in urban areas. Moreover some areas may not be covered by mobile network operator. Therefore, to be able to adapt to diverse specific smart farming applications we adopt a hybrid infrastructure platform by combining the advantages of Edge, Fog and Cloud computing (Figure 4.

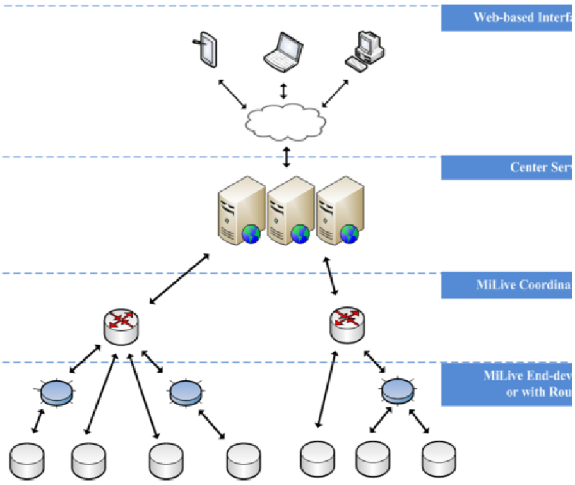

Figure 4. Hybrid platform dedicated for smart farming

3.2. Smart object platform: MiLive architecture

To validate our implementation of metadata for smart farming, MiLive platform will be used [15]. The MiLive is a multicore multimedia prototype node (Figure 5). It is built around 2 boards (size= 76mm*40mm): scalar WSN node (iLive) and Wireless Multimedia node based on RASPBERRY-Pi credit card format board (MWiFi).

The iLive board contains an ultra-low power nanocontroller and a 8-bit RISC AVR microprocessor equipped with the following sensors: 4 Watermark soil moisture sensors, 3 Decagon soil moisture sensors, 1 air temperature sensor and 1 soil temperature sensor, 1 air humidity sensor and 1 light sensor (Figure 1-a). For wireless communication iLive adopts the IEEE802.15.4 standard and it has a RS232/USB slave port which may be used to add specific sensor or device when need.

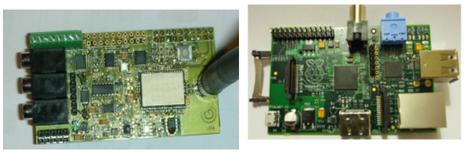

Figure 5. iLive scalar WSN Board (a) - Credit card RASPBERRY-PI board (b)

The MWiFi is RASPBERRY-Pi board containing three cores SoC: ARM11, GPU and ISP. MWiFi runs standard LINUX operating system (Figure 5-B). MWiFi supports different types of camera (USB and CSI) and WiFi module. Thus MiLive enables to implement multitier heterogeneous.

3.3. Functionalities of MiLive

The MiLive platform may be configured to run different modes: Scalar WSN, WMSN, Scalar and Wireless multimedia wireless network.

3.3.1. Scalar Wireless Sensor Network

To minimize energy consumption, MiLive may be configured to run as a scalar wireless sensor network. The MWiFi board is switched off by the power management unit based on the ultra-low power nano-controller. In case that the application does not need multimedia data, a simple iLive board may also be used to minimize the system cost. Notice that single iLive board has only IEEE802.15.4 wireless access medium.

3.3.2. Wireless Multimedia Wireless sensor Network
According to the application context, the scalar WSN board is switched off and the MiLive board will be used as a WMSN. Due to the high bandwidth need, IEEE802.11 is used to support wireless communication but for the IEEE802.15.4 may be activated to send small size messages to minimize energy consumption and increase system robustness.

3.3.3. Scalar and Wireless Multimedia Sensor Network
In this mode all the devices of MiLive may be activated simultaneously to meet the application requirements. Meanwhile to minimize energy consumption according to the context only needed devices are activated.

Thanks to the multicore, multisupport and modular architecture the MiLive enables to investigate the context-aware and resource-aware to increase the lifetime and the robustness of the whole WMSN. The MWiFi is switched on only when needed and it performs image processing (from simple to complex: mosquito detection) and the environment status will be sent through IEEE802.15.4 or IEEE802.11.b/g/a according to the message size and type. For image processing thanks to OpenGL (Open Graphics Library) OpenGL ES (Open Graphics Library for Embedded System), OpenCV (Open Source Computer Vision), Qt and available image processing library we can perform image processing easily on the MiLive. Therefore, the MiLive prototype finally enables to determine the computation resources and network bandwidth needed to meet the requirement of an application such as mosquito detection and precision agriculture.

Figure 6. MiLive platform dedicated to smart irrigation system

The local server of MiLive platform is a multi-support, which enables to collect sensory data from ZigBee, BLE and Wi-Fi wireless sensor nodes. All scalar data form different wireless sensor nodes (e.g., ZigBee) will be translated into the metadata.

4. Description of the logical MiLive platform by SensorML
From above, we can see that there are sufficient number of sensors on MiLive, the environmental information that we can obtain are: soil moisture, soil temperature, air humidity, light intensity and the information about the platform. Now we try to use SensorML to describe the platform, but only onboard temperature sensor will be presented.

The logical structure of MiLive based on SensorML is illustrated by the Figure 7.

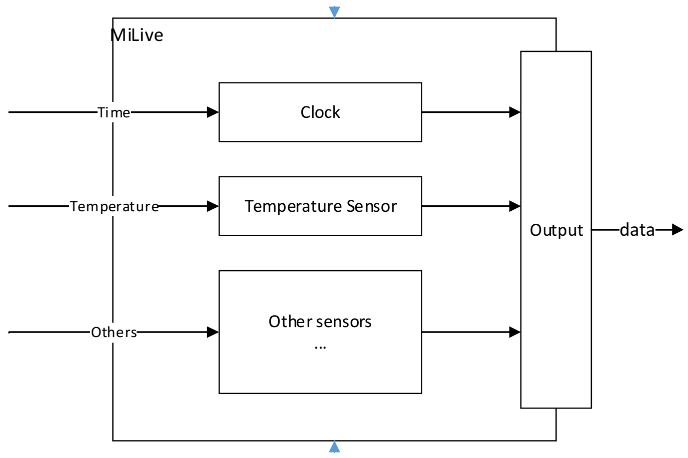

Figure 7. Logical structure of MiLive

Therefore, we can use the SensorML encoding standard to construct the XML description of the platform [14]. The basic description can be very specific by using all useful information including identification, classification, inputs, outputs, parameters and location. Notice that, the most important is to design the metadata, which will be described in the next section.

4.1. Design of the metadata

The data collected from different wireless nodes is multi-modal (temperature, light, etc.) and diverse in nature, so maybe only the developers/humans can understand the sensory data. To make the data machine-readable and machine-understandable, we should design the metadata for it. The data from different sensors has different formats containing diverse information, to construct the metadata is to choose a set of information to describe the original data and this set should be structured.

The sensors on the MiLive board can get data about soil moisture, soil temperature, air humidity and light intensity. All of them combined with the identification information of the board are scalar data, and our metadata for the sensors can be designed as follow:

{Sensor ID, Sensor Location, Date and Time, Value}

This structure is simple but it is enough to express all the information issued from the sensors. The "Sensor ID" can be used as the substitute of the identification information including sensor name, type and other characteristics; the "Sensor Location" can represent the geographical location information; the "Date and Time" indicates the date and time of the data record, and the "Value" is the measurement value of the air or soil temperature, soil moisture, air humidity or light intensity. All of the information can be translated from the original sensory data and after that all the metadata can be stored in the same document. For example, some temperature sensory data are described as following:

- Tempreture_Sensor_1; Location_1; 2018-05-11 09:00:00; 293.15
- Tempreture_Sensor_2; Location_2; 2018-05-11 09:00:00; 302.15
- Tempreture_Sensor_1; Location_1; 2018-05-11 09:00:01; 294.15
- Tempreture_Sensor_3; Location_3; 2018-05-11 09:00:05; 292.15
- Tempreture_Sensor_3; Location_3; 2018-05-11 09:00:06; 292.15

The metadata are the attributes of the data records. There are only 4 attributes for our system data. Can we do something only depends on this metadata which seems to be simplistic? The answer is yes. For example we can put the temperature sensors in the green house then set a threshold, when the average temperature is higher than the threshold the server can remind the farmer or switch on the fan. Obviously there are many other usages with temperature data and other types of measured value in the metadata.

4.2. Encode metadata with RDF

After the sensor data is transformed to metadata, all kinds of data can be stored into databases by using the same metadata model. We can use the relational database approach or NoSQL-based architecture for massive data sets, but it is not the only solution. Because data are highly interconnected, it is also possible to use graph to represent the data and their links. Moreover, the metadata is not enough for machines/computers to understand the data because we only change the format of the data and make it easier to aggregate the data. To make the data more machine-understandable and according to the W3C semantic web stack, we tested an approach based on RDF [12, 13]. RDF uses triples to describe resources and is designed to be read and understood by computers. The information expressed by RDF triples can be regarded as RDF graph and with graph the data can be stored as a network of objects with materialized links between them. There are several forms to express RDF triples and the direct one which is extended from XML is RDF/XML.

RDF is a part of the W3C's Semantic Web Activity so the specification of RDF can be found from W3C documents. The proposed metadata is described by RDF and illustrated by its graph as shown in the Figure 8.

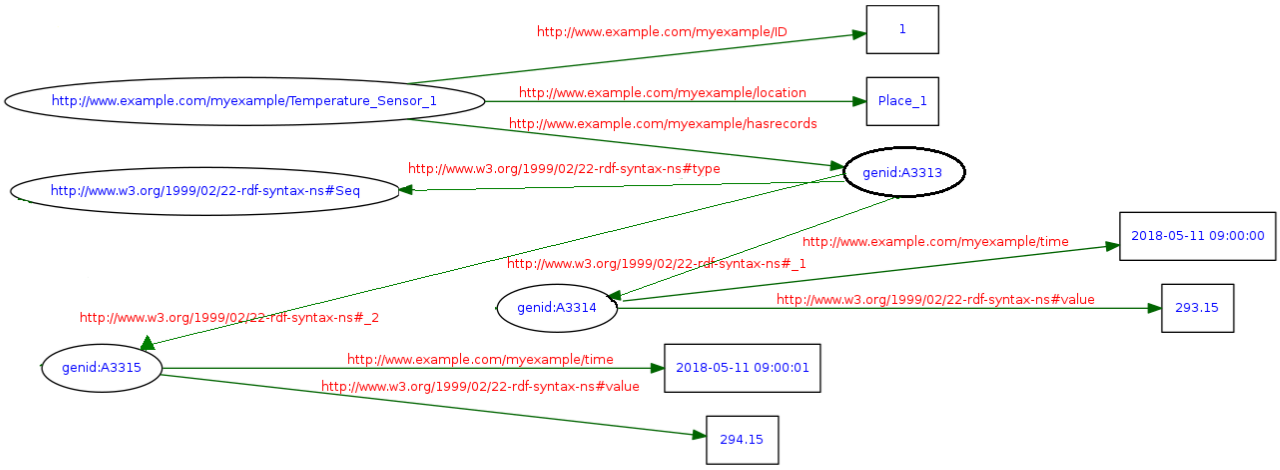

Figure 8. Example of RDF graph

The relations between objects are clear and every applications/services which use the data won't lose information.

4.3. Query the metadata

Also from the W3C semantic web, we can see that the representation of data can enable the query and the reasoning on the data. For the reasoning, more work are needed. In this paper, we focus mainly on the feasibility of using SensorML in the W3C semantic web stack. Therefore, we just make a query example using SPARQL.

Query all the temperature records from sensor with ID "2" (Figure 8):

```
prefix ex:  <http://www.example.com/myexample/>
prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#

select ?time ?temperature
where {
    ?x ex:ID "2".
    ?x ex:hasrecords ?z.
    ?z ?k ?record.
    ?record ex:time ?time.
    ?record rdf:value ?temperature.
}
```

time	temperature
"2018-05-11 09:00:04"	"298.15"
"2018-05-11 09:00:07"	"295.15"
"2018-05-11 09:00:03"	"299.15"
"2018-05-11 09:00:08"	"294.15"
"2018-05-11 09:00:00"	"302.15"
"2018-05-11 09:00:06"	"296.15"
"2018-05-11 09:00:09"	"293.15"
"2018-05-11 09:00:02"	"300.15"
"2018-05-11 09:00:01"	"301.15"
"2018-05-11 09:00:05"	"297.15"

Figure 9. Get all records from temperature Sensor 2

Figure 9 shows the of the SPARQL query of temperature values issued from Sensor 2 encoded by RDF.

4.4. Assessment

According to the example in Section 3, we show that we can use the simple metadata to standardize our sensor data and there is no loss of meaning. With simple rules which are defined by humans. These rules will be understood by the smart object (wireless sensor node) to perform some work automatically.

However, there are still other implicit rules that we should describe in advance actually. For example, how to encode the sensor type into the "Sensor ID" attribute, the measurement unit and the significant digits of the value, the method of geographical representation, etc. All of these need simple and widely accepted standards.

5. Conclusion

Interoperability is the cornerstone for large-scale deployment of IoT applications is still an open research issue. In this paper, we proposed the core metadata for scalar sensor dedicated to environment application such as smart farming. This basic core metadata may be enriched to meet the requirement of any large-scale IoT applications particularly it facilitates data integrating and sharing for Big data or knowledge database. For environment application, the proposed metadata core enables to develop semantic data for building data knowledge base. The results of this work show that, we can combine W3C and OGC (SensorML) standards to use the available upper W3C semantic web stacks. We will evaluate the proposed concept by investigating and developing central and small distributed knowledge database to implement efficient and reactive decision support systems to meet the requirements of cyber physical systems. The performances of these two approaches will be validated by field test results through the deployment of a set MiLive platforms.

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