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Do-it-Yourself Digital Agriculture Applications with Semantically Enhanced IoT Platform

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***Abstract*— Internet of Things (IoT) enables various applications (crop growth monitoring and selection, irrigation decision support, etc) in Digital Agriculture domain. Semantic enhancements to IoT platforms address challenges of interoperability, data fusion, integration of heterogeneous IoT silos, annotation of data streams, just to name a few. This paper discusses the recently developed OpenIoT platform which demonstrated its applicability and efficiency in a number of use cases, including a Digital Agriculture use case (Phenonet). An ontology to represent Phenonet domain concepts in order to facilitate smart collection, annotation, validation, processing and storing of data streams from sensors in the field has been proposed and the results of experimental study, related semantic queries and reasoning using the ontology are presented. A Do-It-Yourself principle-driven zero-programming enabling Phenonet user interface demonstrates benefits, novelty and efficiency of the approach.**

Keywords*— *internet of things, semantic web, semantic digital agriculture, do-it-yourself

I. INTRODUCTION

The term Internet of Things (IoT) collectively describes technologies and research disciplines that enable the Internet to reach out into the world of physical objects. Technologies like RFID, short-range wireless communications, real-time localization and sensor networks have become increasingly pervasive thus making the IoT a reality. According to the recent Gartner hype cycle report [1], IoT is currently at the peak of inflated expectations. The revenue as a result of this growth is estimated to be $1.9 trillion. IoT is described as an enabling and disruptive technology having a major impact on many areas of science, technology, business and economy. The IoT will fuel a paradigm shift of a "*truly connected*" world in which everyday identifiable *things* communicate with one another anytime, anywhere; become increasingly context-aware and smart; self configurable and show adept behavior when exposed to new, changing environments and circumstances; revolutionize revolutionary applications and business models [5].

It is estimated, IoT will grow to 26 billion units by 2020 excluding PCs, tablets and smartphones (40 billion things including tablets and smartphones). This stunning growth in IoT deployments will be a major source of big data fuelling myriad challenges. For example, systems will need to cope with the multi-model (light, noise, video etc.) and diversity of generated data (velocity, volume and spatiotemporal). Specific attention must be paid to address the issues around efficient solution that can structure, annotate, discover, share, store, analyze/process and make sense of IoT data and facilitate the seamless creation of IoT application and services by end-users.

Semantic computing manifests its potential to cope with the challenging problems of heterogeneity and interoperability implied by large amount of unstructured data on the web [3]. The semantic interoperability between things means, a common description of things and the data they observe can be shared with different stakeholders reducing ambiguous data descriptions. The unambiguous things description makes it easy for other application/services to discover relevant things for example using semantic reasoning and search techniques. Further, by employing linked data principles [6], a link between things and the application domain can be developed and facilitate effective reasoning of IoT data.

IoT presents an extraordinary potential in the future, however the current efforts and developments are still far from the IoT vision of a truly interconnected world. The heterogeneity, diversity and spatiotemporal characteristic of IoT make semantic interoperability between things a challenge. Moreover, there is a need for common frameworks that are driven by standards and support 1) representation of things using semantic annotations; 2) representation of data seamlessly across domains; 3) discovery at thing and data level 4) scalable methods to process and analyze large amounts of data; 5) Do-It-Yourself (DIY) principles driven tools for IoT service composition; 6) diverse set of people (technical and non-technical users) to share and control their creations in the "things" environment and 7) ability to break IoT application silos.

The aforementioned challenges outline the problems the IoT e-science use case presented in this paper confronts. To address these challenges, we present a semantically enabled solution for the e-science use case (Phenonet [7]) built on an open semantic IoT platform namely OpenIoT. Phenonet is a large-scale experimentation developed at CSIRO, Australia that studies the impact on plant growth and performance by observing environmental variations such as light, temperature and soil moisture to better evaluate and compare plant varieties. OpenIoT (http://www.openiot.eu) is a blueprint for open source middleware infrastructure enabling semantic

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integration of diverse IoT platforms using the notion of semantic interoperability, discoverable services and IoT Sensing-as-a-Service cloud model. OpenIoT platform is an implemented semantic IoT architectures using ITU-T Y.2060, IoT-A architecture, cloud computing principles and W3C standards. The proposed platform namely Phenonet-OpenIoT takes advantage of the semantic interoperability of OpenIoT platform in breaking application silos in current e-science experimental trials.

This paper makes the following contributions 1) presentation of the e-science use case (Phenonet) challenges, description and requirements; 2) development of a domain ontology to annotate and link sensor descriptions and sensor data and 3) implementation of a semantically driven IoT e-science application using intuitive Do-it-yourself tools. The rest of the paper is organized as follows. Section 2 presents related work in the semantic IoT area. Section 3 presents a description of Phenonet use case, ontology and sample queries. Section 4 presents an overview of the OpenIoT platform. Section 5 presents the Phenonet-OpenIoT implementation details.

II. RELATED WORKS

There is a current body of work in the area of semantic sensor networks such as OGC sensor web enablement standard [8] specifying interoperability interfaces and metadata encodings that enable real time integration of heterogeneous sensor webs into the information infrastructure. The OGC specifications are: Observations and Measurements (O&M), Sensor Model Language (SensorML), Sensor Observation Service (SOS). Sensor Planning service (SPS), Sensor Alert Service (SAS) and Web notification services (WNS). The SWE models are defined in XML which has significant semantic interoperability limitations and difficulty defining associations [3]. The W3C Semantic Sensor Networks Incubator Group has developed the Semantic Sensor Network Ontology (SSNO) [4]. The SSN ontology is a high level schema that describes sensors, observation and related concepts. The SSN ontology has received the consensus of the community and is widely used by number of projects including OpenIoT. The SSN also supports domain ontology extension which is later presented in this paper within the Phenonet-OpenIoT use case.

Another important area of research in recent years is the linked data approach that is essentially used to relate different resources. The four main principles [6] of linked data include: 1) using unique URIs to represent things; 2) providing HTTP interfaces to access the URIs (descriptions); 3) provide RDF information related to URIs and 4) link URIs. The linked data [9, 10] approach allows sensor descriptions and sensor data to be linked to the corresponding domain specific knowledge via different models and ontologies. Making this ontology accessible using the linked data concepts will facilitate easy resource discovery and make IoT data interoperable between domains. E.g., an entomologist studying the movement of locust can seek information from the weather bureau to understand the impact of weather on locust movement pattern. A number of works has been reported within the context of IoT web making sensor data available on the web. Examples include Kno.e.sis linked sensor data [10, 12], Sensor Masher [11], Sense2Web [13] and Linked Sensor Data serving RDF and GML [9]. The primary focus of the aforementioned systems is to make IoT data available via web interfaces (e.g. RESTful). They are limited to providing linked data descriptions of sensors and sensor data. However, to reach the much wider vision of IoT, it is imperative for end-users to create IoT domain specific applications that require fusion of sensor descriptions, sensor data and domain specific knowledge. The OpenIoT platform bridges this gap by providing associations between physical sensor descriptions, sensor data and domain concepts.

There is also plethora of work in the area of IoT middleware platforms. Examples include UBIDOTS (http://www.ubidots.com/), Xively (https://xively.com/), Thing Speak (https://www.thingspeak.com/), Open.Sen.se[1], IoTCloud [14] and SensorCloud[2]. These approaches are non-semantic commercial approaches with particular aim to simplify making data from all kinds of sources (physical devices, human input, online data, etc.) publicly available, and hiding the heterogeneity of data using a common API. Some approaches such as SensorCloud are tailored commercial solutions limited by specific sensor platforms.

All platforms typically provide basic functionalities for filtering and aggregating the data, as well as the formulation of events based on current input data. In this respect, OpenIoT will eventually cover most of these functionalities and will also go beyond that. Most importantly, OpenIoT puts much emphasis on the semantics of the collected, processed and available data (streams). This, in turn, allows for the support of (a) more sophisticated data filtering and aggregation techniques and (b) dynamic sensor/things selection and orchestration functionalities. OpenIoT platform has been developed with an interactive Do-it-yourself, (near) zero programming effort principles catering for both technical and non-technical users. The platform hides the complexities in accessing "smart things" encouraging users to contribute to the creation and sharing of IoT services.

III. PHENONET: SEMANTIC DIGITAL AGRICULTURE USE CASE

A. Challenges

The Australian government grain, research and development corporation (GRDC-http://www.grdc.com.au/) is a leading grains research organization. GRDC in collaboration with CSIRO conducts numerous experimental trials across Australia to understand and research about different grain types. The challenge is to cope with the volume of heterogeneous data produced by variety of trails. The current system support collection of data from these trials but has the following limitations:

- Too many trials producing heterogeneous silos of data that is available in CSV formats making it challenging to discover and interpret

[1] http://open.sen.se/
[2] http://www.sensorcloud.com/

- Ambiguity among description of user trials, crop variety etc (current approach support for metadata generation by end-users stored as key-value pairs in mongoDB)
- Limited search capabilities with hardcoded links between experimental trials and sensors.

To address these challenges, in this paper, we present Phenonet-OpenIoT, a semantically enabled IoT middleware platform for digital agriculture that 1) facilitates automatic annotation of sensor data and experiment data on-the-fly using the proposed Phenonet ontology (discussed later); 2) enables discovery of resources (sensors and domain specific experimental data) from heterogeneous trial data sets 3) provides a standard way for users to publish and share crop trial data promoting interoperability between applications and experiments and 4) allows users to compose and visualize services using discovered sensor and domain specific descriptions using Do-It-Yourself tools.

B. Experiment Description

The Phenonet project [7] uses state-of-the-art sensor network technology to gather environmental data for crop variety trials at a far higher resolution than conventional methods and provides high performance real-time online data analysis platform that allows scientists and farmers to visualize, process and extract both real time and long-term crop performance information from the acquired sensor measurements. Some of the benefits of Phenonet experiments include 1) Efficient and effective management of water resource; 2) Efficient and effective administration of fertilizers usage and 3) Identifying the influence of different conditions on variety of crops in real field environments.

A sample Phenonet experiment evaluates the effect of sheep grazing on crop re-growth by looking at root activity, water use, rate of crop growth and crop yield. In this experiment soil moisture sensors (Gypsum Soil Moisture Sensors –Figure 1) at multiple depths and canopy temperature sensors are used to track the extraction of water from the soil by the roots throughout the crop growing season. This information can then be used to obtain a measurement of root activity and crop growth. Figure 1 presents a sample Phenonet experimental trial. A trial is conducted in a plot which is an intersection of a row and column in a block. A block has the

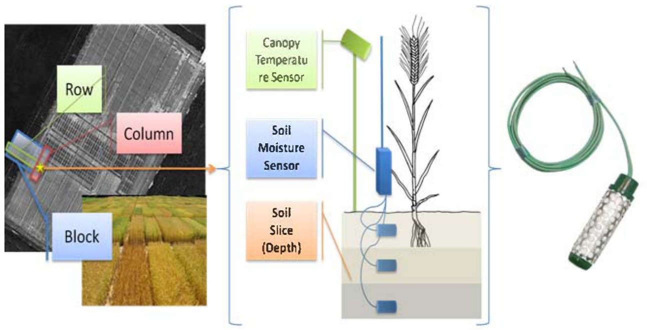


Figure 1: Phenonet Experimental Trial Description and Soil Moisture Sensor

same variety of crop and is divided into many plots each signifying a specific treatment applied to the crop. For example, each plot may have different application of fertilizers at different times.

C. Ontology

The Phenonet ontology is one of the contributions of this paper and is presented in Figure 2. The Phenonet ontology describes the structure of a Phenonet experiment and links the experiment to the sensors descriptions and the sensor data. The simplified ontology ensures representation of concepts is simple and best captures the current state of experiments and trials obtained from user studies. The processes and regions described by the Phenonet ontology use the DOLCE Ultra-Light upper ontology (http://www.loa.istc.cnr.it/old/DOLCE.html). The physical and technical nature of the installed sensor network (e.g. what phenomenon a sensor observes or what platform the sensor is on and, therefore, where it is located) are described using the OpenIoT-Semantic Sensor Network (SSN-XG) ontology (http://academics.openiot.eu/?q=ontology/ns). Existing ontologies fall short in concretely describing Phenonet domain concepts.

For example, crops with a specific genotype are sown into plots the crops are then subjected to a treatment (e.g. irrigation). The deployed sensors observe a sampling feature that samples either the plot as a whole, the experimental site or some sub-feature of the plot (e.g. a layer of soil within plot).

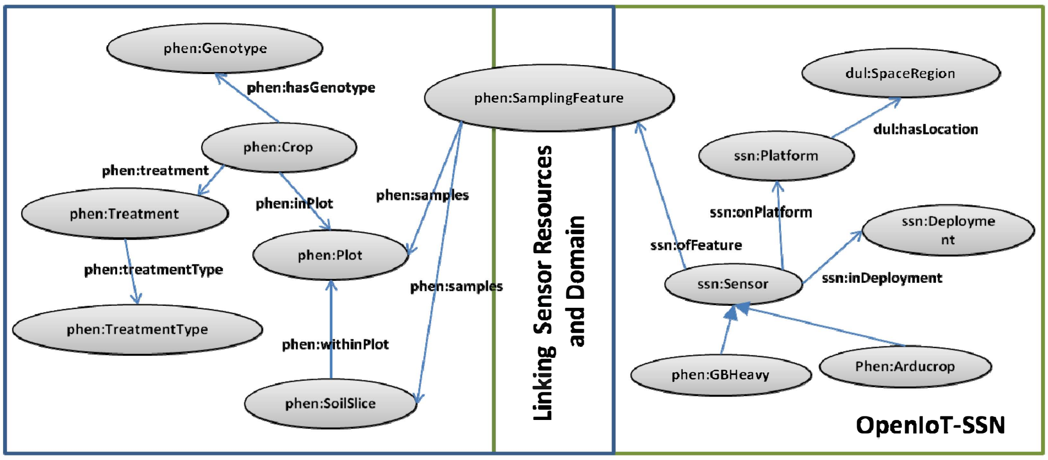


Figure 2: Phenonet – OpenIoT Ontology

The sampling feature allows sensors to be linked to plots and from the plot to the combination of genotype, treatments and events such as sowing dates that define the crop. Features can be related, so that a soil layer can be built from the individual plot/layer segments or plots linked into an experimental site. The ability to relate features means that measurements of larger systems, such as the site weather, can be seen to apply to sub-parts such as individual plots. The ontology allows mapping of the current non-semantic Phenonet data model to the semantically enabled OpenIoT- Phenonet system enabling on-the-fly automatic annotation of sensor data streams.

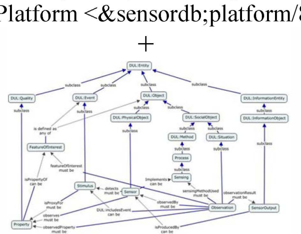
D. Queries and Reasoning

The ontology allows linking the sensor resources with domain specific knowledge enabling transformation of large IoT data into information, knowledge and wisdom as defined by the knowledge hierarchy [15]. The queries can be expressed in the domain of the experiment and using linked data principles and then navigates to sensors that measure appropriate information. Examples include 1) selecting the sensors that observe plots sown with a specific genotype; 2) selecting the sensors that observe plots in a specific block; 3) selecting the sensors that sample a specific depth of soil and 4) selecting sensors using sensor-specific information, such as location.

Conversely, the ontology with help of a semantic reasoner can be used to navigate from a sensor property to experiment-specific information e.g., the types of treatments that have canopy temperature data available. To achieve this we have built reasoning capability into the Phenonet-OpenIoT platform. The benefits reasoning provide to the Phenonet use case include 1) flexible resource discovery by continuous reasoning over newly available sensors; 2) generation of dynamic interfaces by inferring sensor and experiment descriptions; 3) adaptive to changes into domain ontologies and sensor descriptions (less hard coding) and 4) a validation use-case t demonstrate the extensibility of OpenIoT and the ease of its extensibility to implement domain specific logic and reasoning. An example of reasoning implemented in Phenonet-OpenIoT is presented in Figure 3. Sensor classes, such as GBHeavy, are defined as having specific properties such as performance characteristics, the type of phenomenon that the sensor can detect and presentation hints. A suitable reasoner will add these properties to an instance of the sensor class, if they are missing. Similarly, when searching for sensors, a reasoner supplied with a suitable ontology can navigate the experimental structure described in the domain.

<&sensordb;sensor/gbheavy/0011> a phenonet:GBHeavy;
ssn:onPlatform <&sensordb;platform/8109>

+



Phenonet-OpenIoT Ontology

Reasoner

<<&sensordb;sensor/gbheavy/0011> a phenonet:GBHeavy;
ssn:onPlatform
<http://sensordb.csiro.au/phenonet/platform/8109>;
phenonet:cssClass “gbheavy-sensor”;
ssn:observes < http://purl.oclc.org/NET/ssnx/cf/cf-property#soil_suction_at_saturation>

Figure 3: Phenonet – OpenIoT Reasoner Example

IV. OpenIoT: Open Source platform for IoT

The OpenIoT platform is a pioneering effort in developing an Open source semantically enabled IoT middleware. The OpenIoT platform will serve as a blueprint for non-trivial IoT applications, which will be delivered in an autonomic fashion and according to a utility model. OpenIoT environments for things will greatly facilitate the deployment and delivery of applications, since they will enable businesses and citizens to select appropriate data and service providers rather than having to deploy physical sensors. At the same time, they will provide capabilities (such as on-demand large scale sensing), beyond what is nowadays possible. In this section, we present a brief overview of the OpenIoT platform. A more detailed architecture of OpenIoT is presented in [16]. The architecture of the OpenIoT platform comprises the following:

Sensor Middleware (Extended Global Sensor Network, X-GSN) collects filters and combines data streams from virtually any sensors, both virtual and physical devices. OpenIoT uses the widely used GSN platform [17] which has been extended to incorporate automatic semantic annotations of sensor data streams.

Cloud Semantic Data Store (Linked Stream Middleware Light, LSM-Light) enables the storage of data streams streaming from the sensor middleware. The cloud infrastructure stores all the relevant sensor descriptions (metadata), OpenIoT ontology, domain specific ontologies and other functional data required for the operation of the OpenIoT platforms.

Scheduler and Service Delivery and Utility Manager (SDUM) processes all the requests for on-demand deployment of services, sensor discovery and ensures their proper access to the resources.

User Interface Do-it-Yourself Tools enables on-the-fly composition and visualisation of generic service requests using intuitive user interface tools.

V. Phenonet-OpenIoT

A. Architecture

Figure 4 presents the Phenonet-OpenIoT implementation architecture. As previously mentioned, the OpenIoT platform promotes a near-zero programming effort model to create IoT applications and services. The Phenonet-OpenIoT implementation focuses in providing an easy-to-use and flexible platform for domain scientists to analyze outcomes of Phenonet experimental trials with zero-programming. The Phenonet-OpenIoT platform allows scientist to discover relevant data, perform specific operation/analysis on the data and visually represent the data in the most appropriate form. The work flow of the Phenonet-OpenIoT system (rendered using Do-it-yourself tools) can be described as follows:

• X-GSN nodes announce the available sensors to the LSM directory service. The Phenonet extensions implemented on OpenIoT platform automatically generates semantic annotations for the incoming data streams and link them with corresponding domain concepts e.g. experiment type, site, location etc. The data from the sensors are published in SSN compliant RDF format based on each X-GSN local configuration (the architecture in Figure 4 can be made distributed by deploying distributed instances of X-GSN that push data to OpenIoT LSM cloud). A sample X-GSN sensor and experiment annotation in RDF format is presented in Figure 5 and Figure 6. Figure 5 describes a sensor with URI *http://sensordb.csiro.au/phenonet/sensor/arducrop/20140611-1962-0012*. The sensor has been mounted on a *platform*, with a *specific location coordinates deployed* in a *site*, samples a *geospatial feature (defined by plot location)* and has a *sensor class type (an ArduCrop canopy temperature sensor)*. Figure 6 shows a sample description of the Phenonet experiment in RDF. A specific treatment type (*phenonet:treatmentType*) is applied to a specific crop in a specific plot, with a type given by another resource, rather than a class that can be used by a reasoner. Which approach is used is a matter for the ontology designer.

• Users request from the scheduler all the available sensors that satisfy specific attributes (coordinates, experiment type etc) by using the Phenonet-OpenIoT user interface (UI) (depicted in Figure 7) described in detail later. The response from the LSM directory service is parsed by the reasoner (extension to OpenIoT platform) to link sensor descriptions with domain specific concepts as specified in the request.

• The reply is forwarded to the UI from the scheduler and the retrieved information is provided to the user. User with the help of the UI tool will define the request using simple workflows (motivated by do-it-yourself principles) over the reported sensors.

• This information, along with execution and service presentation preferences is then pushed to the scheduler as a service. The scheduler executes a combination of auto-generated SPARQL queries over the sensor descriptions and domain concepts to fulfill the user requests. This information is stored in the LSM directory service by the scheduler.

• After configuring the request, users are able to use the UI for visualizing data associated with the previously registered service. Through SDUM all the registered applications/services related to a specific user are made available to this user. The execution of the service corresponds to a collection of SPARQL scripts, which have been created by the UI and stored by the scheduler to the LSM directory service. The user interface shown in Figure 7 makes use of the domain model to build a list of sensors that satisfy domain criteria (e.g. sensors that observe plots containing crops with a specific genotype and treatment). The user can then request a new scheduled service that matches the chosen sensors and access data via SDUM.

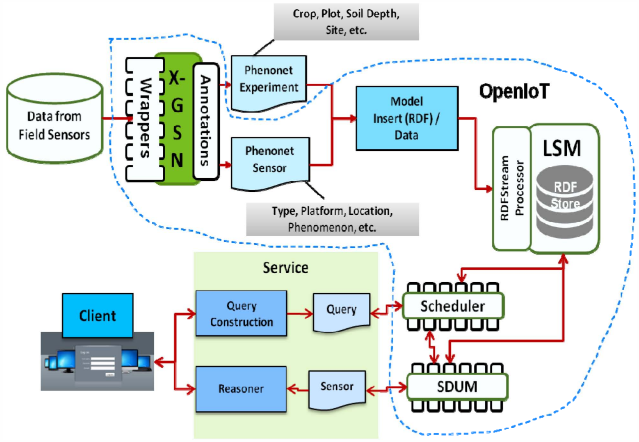


Figure 4: Phenonet-OpenIoT Architecture

```
<rdf:Description
rdf:about="http://sensordb.csiro.au/phenonet/sensor/arducrop/2014
0611-1962-0012"> <ssn:onPlatform
rdf:resource="http://sensordb.csiro.au/phenonet/experiment/kirkega
ard-and-danish/plot/4001/platform/phen077"/>
 <ssn:inDeployment
rdf:resource="http://sensordb.csiro.au/phenonet/deployment/site/ge
s-creek-range/20140611-1962-0000"/>  <ssn:ofFeature
rdf:resource="http://sensordb.csiro.au/phenonet/experiment/kirkega
ard-and-danish/plot/4001/sf"/>
<rdfs:label
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Cano
py Temp</rdfs:label> <rdf:type
rdf:resource="http://sensordb.csiro.au/ontology/phenonet#ArduCro
p"/> </rdf:Description>
```

Figure 5: Phenonet Sensor Description in RDF

```
<rdf:Description
rdf:about="http://sensordb.csiro.au/phenonet/experiment/kirkegaard
-and-danish/crop/revenue_c07r02/treatment/20140611-7210-
0008">
<phenonet:treatmentType
rdf:resource="http://sensordb.csiro.au/id/treatment-
type/grazedmow-low-n"/>
<rdf:type
rdf:resource="http://sensordb.csiro.au/ontology/phenonet#Treatmen
t"/>  </rdf:Description>
```

Figure 6: Phenonet Experiment – RDF Description for Crop Treatment

B. *Implementation Details*

The OpenIoT source is available for free download from https://github.com/OpenIotOrg/openiot/. Table 1 presents the Phenonet-OpenIoT implementation details. The entire platform is deployed in a JBOSS application server.

TABLE I. PHENONET-OPENIOT IMPLEMENTATION

Component	Implementation Details
Sensor Middleware (xGSN)	JAVA-based semantic sensor stream processor. Arduino and ArduCrop sensor used for Phenonet experiments
Cloud Semantic Data Store (LSM-Light)	LSM-Light developed using JAVA and Open Virtuoso triple store.
Scheduler and SDUM	Java applications deployed in JBOSS
Reasoner Service	Apache Jena supported by Phenonet OWL ontology
User Interfaces	Do-it-yourself tools developed in Java Server Faces (JSF)

C. Phenonet-OpenIoT Do-It-Yourself (DIY) User interface

The Phenonet-OpenIoT user interface is developed with use of DIY principles allowing end-users to easily develop and deploy Phenonet IoT application with near zero-programming efforts. The UI hides the complexities of semantics and ontological representations from the user by presenting concepts that the user is familiar with and understands e.g. plots, trials, sensor device barcode etc. The OpenIoT visual tools are generic and do not cater to specific needs of the Phenonet use case requirements (e.g. support for reasoning, representation of domain concepts etc). Hence, the development of the DIY interface is a key contribution of this paper. The UI is depicted in Fig. 7 and has the following features:

1) *Resource Discovery*: The user interface allows a user to search for sensors based on domain-based criteria, including genotype, crop treatment and the barcodes used to identify trial plantings, as well as sensor-based criteria, such as specific platform or location obtained from the ontology dynamically (discovery based on location is presented in Fig 7).
2) *Service Composition*: a faceted search interface is provided, presenting a menu of sensors matching the discovery criteria to the user. The user can then create and query a service based on selected sensors and incorporating scientific analysis (sample queries presented in section 3.4)
3) *Service Visualization*: represent the service using a variety of visualization outputs such as time-series graph as presented in Fig. 7.

VI. Conclusion

In this paper we presented the semantically enhanced digital agriculture use case Phenonet built with the OpenIoT platform (Phenonet-OpenIoT). We demonstrated and showcased how the semantic interoperability of the OpenIoT platform can help in addressing the challenges faced by Phenonet application. In particular, we have extended the OpenIoT platform to support the Phenonet use case by developing a domain specific Phenonet ontology using W3C SSN standard to link sensor resources with domain concepts and incorporating novel semantic reasoning capabilities. Large-scale validation of Phenonet ontology and OpenIoT platform are in the final stages of completion. Future work includes extending the use of OpenIoT platform to more diverse services in digital agriculture.

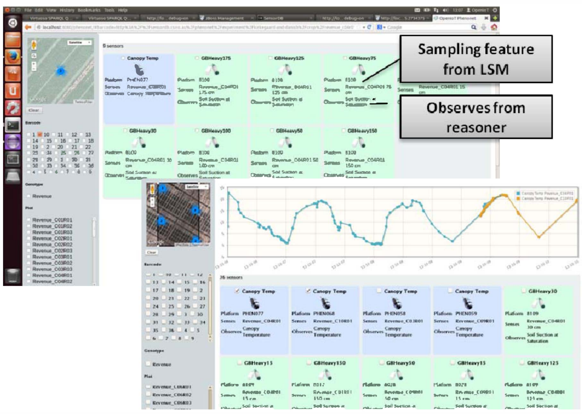


Figure 7: Phenonet-OpenIoT Do-it-Yourself User Interfaces

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References

[1] G. Eason, B. Noble, and I.N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955. (*references*)

[2] Gartner, “2014 Hype Cycle”, (2014) http://www.networkworld.com/article/2464007/cloud-computing/gartner-internet-of-things-has-reached-hype-peak.html, (accessed: Sept 12, 2014)

[3] Roeck. D.D, Slegers. K, et.al, (2012). “I would DiYSE for it!: a manifesto for do-it-yourself internet-of-things creation.” In Proceedings of the 7th Nordic Conference on Human-Computer Interaction (NordiCHI '12). ACM, New York, NY, USA, 170-179.

[4] Barnaghi. P, Wang. W, Henson. C, and Taylor. K. 2012. “Semantics for the Internet of Things: Early Progress and Back to the Future”. Int. J. Semant. Web Inf. Syst. 8, 1 (January 2012), 1-21.

[5] Lefort, L., et al. (2011), “Semantic Sensor Network XG Final Report,” W3C Incubator Group Report (2011).

[6] Sundmaeker, H., et al., eds. (2010), "Vision and Challenges for Realizing the Internet of Things," IoT European, Research Cluster, Mar. 2010.

[7] Berners-Lee, T. (2006), “Linked data”, available at: http://www.w3.org/DesignIssues/LinkedData.html.

[8] CSIRO, “Phenonet: wireless sensor in agriculture”, (2014) available at: http://www.csiro.au/Outcomes/ICT-and-Services/National-Challenges/Wireless-sensors-in-agriculture.aspx

[9] OGC, “Sensor Web Enablement”, available at: http://www.opengeospatial.org/projects/groups/sensorwebdwg

[10] Page, K., et al. (2009), Linked Sensor Data: RESTfully serving RDF and GML. In, Semantic Sensor Networks 2009 (SSN09).

[11] Patni, H., Henson, C., & Sheth, A. (2010), “Linked Sensor Data”, In Proceedings of 2010 International Symposium on Collaborative Technologies and Systems.

[12] Phuoc, D. L. (2009), "SensorMasher: publishing and building mashup of sensor data", in Proc. of the 5th International Conference on Semantic Systems (I-Semantics 2009).

[13] Patni, H, et al. (2010), "Provenance Aware Linked Sensor Data", in Proceedings of 2010 2nd Workshop on Trust and Privacy on the Social and Semantic Web, Co-located with ESWC, Heraklion Greece, 30th May - 03 June 2010.

[14] De, S., et al. (2011), “Service modeling for the Internet of Things”, 3rd Workshop on Software Services: Semantic-based Software Services.

[15] Fox, G.C. et. al.; (2012)"Architecture and measured characteristics of a cloud based internet of things," International Conference on Collaboration Technologies and Systems (CTS), , vol., no., pp.6,12, 21-25 May 2012

[16] Rowley, Jennifer (2007). "The wisdom hierarchy: representations of the DIKW hierarchy". Journal of Information Science 33 (2): 163–180.

[17] Soldatos, J.; Serrano, M.; Hauswirth, M., (2012) "Convergence of Utility Computing with the Internet-of-Things," Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), Sixth International Conference on , vol., no., pp.874,879, 4-6 July 2012.

[18] Karl Aberer, Manfred Hauswirth, Ali Salehi: Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks. MDM 2007: 198-20