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A Method for Mapping Sensor Data to SSN Ontology

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Abstract

Along with the continuous development of the sensor network technology, sensors from all over the world are constantly producing sensor data. However, the sensor data from different source is hard to work together for lack of semantic. Fortunately, SSN ontology provide a way to represent sensor data semantically, but how to transform sensor data into the instance of SSN ontology conveniently is still an issue to be considered. This paper proposed a solution to map sensor data to SSN ontology automatically based on a predefined XML-based document. We design a mapping language SASML (Sensors Annotation and Semantic Mapping Language) which provide a schema to annotate sensors and sources so as to generate a XML document for mapping. Then, an algorithm (namely SDRM) is designed to automatically transform sensor data, which described by SASML, to RDF conforming to SSN ontology, according to the mapping document and the element correspondences between the SASML and SSN ontology. Further, a case study about sensor data from greenhouse is presented to illustrate our method, and a prototype is also developed to demonstrate the feasibility and effectiveness.

Keywords: *sensor data, SSN ontology, mapping, semantic web, RDF*

1. Introduction

Recent years, the research of sensor network [1] is in the period of a hot spot and has been applied in different fields (*e.g.*, the environmental monitoring, health care, agriculture [2, 3]). No matter in which field, however, the different sensors observe the data which is in different formats, so it is difficult for users to integrate and share the sensor data. It gradually becomes the most challenging problem in the application of the sensor network. Since sensor data is isolated raw data which is observed by sensors, the mutual connections of the data can't be represented so that sensor data can't be utilized very well. For example, an observation value is isolated, so it is hardly for us to simultaneously be aware of when the value is generated, which type of the sensors it is observed by, and which kind of unit is used. Therefore, this raw data can't be utilized conveniently.

In order to make full use of the sensor data, we need to do a series of work for sensor network by means of the semantic web to transform the sensor data into the semantic data which can be understood by computers. In this way, the sensor data will be connected with each other so that it is convenient for the applications development. After the sensor data being converted to RDF, the mutual connections of the data can be represented. Then, based on the inner links, we can easily know the type of sensor as well as the indicator

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which is observed by the sensors (*e.g.,* temperature, humidity or CO2), thus we can further know about the information about its unit (*e.g.,* Celsius, RH or Klux).

At present, researchers are studying the conversion of the sensor data to RDF. Semantic Sensor Networks ontology namely SSN ontology [4] has become a standard in most fields of semantic sensor network, and there have emerged some researches about the application of the SSN ontology, *e.g.,* [5-8]. In agricultural areas, some researches have combined the sensor network with the semantic web on the basis of the SSN ontology (*e.g.,* [9]). The researches above are of great help for our study.

However, it is extremely inconvenient for the sensor data to be manually converted to RDF which conforms to the SSN ontology. Currently, there are two main methods which can transform the sensor data into RDF. One method is hard coding, but this method lacks universality. When data source changes, we should rewrite the program code. The other method is based on a mapping language (*e.g.,* D2RQ and R2RML) which can be used to describe the mapping between a data source and ontology. However, the existing mapping languages are usually somewhat complex and not specifically designed for the sensor data transformation, so this method lacks specificity. Therefore, we propose a method which is oriented to the semantic annotations of the sensor data and mapping to SSN in this article. Through the custom algorithm, the sensor data will be automatically transformed into RDF.

The main contributions of this study can be summarized as follows: (1) we design a mapping language named SASML (Sensors Annotation and Semantic Mapping Language) which provide a schema to annotate sensors and sources, and the elements of SASML can be mapped to the related concepts and properties of SSN ontology; (2) an algorithm SDRM (Sensor Data to RDF Mapping) is proposed, which can convert the sensor data to RDF automatically, according to the annotations of sensors and sources in the SASML mapping file; (3) we develop a prototype system to verify the feasibility of the mapping method by using the sensor data which is observed by the sensors in the greenhouse based on IoT.

The remainder of this paper is organized as follows. Section 2 mainly discusses the related work of this article. Section 3 describes the problem and method overview. Section 4 introduces SASML and SDRM. In Section 5, a case study is presented. Section 6 introduces the prototype system. In last part of this article, we give the conclusion and future work.

2. Related Work

At present, there have been many studies to focus on transform the sensor data into RDF. Currently, a lot of applications have emerged in the field of linked sensor data. For example, Esk Hydrological sensor network [10] and SENSEI [11] have done abundant work on the transformation of the sensor data to linked sensor data [12-14]. In many other fields, the study of the semantic sensor network is also indispensable, *e.g.,* the semantic medical monitoring system model [15] based. These studies have put different approaches to transform sensor data to RDF.

In the researches above, most of them focus on how to map the sensor data to an existing ontology through a specific mapping language such as D2RQ [16], R2RML [17] [18] and some other mapping languages. In [2, 19], both of them use D2RQ language and D2R server to process this issue. There is also a kind of mapping language RML [20] which is the extension of R2RML and is designed as a general mapping language for heterogeneous data. Its advantage is that it does not depend on the format of input data. However, although these kinds of mapping languages are general for different data sources as well as different ontology, they are not especially designed for the sensor data and are somewhat complex for the task of mapping sensor data to SSN ontology in most cases.

In view of the work above, the various kinds of semantic methods of the linked sensor data are very worthy of referencing. In this article, we customize a more concise method for the sensor data and use SASML to annotate the corresponding relationships between the SSN ontology and the sensor data in the mapping file. Through the transformation algorithm SDRM, the sensor data will be converted to the RDF. Comparing with D2RQ and R2RML mapping language, our method is easier to understand and is designed specially for the mapping between sensor data and SSN ontology.

3. Problem Description and Method Overview

3.1. Problem Description

Along with increasing requirement of semantic sensor web, more and more sensor data is represented in OWL format. Therefore, it is very significant for users to find a convenient way to equip sensor data with semantics. Thus, we design a service system to integrate the sensor data semantically, and the system framework is shown in Figure 1. This paper mainly focuses on how to represent the mapping which is based on SSN ontology as well as transform the sensor data into RDF. The correspondences between sensor data stored in the database and the concepts and properties derived from SSN ontology should be defined. We annotate the corresponding relationships in a XML file based on the SASML manually, and convert the sensor data into the instances of the SSN ontology through the mapping algorithm SDRM automatically. The transformation algorithm can convert the sensor data of different data sources to SSN ontology instances by using the same kind of method.

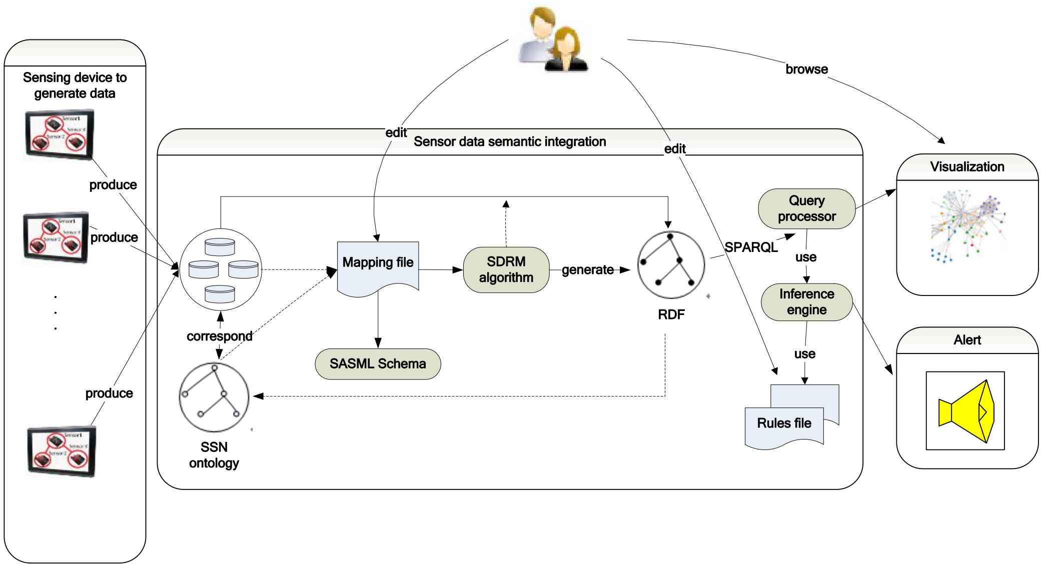

Figure 1. Service System Framework

3.2. Method Overview

According to the framework of our system, a method to map sensor data to SSN ontology is proposed. The goal of our method is to transform the sensor data in databases into the RDF which conforming to SSN ontology. As shown in Figure 2, the main steps to generate RDF are as follows.

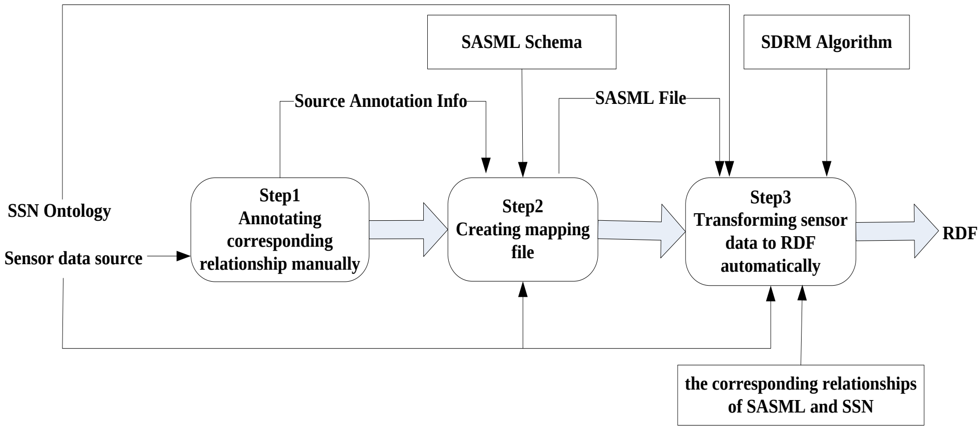

Figure 2. An Overview of the Method

Step 1: Annotating the corresponding relationships manually. In this process, the main work is to extract the information of the sensor data from data sources, and annotate the sensor data using SASML schema.

Step 2: Creating the mapping file. After annotating the corresponding relationships manually, we mainly generate the mapping file based on the SASML schema. The SASML mapping file includes the labeling information of the data sources and the sensor data.

Step 3: Converting the data in database to RDF automatically. In the final step, the system takes the mapping file as input, and using the predefined correspondences between elements between SASML and SSN ontology to transform sensor data to RDF automatically via SDRM algorithm.

4. The Definition of SASML

4.1. The Structure of the Mapping File

We need to extract the concepts and properties from the SSN ontology which correspond to the sensor data, according to the schema of the database and SSN ontology. However, if the data source changes, the corresponding relationships and the algorithm will also be modified, which will bring a lot of unnecessary work. As a result, we design a XML-based mapping language SASML to deal with this issue. The corresponding relationships will be stored in a mapping file based on SASML schema, which provides enough information for automatically transform sensor data to instances of the SSN ontology.

SASML falls into two parts: (1) SourceMapping. This part is used to describe the source information and indicate the key columns (*e.g.*, id of sensors, observation value, and observation time) for mapping with SSN ontology. It consists of the source id and the table names which consist of the key columns. (2) SensorAnnotation. This part is used to annotate every sensor, which is from the specific data source, with concrete sensor type, unit and location. It mainly includes the source id and the basic information of the sensors. The schema of SASML is shown in Figure 3, and the usage of each element is introduced as follows.

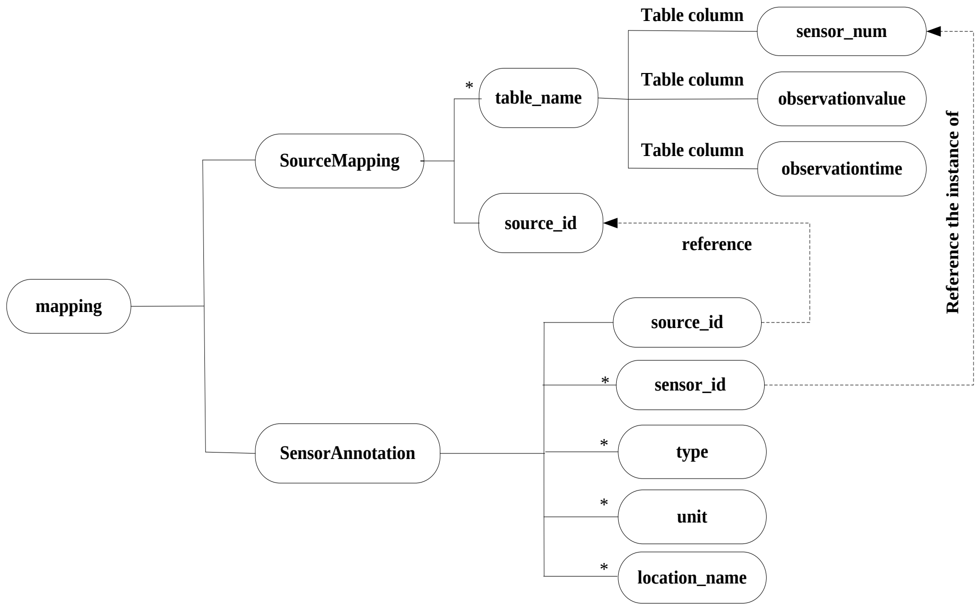

Figure 3. SASML Schema

As shown in Figure 3, *SourceMapping* is defined to indicate the information of different sources which is needed to be used for mapping. Among these annotations, the *source_id* represents the serial number of the source which is defined by users. *table_name* denotes the table's name of the source. *sensor_num*, *observationvalue* and *observationtime* represent the columns' names of the table, among which the *sensor_num* represents the column name of the serial numbers of each sensor. *observationvalue* represents the column name of the value observed by sensors. *observationtime* denotes the column name of the time when the sensors observe the value.

SensorAnnotation in Figure 3 shows that it is the annotation for each sensor of the specific source, and contains some basic information for these sensors. Among them, *source_id* is the id of the selective data source, and it should be one of the *source_id defined in SourceMapping*. *sensor_id* represents the serial number of the sensors, and the value of it should be one of the instances from the column indicated by the *sensor_num* of *SourceMapping*. *location_name* denotes the location information of the sensor. In order to facilitate users to know more about the information of the sensors, we add the type of the sensors as well as the unit of the observation values. The *type* represents the type of the sensors (*e.g.,* temperature, humidity). The *unit* denotes the unit of the observation value (*e.g.,* Celsius, RH). These pieces of information may be existed in data source or not. For the latter case, users should add the information manually to enrich the semantics of sensor data.

4.2 Correspondences between SASML and SSN Ontology

Since the SASML only provide the source and sensor information, it has not enough information for the mapping of sensor data to SSN ontology. As such, we should define the relationships, between the elements of SASML and SSN ontology, which are the hidden clues for the mapping process.

(1) The corresponding relationships between the element of SASML and the class of SSN ontology are listed in Table 1.

Table 1. The SASML Element, the Class and the Description of Them

SASML Element	SSN Class	Description
location_name	ssn:Deployment	the location of the sensors
sensor_id	ssn:Sensor	the number of the sensors
type	ssn:Property	the type of the sensors
observationvalue	ssn:SensorOutput	the output of the sensors
unit	ssn:UnitOfMeasure	the unit of the data
the text of observationvalue	ssn:ObservationValue	the values of the sensors observation
observationtime	ssn:Observation	the time of the sensor data

(2) The related properties, the domain and range of the properties in SSN ontology are listed in Table 2 [4].

Table 2. The Properties, Domain, Range and the Description

Property	Domain	Range	Description
ssn:ObservationResultTime	ssn:Observation	time^^string	the specific time of generating value
ssn: observes	ssn:Sensor	ssn:Property	the type of the sensors
ssn:isProducedBy	ssn:Sensor	ssn:SensorOutput	the output of the sensors
ssn:observedProperty	ssn:Property	ssn:Observation	the observationtime that a type of the sensors observes the value
ssn:observationResult	ssn:Observation	ssn:SensorOutput	the observationvalue which is produced by the sensors
ssn:observedBy	ssn:Sensor	ssn:Observation	the observationtime that the sensors observe the value
ssn:hasDeployment	ssn:Deployment	ssn:Sensor	the location_name of the sensors
ssn:hasValue	ssn:SensorOutput	ssn:ObservationValue	the specific value of the output
ssn:hasDataValue	ssn:ObservationValue	data^^string	the observationvalue of the output
DUL:isClassifiedBy	ssn:ObservationValue	DUL:UnitOfMeasure	the unit of the observationvalue

The correspondences defined above can act as glue to bridge the gap between the elements of SAML and the class and properties of SSN ontology, which can let the transformation algorithm understand the relationships between data source and SSN ontology.

To illustrate the relationships, we give an example which is shown in Figure 4. The left part of the Figure is the annotations of the sensors and data sources in the SASML mapping file. The related classes and properties of the SSN ontology which correspond to the annotations of the mapping file are displayed on the right side.

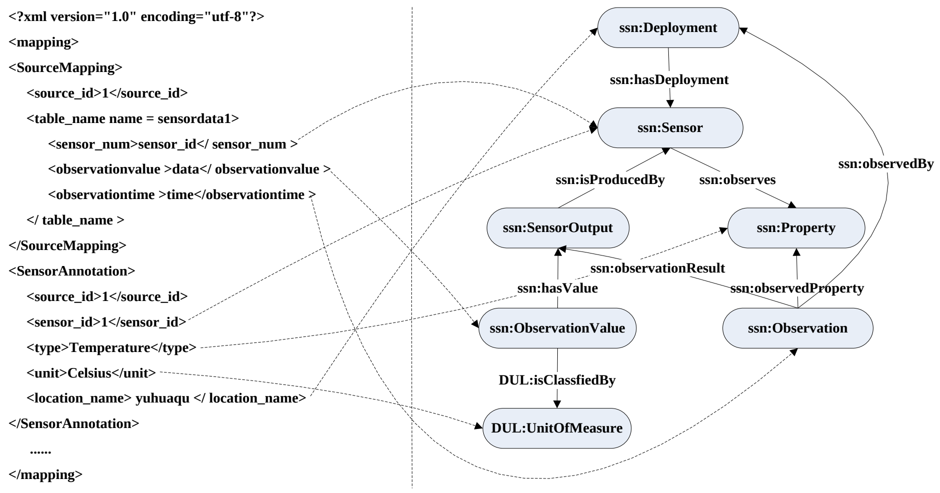

Figure 4. The Correspondences of the SAMXML File and the SSN Ontology

4.3 The Description of SDRM Algorithm

Given a data source, a mapping file SASML and the corresponding relationships of the SASML and the SSN ontology, we design an algorithm SDRM to transform the sensor data into RDF by reading and parsing the relationships which are annotated in SASML. First of all, we use DOM to parse the corresponding relationships of the mapping file. Secondly, the instances of the SSN ontology are created by using the following information: the elements which are parsed from the mapping file, the corresponding classes and properties in the SSN ontology, and the value retrieved from the database. Finally, according to the corresponding relationships, the instances will be connected through object properties and the data is added into the instances through data properties. Thus, the sensor data from data source are automatically converted to RDF triples. We have designed a Sensor Data to RDF Mapping (namely SDRM) algorithm, which is described in Table 3.

As shown in Table 3, SDRM transforming algorithm can parse the mapping file SASML and get *source* node *and* its sensor list *sensorlst* (line 1-2). From *source*, we can get the *tablename* and *keycolumns* (i.e. the column names of observation value and time) (line 3). According to the *tablename*, the observation resultset *rs* can be obtained (line 4). In line 5, we get the OntClass set and OntProperty set from SSN ontology model according to the correspondence list *L*. Then for each sensor, we create individual I^{sensor} as well as the annotation individuals $I^{annotation}$, and connect them using corresponding Object Property (line 6-11). Further, for each observation from the data source, we create individual $I^{sensorOutput}$, observation value individual I^{OBV} and observation time individual I^{OBT}, and set values for corresponding Datatype Property (line 12-16). Then, we connect $\mathrm{I}^{sensorOutput}$ with I^{OBV} and I^{OBT}, and connect I^{sensor} with $I^{sensorOutput}$ (line17-18). Finally, the sensor data in database is transformed into the instances of SSN ontology and stored in OWL file.

Table 3. The Algorithm for Transformation from the Sensor Data to RDF

Algorithm.transform(*OM*, *SASML*, *DB*, *L*)

Input: the SSN ontology model *OM;*
the mapping file *SASML*;
the sensor data in database *DB;*
the corresponding relationships list *L;*
Output: the ontology model *OM* with instances;
Steps:
1. parse *SASML* to get *source* node; //Here we assume just one source.
2. get corresponding sensor nodeList *sensorlst by source* id
3. get *tableName* and *keyColumns* name form *source*
4. *rs=DB.getResultSet(tableName);*
5. get OntClass set OC^{OM} and OntProperty set P^{OM} from *OM* according to L;
6. **for each** *sensor* **in** *sensorlst*
7. create sensor individual I^{sensor};
8. get annotation set *annoSet from sensor*
9. create individual set $ISet^{annotation}$ based on *annoSet;* (according to *corresponding OntClass*)
10. **for each** $I^{annotation}$ **in** $ISet^{annotation}$
11. connect I^{sensor} with $I^{annotation}$; (using corresponding Object Property *from* P^{OM})
12. **while** (rs.next())
13. create Individual $I^{sensorOutput}$;
14. create Observation Value individual I^{OBV}; (according to *corresponding OntClass*)
15. create Observation Time individual I^{OBT}; (according to *corresponding OntClass*)
16. Set values for corresponding DatatypeProperty using *rs.getvalue(keycolumn)*
17. Connect $I^{sensorOutput}$ with I^{OBV} and I^{OBT}; (using corresponding Object Property from P^{OM})
18. Connect I^{sensor} with $I^{sensorOutput}$; (using corresponding Object Property *from* P^{OM})

5. Case Study

5.1 The Sensor Data Sources

As a case study, we apply our method to the sensor data from greenhouse which is based on IoT technology. The SSN ontology is used as the target ontology.

According to the semantic annotation language SASML and the mapping algorithm SDRM presented above, we have implemented the transformation from the sensor data to RDF and applied it semantic greenhouse system to validate the correctness and feasibility of SASML and SDRM. The observation values are obtained via the sensors which are deployed in the greenhouse and stored in the database. The database schema is shown in Figure 5.

The database schema includes the Tables' description of *Sensor*, *Observation*, *Location*, *Type* and *Unit*. The *Sensor* table contains the serial numbers of sensor, type, unit and location. The *Location* table represents the location information of sensors, including location number, location name, latitude and longitude. The *Observation* table contains the observation values of the sensors and the time of observing the values. The *Type* table and the *Unit* table denote the type of sensors and the unit of the observed value respectively.

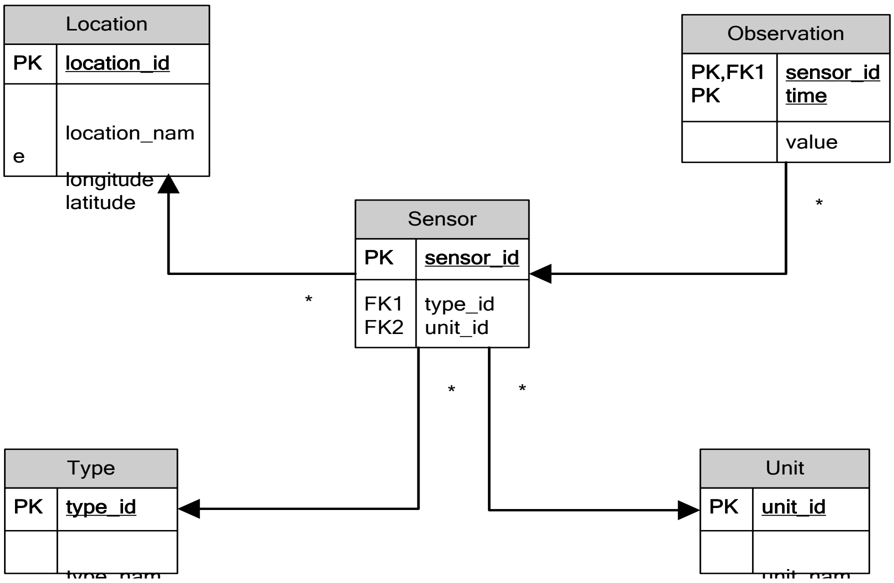

Figure 5. The Database Model

5.2 Transformation Process

According to the database schema given above, we edit the SASML mapping document manually. In the mapping file, we annotate the sensors which are deployed in the greenhouse and describe necessary information for the data sources. The segment of the generated mapping file is shown in Figure 6.

```
<?xml version="1.0" encoding="utf-8"?>
<mapping>
<SourceMapping>
        <source_id>1</source_id>
        <table_name name = sensordata1>
            <sensor_num>sensor_id</ sensor_num >
            <observationvalue >data</ observationvalue >
            <observationtime >time</ observationtime >
        </ table_name >
</ SourceMapping >
<SensorAnnotation>
        <source_id>1</source_id>
        <sensor_id>1</sensor_id>
        <type>Temperature</type>
        <unit>Celsius</unit>
        <location_name> yuhuaqu </ location_name >
</ SensorAnnotation >
   ......
</mapping>
```

Figure 6. The Segment of the SASML Mapping File

In this case study, the data source is the sensor data from the greenhouse based on IoT. As shown in Figure 6, the tag <*SourceMapping*> represents the source which is chosen by users in this experiment. The annotations in tag < *SourceMapping* > include the table name and the key column names respectively. The tag <*SensorAnnotation*> annotates the information of the sensors which are deployed in the greenhouse. The annotations in the tag <*SensorAnnotation*> denote the serial number, the type, the unit and the location of the sensors respectively.

Then, we use the SDRM algorithm to generate the result RDF according based on the SASML mapping file. To illustrate the result, we take the sensors in greenhouse which measure temperature as an example to show the result RDF segment. As shown in Figure 7, all the classes are from the SSN ontology and the DUL ontology which is quoted by the SSN.

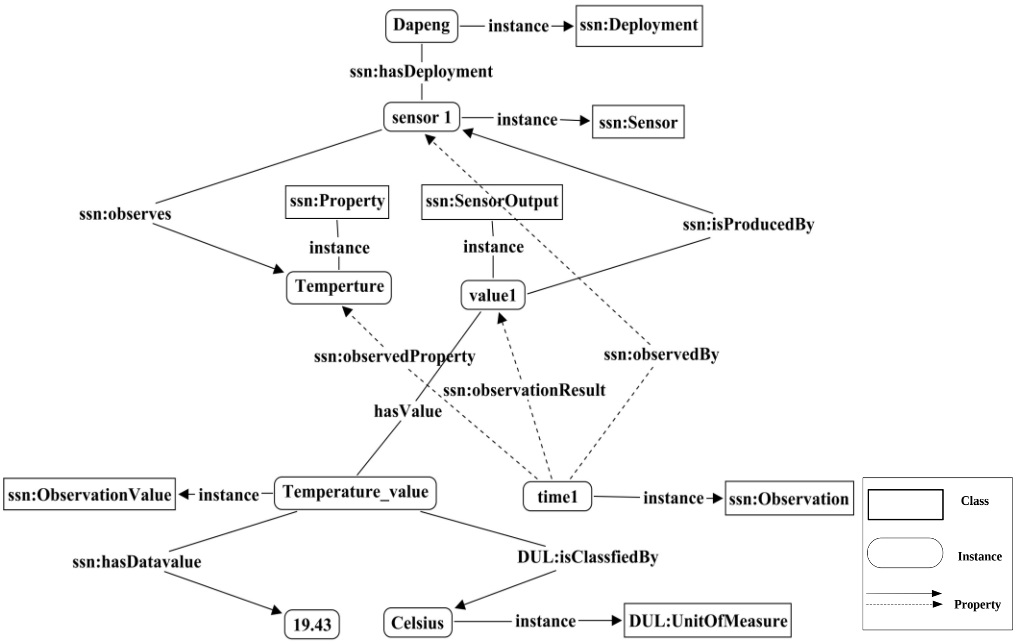

Figure 7. Temperature Sensor Example

We create the corresponding instances according to the database model. All the properties are also from the SSN ontology and the DUL ontology. The *sensor1* which is deployed in the system is a temperature sensor, and the type of the output is *Temperature_value*. The unit of the value which is observed by *sensor1* is Celsius and the value is 19.43. The *sensor1* is connected with the *ObservationTime*. In a similar fashion, all the sensor data is converted to the instances of ontology which are all linked together.

We also validate the correctness of the result RDF in protégé 4.3. The result is shown in Figure 8.

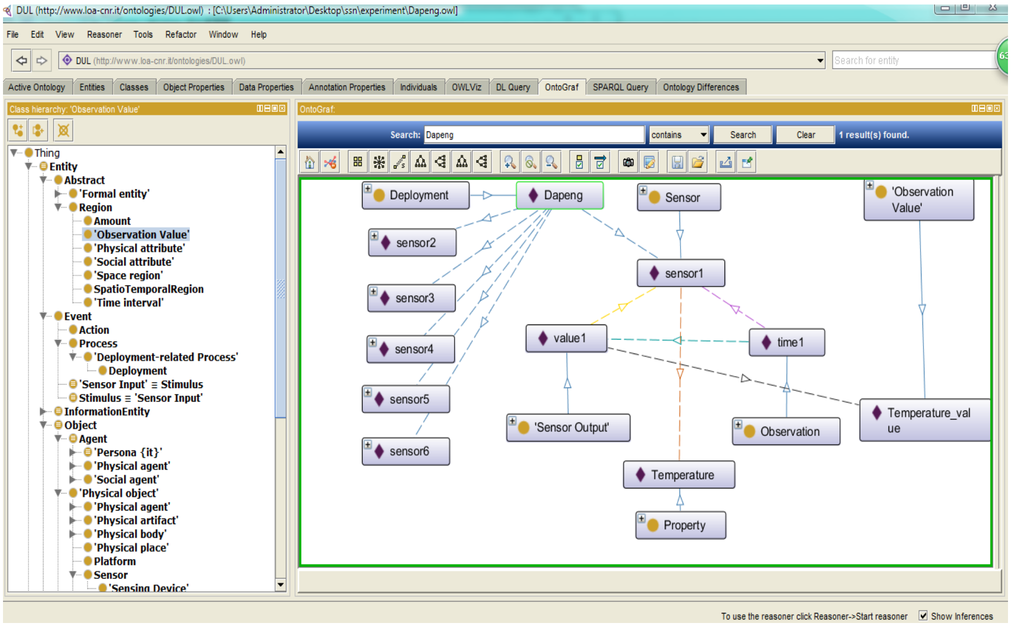

Figure 8. The Validation of the Result RDF in Protégé 4.3

6. The Experimental Prototype

The goal of the prototype system is to facilitate the process of creating SASML mapping file, transforming data source to RDF, and showing the result RDF. We develop this system using Netbeans 7.3, and provide an interface for users to complete the annotation, and the mapping file can be generated automatically. The GUI of the experimental prototype is shown in Figure 9.

In the first tab of the prototype, the left tree is used to select data source. Then two areas (*SourceMapping* and *SensorAnnotation*) are provided for users to input information according to the schema of SASML. A set of operations is provided in *SourceMapping* area which is in the middle of the GUI to facilitate the selection of information (*e.g.*, Table name, sensor column, observation value column, observation time column) from the data source.

The annotation for sensors is in *SensorAnnotation* area in the right pane of the interface. If there is not enough information (*e.g.*, unit, type of sensors) in database, users can also add the information of the sensors manfully. The annotation information of every sensor will be displayed in the table at the bottom of the GUI. When all annotation is completed, the mapping file will be generated automatically. Once the XML-based mapping file is constructed, it can be used for generating RDF.

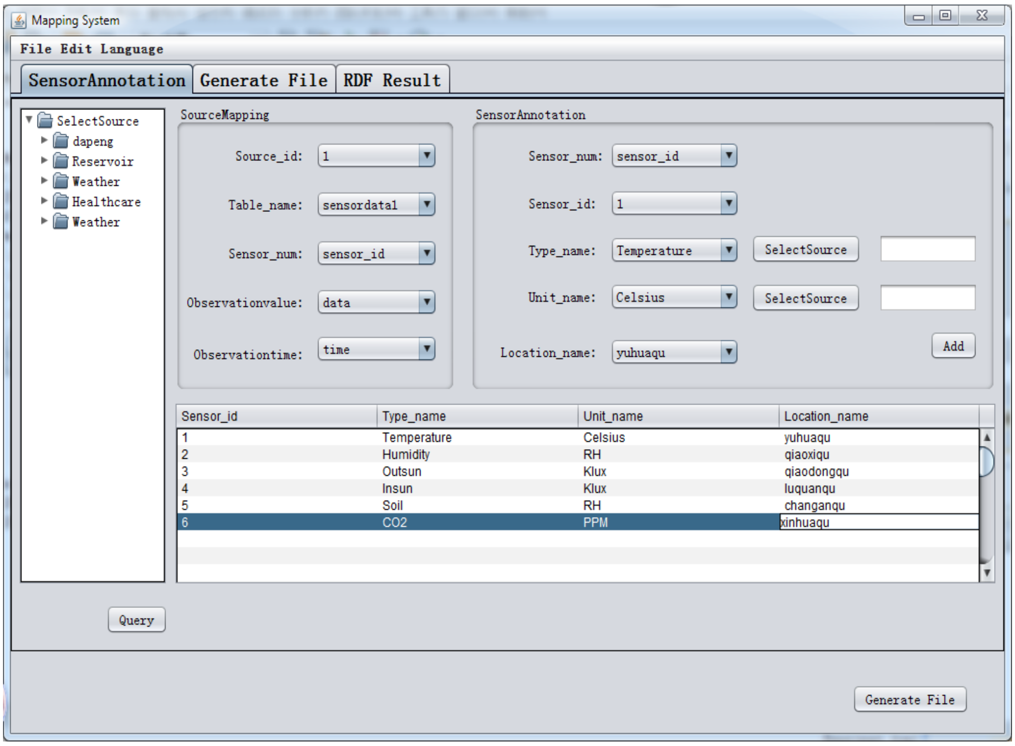

Figure 9. The Experimental Prototype

7. Conclusion and Future Work

This paper discusses how sensor data can be transformed into the RDF conforming to SSN ontology automatically by using the mapping language SASML and the algorithm SDRM. SASML covers the annotations of the data and can be used to annotate the basic information of different data sources in the database. Further, we have developed a prototype system to facilitate the mapping process. Besides, we have taken the sensor data from greenhouse as the experimental data source to demonstrate the feasibility and effectiveness of our method.

Although our algorithm is convenient and easy to use, the commonality is not very perfect yet. Therefore, in the future, we will strengthen our system and enhance the commonality of the SASML and SDRM to make it suitable for more cases.

Acknowledgements

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