Application of SensorML in the Description of the Prototype Air Monitoring Network

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Abstract: The aim of this publication is to present the use of OGC standards – SensorML and Observations & Measurements – to describe the sensor network and measurement process in the prototype of air quality monitoring network launched in Nowy Sacz in Poland. Standards are used to create structures of relational databases to achieve interoperability through data collection in an orderly manner in the field of environmental data and in the description of monitoring process. This is important especially when the system consists of a number of low-cost measuring devices, that are designed to complement existing measurement network.

1 INTRODUCTION

There are currently a lot of mobile and stationary sensors that measure various environmental parameters, operating independently or as part of a number of measuring stations and monitoring networks. Constantly also there are performed different types of observations and measurements, both in situ and in laboratories. All these activities generate huge amounts of data about the state and quality of the environment on Earth.

To fully benefit from such a huge and diverse resources, as from global database (knowledge), it is necessary to provide the possibility of exchanging and sharing data between different systems, so it requires to ensure their interoperability.

The concept of interoperability is closely linked to information technology, especially to information systems. Interoperability is generally referred to as "... the ability of two or more components to exchange information, understand it and use it..." (Institute of Electrical and Electronics Engineers, 1990). More specifically, it may be defined as "... the ability of various elements of functional information systems to communicate, run programs, or transfer data between them in a way that does not require from the user any knowledge, or requires from the user a minimum knowledge on the unique properties of these elements..." (ISO/IEC 2003).

One way to ensure interoperability, is to provide the data in a clearly defined schemes available in specialized for this purpose network services, with individual communication protocols. This type of concept, regarding spatial data, is used in the Spatial Data Infrastructures (SDI). Using SDI allows for a certain extent to automate the use of shared metadata and spatial data. An example of the practical implementation of such a model is INSPIRE, consisting of SDI of individual EU Member States. Experiences of the implementation phase of this one the world's largest data harmonisation effort of environmental information infrastructures can be found in (Kotsev et al., 2015).

The key to ensure interoperability in the field of environmental data are specifications developed by OGC (Open Geospatial Consortium) and standards developed by ISO (International Organization for Standardization). They provide the basis for the construction and operation of spatial information infrastructures, while ensuring technical interoperability, both in terms of communication of services and data exchange.

OGC, ISO and other institutions have developed a number of norms, standards, specifications and recommendations for description of measuring processes and sensors (metadata) in order to achieve interoperability capabilities. As one of the most important in this regard should be considered

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SensorML. Besides it, important are, among others: IEEE 1451, ECHONET, Device Description Language (DDL), and Device Kit (Tang and Yeh, 2001).

The aim of this publication is to present the use of OGC standard – SensorML – to describe the sensors and measurement process in the prototype of air quality monitoring network launched in Nowy Sacz in Poland. Section 2 summarizes the IEEE 1451 standard dedicated to transmitters service standardization, and primary elements of the specification SensorML 2.0. Section 3 describes the use of specifications Sensor ML to describe the measuring process of the air quality monitoring network based on prototype measuring stations. Section 4 provides a summary.

2 STANDARDS OF SENSORS AND DATA DESCRIPTION IN MEASUREMENT SYSTEMS

Speaking about interoperability of measurement data, we mean primarily final results of the measuring system, which is properly formatted and described data block, most often located in a standardized database or data warehouse. From there, it can be easily downloaded and processed by other systems. However, it should be noted that the standardization of measurement data recording can be done from the very beginning of the measurement process.

2.1 IEEE 1451 Standard

In order to standardize communication protocols and use of intelligent sensors, standard IEEE 1451 (Saponara et al., 2011; Kim et al., 2011) has been established. The origins of the work on the standard dates back to the late twentieth century. Then the leading manufacturers of sensors, and IEEE and NIST, began the work associated with the standardization of smart sensors use. The result of this work is a family of standards under the title IEEE 1451 Standards for a Smart Transducer Interface for Sensor and Actuators (Dziadak et al., 2011; Lee, 2007). In this standard, an intelligent sensor is able to measure the acquisition, pre-process it, format the data and send them, using an available network, to a higher level in the measurement system. The definition of a smart sensor is broad and includes both sensors and actuators with a controller chip enabling network communications or with the controller. Block structure of the transmitter, compatible with the present standard, is shown in Figure 1. We can distinguish two main blocks: - Transducer Interface Module (TIM) and Network Capable Application Processor (NCAP).

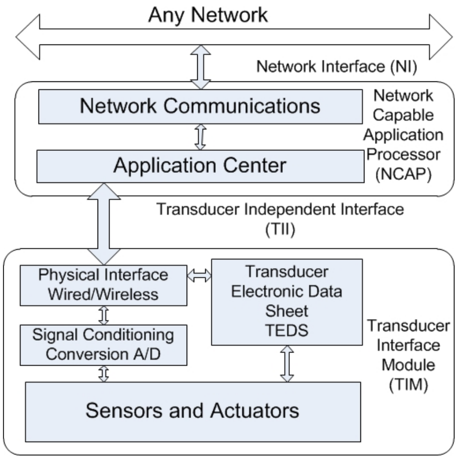

Figure 1: Structure of the smart transmitter in accordance with IEEE 1451.

Transducer Interface Module consists of sensors or actuators, conditioning and processing block A/D of TEDES base and interface. It is responsible for proper installation and operation of the sensor and for the performance of measurement. Sensors should be operated in a plug and play mode. Data for the sensor installation in the measurement system are downloaded from an electronic database TEDS. Base TEDS is an electronic catalog card of the sensor which contains all the necessary information, such as: sensor type, measuring range, resolution, accuracy, sensitivity, response time, and identification data.

Network Capable Application Processor is a block providing control of the measurement process and communication between the block of TIM transmitters and higher layers of the measurement system. Most often, NCAP is a controller/computer with the appropriate hardware and computing capabilities allowing for translations of interfaces and coordination of the process. NCAP can also provide Web services and APIs dedicated to data receivers (Higuera and Polo, 2012). Communication with both the TIM block and the network, can be implemented using a variety of techniques and technologies (Pu et al., 2016). The coupling between the IEEE 1451 standard and the standards of upper layers of the OGC model, is shown in Figure 2.

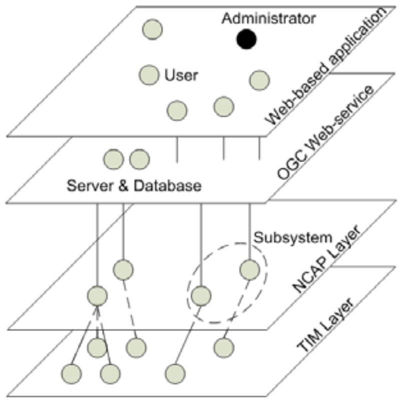

Figure 2: Structure of the smart transmitter in accordance with IEEE1451.

The IEEE1451 standard is used to operate smart sensors in the network for monitoring surface water quality in the Sado Estuary Natural Reserve in Portugal. In this network the communication between the block of TIM transmitters and the NCAP block is carried out with the use of RFID (Postolache et al., 2011). Another example is air quality monitoring system measuring NO_2, SO_2, CO, O_3, in which the authors in the controller ADuC812 realized the TIM block with a complete base of TEDS for used sensors (Kularatna and Sudantha, 2008). In the authors' system, the standardization of the sensor description operates at the network level, however, the modularity of the sensor is assumed.

2.2 SensorML V2.0

SensorML v2.0 is a specification for describing functional model of the sensors activity and associated measurement processes. Using SensorML can be described a wide range of sensors, including both mobile and stationary sensors, and performing measurements "in-situ" or remote. In addition, this language allows for, among others: description of algorithms needed to manage sensors, location of the observation made by means of sensors, etc.

This language is one of the components developed by OGC as part of the specification Sensor Web Enablement (SWE) and the Sensor Web initiative (Liang et al., 2005). SWE focuses on developing specifications to cover all types of sensors and making them accessible, usable and controllable via the Web (Bröring et al., 2011). For this reason, some elements (data types, classes, etc.) are connected between the various components of the project.

Examples of the use of SWE standard, along with a brief description of the individual components of this specification, can be found in (Conover et al., 2010). In (Chen et al., 2013), the authors described the use of SWE to create a Web directory service, based on directory service OGC, allowing for location, access, retrieval of parameters and use of sensors and algorithms describing the sensors. Technologies and standards included in the SWE were also used to create an event-based service receiving spatial data “on-demand” (Fan et al., 2013). In (Kotsev et al., 2016) OGC specifications are used in the AirSensEUR open software/hardware multi-sensor platform for measuring ambient air quality.

In turn, (Chen et al., 2012) using BPEL and processes chains from SensorML, proposed a method to create workflows for the so-called e-science, that is those fields of science, which require calculations in highly distributed network environments or using huge data sets processed in grid environments. In (Hu et al., 2014) proposed a model of sensors description for satellite remote sensing based on the object- and language-oriented paradigm of SensorML. In (Jiménez et al., 2014), the SensorML specification, with standards ISO 19156 and ISO 19115, were used to enhance the interoperability of data in the field spectroscopy scientific community. In (Hu et al., 2015) presented a different perspective on geospatial data processing and on the basis of the language of SensorML (which is an event-driven technology) created TaskML, which is the task-driven technology. SensorML was also used as a framework for many applications (Bröring, 2012), among others: EU directive INSPIRE, EU-funded projects SANY, South Africa AFIS project, and US OOSTethys community Project. In (Jirka et al., 2012) is presented a lightweight profile for the OGC Sensor Observation Service that ensures the necessary interoperability for environmental data provided by the EEA’s member states. The possible applications of SensorML in Polish SDI was proposed in (Rogulski and Rossa, 2015).

An overview of the currently developed norms and standards can be found in (Sánchez López, 2011). The authors discuss there, among others, standards created by ISO (ISO/IEC 18000) or IEEE (IEEE 1451). SensorML and O&M can also be used in one of the newest OGC specifications – OGC SensorThings API, created for the integration of sensors, processes and results of observations and measurements within the Internet of Things (IoT) (Huang and Wu, 2016).

The basic idea of modelling using SensorML specifications is to create measurement processes for which it is possible to determine the inputs, outputs, parameters and additional information characterizing individual steps of the process. These steps may be other processes, measuring devices or sensors used for measurements and observations. In its simplest form, the measurement process may consist of a single step. It is possible to create many different types of processes relating to any components of the environment. All of them are based on certain common attributes present in the base process. The processes can follow both the physical processes associated with the measurements and observations, as well as processes other than physical (e.g. associated with a numeric processing of the measured values or with modelling).

The core of SensorML specification is made of the following two abstract classes, on which other classes inherit:

- DescribedObject – a class that provides basic, common characteristics for classes of processes (components), inherit from this class. Among them we find a lot of descriptive characteristics relating to general information about the process (e.g. keywords, classifications), limitations (e.g. validity period, access, intellectual property), classifications (characteristics and parameters), references (contacts and documentation), and history. Some of them are grouped in code lists providing the ability of easy analysis,
- AbstractProcess – basic abstract class that inherits from DescribedObject, offering additionally attributes associated with inputs, outputs and process parameters, indicating the purpose of the process, as well as with the further development of more sophisticated (e.g. descriptively) derivatives processes.

On the basis of abstract classes following classes are designed:

- SimpleProcess – for indivisible processes, that is, the implementation of which is treated as a whole, consisting of one step. This class contains additional properties that allow to describe the methodology used in the process,
- AggregateProcess – for complex, multi-step processes, with the possibility of mapping data flows between steps, that is determining that the output of the step are input of the next step,
- PhysicalComponent – to describe real, simple, physical devices or sensors (processes components), for which is important to define spatial coordinates and time,
- PhysicalSystem – used to model physical devices, more complex than in the case of Physical Component, as the processes for which the location in the real world is known and important,
- Processes with Advanced Data Types – class offering support for more advanced data types than those offered by abstract class AbstractProcess (e.g. DataArray, Matrix, DataStream and Choice).

Some of the attributes belonging to the above classes of SensorML specification, link to SWE Common 2.0 components, as well as to the types and structures defined in standards, in particular those from ISO 19XXX series.

3 APPLICATION OF SENSORML IN THE NETWORK OF AIR QUALITY MONITORING DEVICES

SensorML specification was used to design structures in a relational database, where are stored the data on the measurement network built using prototype measuring devices in the city of Nowy Sacz in the southern Poland. The devices were designed by a team of researchers of the Faculty of Electrical Engineering of Warsaw University of Technology, and the measurement network was established with the participation of scientists from the Faculty of Building Services, Hydro and Environmental Engineering of Warsaw University of Technology. Measuring devices measure basic meteo parameters, concentration of PM_1, $PM_{2.5}$, PM_{10} and CO. Prototype devices were installed in September of 2016 and became operational in five locations in Nowy Sacz. Installation locations (shown in Figure 3) have been established by the city authorities.

The purpose of the devices installation is densification of the existing measurement network for the area of Nowy Sacz, which consists of one professional measurement device, owned by the Regional Inspectorate for Environmental Protection (RIEP). Another measuring station belonging to RIEP is located in Szymbark near of Gorlice (approx. 28 km in a straight line, but it does not measure PM), and next in Tarnow (approx. 45 km in a straight line). In the Małopolska Voivodeship, a higher density of measuring stations occurs only in and around Kraków, what is quite a considerable distance from the city of Nowy Sacz. The city of Nowy Sacz has more than 80 thousand residents, and throughout Nowy Sacz County – approx. 200 thousand.

Figure 3: Locations of prototype devices. For comparison by a different colour indicated also station of RIEP (based on: Google Maps).

The devices operate 24 hours a day. Every minute, they send a message to the server with the values of measurements and basic meteo parameters. Data transmission from the devices is done using the built-in modems and GPRS. On the server side works a software to collect (listening service written in Java) and storage of data (database MySql).

Data from the various additional devices are available to residents at: http://www.nowysacz.pl/pomiary-powietrza, making it possible to check the air quality in the various districts. Ultimately, based on data obtained from measurements and on forecasts, an air quality index will be determined.

In connection with the planned development of measurement network throughout the region of Nowy Sacz and with the desire to achieve interoperability of data to describe the devices and the measurement process, SensorML 2.0 language has been used.

The measurement process, modelled using SensorML, consists of the following steps:

1. Collecting data using physical sensors gathered in the measurement stations.
2. Automatic verification of data, or verification by the operator.
3. Determination of indicator of air quality by the appropriate algorithm (phase in progress).

The first stage was modelled as the Physical Component, since it is made of components whose location in the real world is known and of importance. At this step there is the measurement of air parameters (pollutions) and basic meteo parameters. This is accomplished by sensors concentrated in the measurement stations that sense air and provide digital numbers representing the measures of a property of that environment.

For the other two steps, their location is not important and they are not implemented by the physical measuring devices, therefore they are modelled as the Simple Process. In the second step takes place the verification of measurements results - automatic and by a human. In the case of, for example, sensor failure, the measurements results can be classified as erroneous and do not take them to the air quality assessment in the third step.

In the third step, on the basis of measurements of pollution, meteorological data and forecasts, will be determined air quality index, as the most affordable for the residents. An appropriate algorithm will play here a main role.

All three steps of data acquisition and processing are combined in a multi-step measurement process using class AggregateProcess.

For the first step, the most important parameters involved in the process described herein are following:

- Process type: Physical Component,
- Inputs: temperature, humidity, pollutions,
- Outputs: weather (temperature, humidity), pollutions (PM_1, $PM_{2.5}$, PM_{10}),
- System Location: locations of measuring points (as shown in Figure 3),
- System Components: Temperature sensor, Humidity sensor, Pollution sensor.

For the second step, the most important parameters involved in the process described herein are following:

- Process type: Simple Process,
- Inputs: weather (temperature, humidity), pollutions (PM_1, $PM_{2.5}$, PM_{10}),
- Outputs: weather (verified temperature and humidity values), pollution (verified PM_1, $PM_{2.5}$ and PM_{10} values),
- System Components: verification of pollutants, verification of meteo parameters.

For the third step, the most important parameters are as follows:

- Process type: Simple Process,
- Inputs: weather (verified temperature and humidity values), pollutions (verified PM_1, $PM_{2.5}$ and PM_{10} values),
- Outputs: air quality index,
- System Components: determination of air quality index.

To enable the collection and storage of data on sensors and measurement system, according to the SensorML specification, application diagram was brought to a relational database schema. The conceptual diagram of the most important entities is shown in Figure 4.

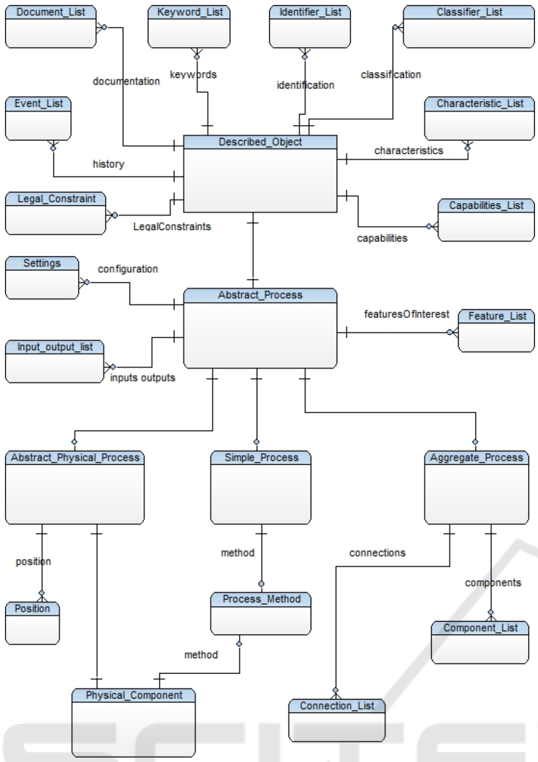

Figure 4: ERD diagram based on SensorML.

Described_Object is a basic entity in the model, corresponding to the class of DescribedObject from SensorML. Complex class attributes, attributes that are different data types, or cardinality more than 1, are modelled as separate entities:

- Keyword_List – keywords describing sensors and various stages of the measuring process,
- Identifier_List – a list of generic identifiers describing sensors (names of sensors, manufacturers, models, serial numbers) and the successive stages of data processing,
- Classifier_List – list of classifiers describing sensors (e.g. dust sensor, sensor measuring temperature, humidity), and the various stages of the measurement process (manual correction of the measurement results by the operator, automatic determination of the air quality index),
- Legal_Constraint – information about intellectual property of used tools and algorithms – based on ISO 19115 (intellectual property of measuring station design, its software and algorithms used in the subsequent phases belongs to the scientists from the Warsaw University of Technology),
- Characteristic_List – a detailed description of used sensors and measuring stations (including dimensions, connection method of individual components) and the parameters of the algorithms used in the subsequent stages of the process,
- Event_List – a history of changes to the system parameters (e.g. information of sensors replacements, repairs of measuring stations, configuration changes, etc.),
- Document_List – documentation of sensors (from external suppliers), measuring station and software used for the collection and transmission of data, and documentation of developed software tools used in the subsequent stages of data processing.

Abstract_Process is an entity related to the class AbstractProcess. Complex class attributes or attributes, which are other types of data, were modelled as separate entities:

- Settings – information about the current settings of individual components,
- Feature_List – a list of objects for sensors observation (e.g. atmosphere surrounding an air monitoring station – in the case of sensors, air quality in Nowy Sacz – in the case of algorithms),
- Input_Output_List – entity corresponding to the attributes of 'inputs' and 'outputs' – contains a list of inputs and outputs of specific steps.

Aggregate_Process is an entity related to the class AggregateProcess, it ties all measurement process steps. It includes:

- Connection_List – connections between outputs and inputs of individual steps,
- Component_List – connections between the elementary steps that make up the aggregate process.

Abstract_Physical_Process is an entity related to the class AbstractPhysicalProcess. It includes:

- Position – information about the location of individual sensors and the time of which they were installed in a given location.

Physical_Component is an entity related to the class PhysicalComponent. It includes:

- Process_Method – a description of the methodology of the measurement or processing by algorithms.

Complete list of attributes in the individual entities have resulted primarily from a list of attributes (properties) of each class of specifications of SensorML 2.0, SWE Common 2.0 and ISO 19115 standard. In addition, the model includes columns relating to the physical implementation of the relational schema in the database.

In order to record measurement results and bind them to the respective steps of the measurement process, an another standard of OGC has been applied – Observations & Measurements (O&M). A simplified conceptual diagram, designed to record the results of measurements, is shown in Figure 5.

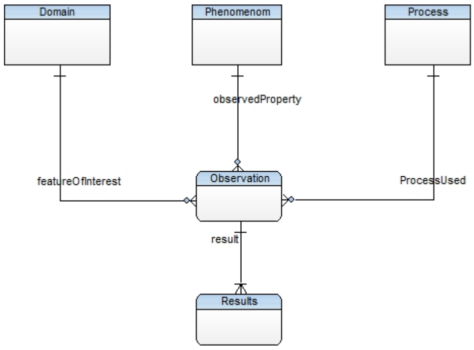

Figure 5: ERD diagram based on O&M.

Also in this case, individual entities and their attributes essentially correspond to the classes and attributes from the specifications O&M. The relational model includes, among others, following entities:

- Domain – contains a list of objects from the real world (featureOfInterest) which are investigated by means of measurements (the list includes values: atmosphere, air),
- Phenomenon – contains a list of object properties (observedProperty) which are investigated by means of measurements (the list contains humidity, temperature, pollution, dust),
- Results – contains a list of measured values,
- Process – contains a link to the measurement process described by SensorML,
- Observation – contains general data on the elemental measurement which includes measured values, among others, of various types of dust and meteorological parameters.

4 CONCLUSIONS

Standards and specifications used to create structures of relational databases are used to achieve interoperability through data collection in an orderly manner. Application of the standard SensorML and guidelines from other standards of ISO and OGC, is enabled by standardized description of the measurement process. This is important when the system consists of a number of measuring stations and sensors. Building new, low-cost measuring devices, that are designed to complement existing measurement network, it was necessary to select how to describe of devices, process, as well as acquired data. In this context, the use of OGC standards was quite natural, especially in the context of the recently published OGC specification - SensorThings API. Although, the currently operating devices in Nowy Sacz are not directly available to other users (and only the results of these measurements), the use of OGC standards does not close the possibility to this was available in the future.

In the case of this system, there is a plan for further development by adding more measuring stations and sensors that measure other substances. It is also possible to move existing measuring stations to new places, so the above scheme will allow for the storage of structured and standardized system information. As a result, it is possible to build a system whose elements will be fully interoperable.

In the future, it is planned to expand the system by, among others, adding a set of interactive webservices (with interoperable interfaces like the OGC Sensor Observation Service – SOS), which can be easily integrated with existing SDI and geographical information systems. This will make possible to easily create extracts of data describing system and combine them with data from other sources, by which a full interoperability of the system will be achieved.

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