Making sense of standards

An evaluation and harmonisation of standards in the sensor web

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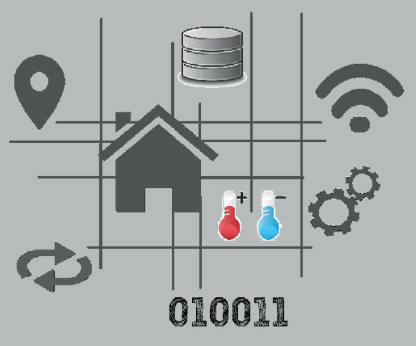
Geomatics for the Built Environment

Technische Universiteit Delft

SOS Sensor things API Observations & Measurements SSN SensorML



Cover: print screen of a map environment with a geo tag and visualization of sensor standards in the geo web

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By

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ABSTRACT

Sensor data plays a significant role in our life. Sensors are devices that can sense our environment. This sensor data is part of the Sensor Web and needs a vast data infrastructure design, because many organisations are involved, the abundance of different sensors and because of the big volume of data and near-real time data. The extent to which sensor data can be used depends on a variety of factors, among them the observations of the sensor, the data about the sensor itself and interoperability between sensor systems. Standards will lead the way to a well-functioning interoperable Sensor Web, meaning all the systems can communicate with and understand each other. Therefore, the sensor standards need to be discoverable, interoperable and usable in their own domain. Currently this is not yet the case. There is not sufficient information available about the gaps and overlaps in the Sensor Web and there are a lot of different standards and therefore the systems are not capable of communicating to each other. Currently the standards are made and maintained by different organizations. There is one cluster of standards assembled by Open Geospatial Consortium (OGC), called Sensor Web Enablement (SWE), which forms the spine of the Sensor Web, but there are also other non-OGC standards that are useful for the Sensor Web, such as the IEEE standards and W3C's Semantic Sensor Network.

A use case demonstrates both the usefulness and the gaps and overlaps of the standards in the Sensor Web, because it sketches a real-life situation in which standards can bring interoperability. The Smart Emission project in Nijmegen is a suitable candidate to assist in answering questions regarding sensor standards. In Nijmegen there is a citizen request for air quality data. The Smart Emission Project was initiated to respond to this request. The project is a collaboration between different organizations to to keep the city liveable by incorporating citizen participation in the Sensor Web. Sensors that measure different environmental indicators namely air quality, sound pollution, and meteorological data are placed all over Nijmegen to sense the city. The plan is to provide the data to the citizen for both viewing and downloading via applications. The project team is currently using OGC sensor standards, namely the SensorThingsApi and Sensor Observation Service, but is interested in alternatives, such as for remote access to the sensor, and can profit from research on sensor standards.

The requirements for implementation in the use case are extracted from meetings with citizens, network maintainers, experts in the Sensor Web and project members. Validation of requirements from the Smart Emission project demonstrates weaknesses and strong points in the current standards and how they can be used in a combination to provide the right data to the citizen. Validation is done through a data model based mainly on Observations and Measurements. Results show that not all requirements for the use case are met and that standardisation is not achieved for every requirement. To improve standardisation for future projects the adapted Open Systems Interconnection (OSI) model in combination with a digital sensor portal is suggested to be used.

The OSI model, adapted from computer science and used for data interoperability on the Internet is an ordering system and can indicate the right standard for the right usage. It is a layered system in which data is added in all the five layers. The chosen data flows through this system and ends up with relevant information for the user and the system. The adapted OSI-model is changed on several aspects. The layers are different than the original OSI-model. Furthermore division between standards is made by categorizing them on implementation method. Using the Adapted OSI-model will fill the gaps and demonstrate the overlaps in the Sensor Web make it more interoperable.

In this thesis data modeling of a use case has been used to analyse sensor standards. The results show that in the current situation the sensor standards are insufficient ordered, interoperable and harmonised. The Adapted OSI-model can bring order and the model can open up the way towards a more interoperable sensor web.

Keywords: smart cities, sensor standards, Sensor Observation Service, SensorThings API, Semantic Sensor Network, SensorML, Observations and Measurements, standardisation, harmonisation, data modeling, Open Systems Interconnection model.

PREFACE

This thesis is partly a result from a personal interest in sensor standards and sensor technologies as well as an essential investigation into the sensor standards. As a Geomatics student the thesis topic was a relatively new topic, touching other disciplines, such as computer sciences, climate change and smart cities. This multidisciplinary approach required a lot of digging into literature. The more I read the more interested I became in sensor standards and their possibilities and current limitations. It is a topic that is invisible for most people, but influences people's life every day, without them even noticing. This indirect power fascinates me. If it works, nobody complains, but if it is dysfunctional, it is too late. However it is necessary to raise awareness about its existence to trigger companies and institutes to use sensor standards.

A lot of people helped me into the right direction. My direct supervisors Wilko Quak and Bastiaan van Loenen at the TU Delft and Michel Grothe at Geonovum in the first place. Without their feedback and support this research would not have been successful. Furthermore the project members who were willing to give me insight in their part of the project and the role of standards there. Just van den Broeke, Antoine, Bas, Pieter Marsman. Furthermore Linda Carton and Paul Geurts, for leading the Smart Emission Project and organizing meetings. Last but not least the participants who were volunteering to place sensors and discuss their needs with the project group.

I owe a lot of thanks to all my fellow Geomatics students who helped me mentally and by giving feedback on the texts. Sometimes a cup of coffee and a few words of motivation can help your through hard days. Also I would like to thanks my direct colleagues at Geonovum who gave suggestions, and granted me insight into their domain of expertise. It was great working with them.

LIST OF FIGURES

1 INTRODUCTION

Nowadays sensor technology is used in many electronic and non-electronic *things* for different purposes. According to one definition sensors are devices that sense and trigger specified actions after input from their physical surrounding through existing phenomena. The response are signals that can either be translated to a display that can be understood by humans or sent electronically for further processing [techtarget, 2016]. Some authors predicted already in 2003 that sensors may drastically change our life [Spencer, 2003]. However, it is not certain what the future for sensors will look like. The fast pace of developments triggers researchers and developers to anticipate and prepare for changes in the future [Intille et al., 2012]. This is accelerated by the European law, Inspire, that directs European member states to publish their geo-spatial data in a transparent and readily manner [Inspire, 2016b]. Sensor data will be part of the infrastructure for spatial information, because the members of the European Union are required by the Inspire's directive to publish sensor data if it is part of an Inspire theme. Standards are part of this task that is set in 2020. Inspire provides specifications that describe how to use Observations & Measurements and Sensor Web Enablement-related standards [Inspire, 2014, 2016d]. Inspire will greatly contribute to the development of sensor networks and consequently to the Sensor Web. A sensor network is a digital network of sensor-based measuring devices registering spatially distributed conditions [Aloisio et al., 2006]. The sensor standards serve more goals than being merely standardized rules. Standards bring stakeholders and developers involved in sensors together to think about global structures and the essence of the Sensor Web and the sensor standards can be considered successful if the stakeholders are on the same page and if that is reflected in the standard [García-Hernández et al., 2007]. The involved parties are aware that it is essential to think about an universal standard, but in the way towards this goal there are still several steps that need to be taken [Kim et al., 2004; Kolas et al., 2005]. An important step that has been taken is the foundation of the Standards Harmonisation Working Group in 2005 [Lee, 2007]. This step is important, because it remarked the necessity to make dataset comparable both within itself over time and with other survey datasets having related characteristics. Harmonisation is done to strive for a common knowledge base of standard definitions and methods **??**. This thesis can help to achieve this goal by addressing the following research question: *To what extent is there an alignment of existing sensor standards for describing observations and sensors, and how can they be further harmonised?* We will perform a use case driven approach. More specifically, the use case that will be incorporated is the Smart Emission Project which focuses on the city Nijmegen and has been started in 2015. The Smart Emission Project is planned to be finished at the end of 2016 and is a pilot for using sensors in a smart city.

1.1 PROBLEM STATEMENT

Currently there is a research gap regarding the observations based- and device based standards of both OGC's Sensor Web Enablement and non OGC standards. [**?**] Sensor standard information is not coherent enough yet to provide full understanding of the infrastructure of the Sensor Web and how the standards relate to each other. The problem that is observed regarding the sensor standards is twofold.

1 The first issue is practical, namely the type of data coming from the sensors. If a user asks for specific sensor data, the user needs meaningful and understandable response from the sensor. This requires an appropriate standard. An appropriate standard is a standard that regulates formulation, publication, and implementation of guidelines, rules, and specifications for both common and repeated use, with the goal to achieve the optimum degree of order or uniformity in the given field. [Lee, 2007]. There used to be a gap in the current standards regarding sensor description, messaging data and the location of the sensor, which causes the Sensor Web to be non-interoperable. Even though sensor standard organizations are working on it, it is not always functioning as it should be and the implementations are non diverse and complex [Lee, 2007]. Figure 1.1 shows what kind of data a sensor produces. If the data is presented to a user in this way it is difficult to understand.

2 The related other problem that can be noticed is the absence of a commonly used well-functioning standard for sensor data, because different institutes and companies are working on their own, which creates a metaphoric impermeable jungle of standards. The issue is that there are different standards used and every producer of swith other sensor datasets, the research is hampered by not solving complex issues such as non-interoperability of air quality or noise pollution data sets.

A solution for these problems can improve the Sensor Web. Lee agrees on this by stating that the proper ensor data uses its own standard. If these standards are not interoperable way to provide sensor data to the user is by harmonizing these standards to achieve the highest degree of interoperability [Lee, 2016]. In 2014 during a Internet Of Things conference sensor standards were discussed. It was agreed upon by the audience that for integration of devices in the Sensor Web more interoperability of the standards is required [van der Schaaf and Herzog, 2015]. Besides conferences about the theoretical implementation of the sensor standards, there are also a lot of practical implementations taking place, because the current sensor standards enable the user to receive understandable data from the sensor. However, after exploratory research under groups of stakeholders in 2016 in the Smart Emission Project in Nijmegen, the maintainers of the network indicated that they are not yet satisfied with the existing sensor standards, because their requirements are not met by the sensor standards. The goal of using one universal standard is achieving interoperability between datasets from different organizations. Interoperability is required in order to get the same correct output for a query in different datasets. This goal can also be seen in figure 1.2. In this example there are three datasets. In the current situation a question cannot be answered, because the standards are not interoperable. A query done on a sensor data set can give another answer than asking the same query on dataset B. Possibly, the question cannot even be answered. In the desired situation there is one universal standard. If a question is asked about one of the datasets the answer will be in the same way. An example of such a question will be given in chapter 4, where a user can request data regarding his direct environment. If there is one standard it is possible to check quickly if a question can be answered with the available data or if there is something missing. It should also give the option to see what exactly is missing. This saves times and money for organizations.

```
11/13/2015 11:09:45,S.AudioPlus2,3222314
11/13/2015 11:09:45,S.AudioPlus1,2828583
11/13/2015 11:09:46,S.Audio0,2686976
11/13/2015 11:09:46,P.18,184550243
11/13/2015 11:09:46,P.17,184550243
11/13/2015 11:09:46,P.16,184550242
11/13/2015 11:09:46,S.36,0
11/13/2015 11:09:46,S.CO2,1116000
```

Figure 1.1: Raw sensor data

The sensor standards not only help corporate businesses and institutes, but also starting companies, academic researchers and the independent users that are interested in sensors and sensor data. To make the standards available for all of these groups there should be clear tutorials on how to use them.

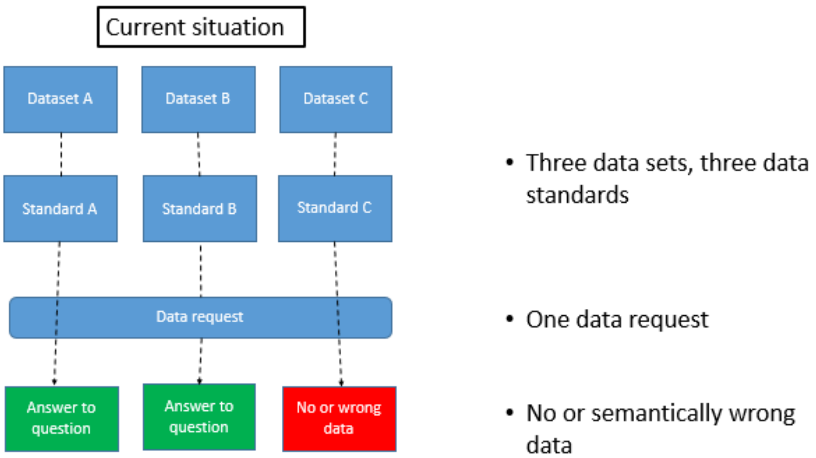


Figure 1.2: Goal of universal standard

1.2 RESEARCH QUESTION

The aim of this research is the interpretation of sensor data and modeling of this data to explore the feasibility of implementation of one or more sensor standards in the context of the use case, the smart emission project. Even though it is widely known that standardisation improves the Sensor Web, stated by for instance Sheth et al. [2008], there is still a problem regarding missing and non-interoperable sensor standards. The problem about a missing universal sensor standard will be addressed by answering the main question:

To what extent is there an alignment of existing sensor standards for describing observations and sensors, and how can they be further harmonised?

To answer the above mentioned research question, the following sub-questions are answered:

- What are the commonly used sensor standards?
- To what extent do commonly used sensor standards align?
- Which sensor standard or standards are used in the Smart Emission use case?
- What steps can be distinguished to align the use case standard to the commonly used sensor standards?

1.3 RESEARCH OBJECTIVES

This study concentrates on unravelling the knot of standards that are available. Therefore there are several objectives that will be worked towards in this thesis. The objectives are:

- Sum up the commonly used sensor standards.
- Align the commonly sensor standards.
- Explain the context of the use case and sum up the used sensor standards.
- Define the steps to align the use case standards and the commonly sensor standards.
- Pinpoint the gaps and overlaps in existing sensor standards and offer a solution towards bridging the gaps.

1.4 HYPOTHESIS

The hypothesis for this research is that the OGC sensor standards are a steady basis to describe both observations and sensors for the use case. However there are still steps to be taken before harmonisation of the existing standards is achieved. There are also other institutes that work on sensor standards and these are required as well. The Smart Emission project needs a specific kind of standard adapted to its situation and the new technologies and user requirements. The meta data that is produced by the sensors needs to be clearly displayed. This can only be done if the current sensor standards offer this option. The whole trajectory from data acquisition to visualization needs to be analysed and sensor standards considered for every step. Furthermore both the needs of the users and the maintainer are relevant. The needs of both the users and the maintainer need to be considered as primary actors in the research. A primary actor is the actor that initiates the use case. Other types of actors are supporting actors who offer a service. [**?**] A supporting actor can be a developer or project team member. Renowned institutes, such as OGC and W3C create the standards that are mostly used. These organizations have the status, the budget, the time, the network and the expertise to create and promote their standards. The Smart Emission Project will probably use these standards. The project will also test some new initiatives for standards, because it is an innovative research pilot. Alignment for standards is hard to predict. However if one organization works on several standards, they are probably interoperable to some level. inter-organizational standards can base their standards on other standards, but might not be interoperable in every level. The steps to align them possibly include a alignment matrix or another assessment method and the testing of this alignment matrix by the use case. In chapter 7 there will be a consideration if the results support the hypothesis.

1.5 RESEARCH SCOPE

The aim of this research is the interpretation of sensor data and modeling of this data to explore the feasibility of implementation of one or more sensor standard(s) in the context of the use case, the smart emission project. However, the Smart Emission project consists out of more than only standardisation. The project also includes work on sensor data quality, visualization of the data, database configuration, and application-building, which are all not part of this research. However, the quality of the visualization of the data depends on the quality of transformed data and meta data. An extensive analysis of the sensor data and collaboration with sensor and software experts will be part of the project but not of this research. Furthermore, the sensor data will be collected by a company specialized in this work and will neither be part of the research. This research will focus only on the sensor data of Nijmegen of 25 stationary sensors. The use case example to test a real life situation is the air pollution in Nijmegen. Data verification before the first transformations is not part of this research and also the analysis of the data collected by the sensors for specific goals is not the goal of this thesis, because the time available to do research is not sufficient to focus on more than standardisation and harmonisation. However all these experts can benefit from the results of this research. There are several layers where standards are used. Due to the abundance of sensor standards these will not all be part of the research. There are several standards that will be thoroughly assessed on the application level: SensorML, Semantic Sensor Network, Sensor Things API, Sensor Observation Service and Observations and Measurements. The rest will be mentioned but will not be part of the assessment. Implementation of combined standards will be done for the project, but will take too long to be part of this study to make a conclusion about, because the project is planned to be finished at the end of 2016. Therefore this study will look at the feasibility of the technical implementation by validation of the created data model. Furthermore this study will not include every type of sensor included in the Smart Emission project to keep it conveniently to oversee. The research scope is limited to a citizen of Nijmegen interested in air quality and requesting air quality data via an application. Creating a whole new standard is not useful in the already confusing field of sensor standards. It is also not feasible in the time given, therefore this research focuses only on the already existing standards such as the Sensor Web Enablement standards and tries to give recommendations on how to harmonize, combine and improve them. This is done through the example of the Smart Emission use case.

1.6 TERMINOLOGY

In this section the Sensor Web-specific terms will be explained. An observation is defined as "an active acquisition of information from a primary source" and "observations may be made directly (by seeing, feeling, hearing, tasting, or smelling) or indirectly using tools." and a measurement is quantitative, but they are often used interchangeable. According to the official Inspire documents the difference between an observation and a measurement is that an observation is an "act of measuring or otherwise determining the value of a property" and a measurement is a "set of operations having the object of determining the value of a quantity" [Inspire, 2016a]. In this case, the sensor is a device to measure physical quantities and transforms them into electrical signals [OGC, 2016b; Bröring et al., 2011]. There are several definitions for the Sensor Web. In this study the computational definition will be used. "The Sensor Web is a group of interoperable web services which all comply with a specific set of sensor behaviours and interfaces specifications." Using this definition the sensor web is defined by its specifications it complies to and can be identified as a unique entity, such as the Sensor Web Enablement [Di, 2007]. A procedure is the instrument, algorithm or process used from phenomena to sensor data. Property is "an observable quality of an event or an object" [Compton et al., 2012]. There are many synonyms and terms that resemble standards, such as languages, protocols and services. To make the text readable those terms will be avoided as much as possible. Jabobs defined standardisation as "formulation, publication, and implementation of guidelines, rules, and specifications for common and repeated use, aimed at achieving optimum degree of order or uniformity in a given context, discipline, or field" [Jakobs, 2014]. Harmonisation in this context is to find common traits between standards, identify requirements that need to be retained, and provide a common standard [ULstandards, 2016]. The sensor standard is a standard that describes data models for geographic information and a standard for a specific theme, in this case the sensor. However this research will involve more than only the traditional accepted OGC standards. The aforementioned terms are commonly used in this research. Other sensor-specific terms will be explained when they are first mentioned.

1.7 READING GUIDE

Chapter 2 explains the used methods on the basis of a work flow and will take the reader step-by-step through the methodology. Chapter 3 states the relevant related work done on sensor standards, the current solutions, their limitations and the new solution that will be used in this research. Chapter 4 explains the context of the use case and why the use case is relevant for this research. A detailed description of the project can be found in chapter 4. Chapter 5 gives the resulting models and tables. Chapter 6 validates the models by testing them on the use case. Chapter 7 gives the conclusions and recommendations based on the results and validation.

2 METHODOLOGY

Scientific methodologies must be repeatable to facilitate a useful result [Van Zyl and Vahed, 2009]. Therefore the process to draw a conclusion will be explained step by step in this chapter. The methodology starts with a literature study. Secondly it continues with the elaboration of the use case. The next step is the test of the use case based on a data model. In this section the data model is the newly created prototype. Recommendations for sensor standards will be given not primarily based on the use case, also on findings in literature. The use case is a way to test the validity of a standard or a combination of standards. The standards that are tested are based on the necessity for the use case, but OGC's Observations and Measurements will be the basis and complemented by the required other sensor standards, because most other OGC data models are based on Observations and Measurements intuitive data models. The current plans for standards in the Smart Emission project can be seen in figure 2.1. This picture is relevant to understand the context in which the standards function. The orange box indicates where in the information architecture the standards are implemented, although standards can have an influence on the data in the entire data flow. This depends on the type of sensor that is described. To the left there is the initial data emitted from the Jose sensor, this is put on a Josene server. The server outputs JavaScript Object Notation (J-son) data to the Mongo-DB database which is used for the first service, the raw service, where the raw data can be queried. This data is preprocessed to be more understandable, then the processed sensor data is stored in a PostGIS database where it will be post-processed. On this data, that has been stored in PostGIS the standards are applied to be able to visualize it. The pictures in the bottom are the logos for the Smart Emission project and give an indication of the data that is processed from the sensors.

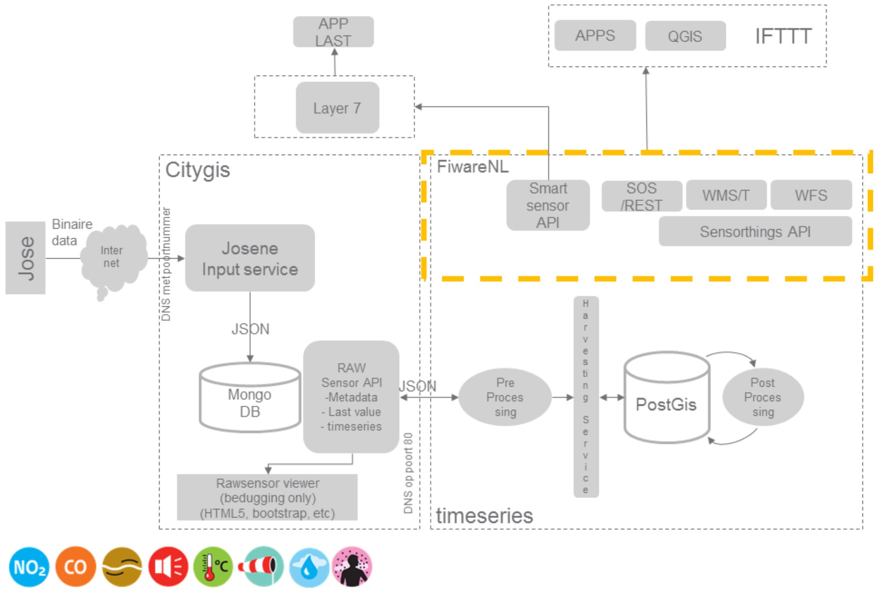


Figure 2.1: Standards in project

2.1 WORK FLOW

In figure 2.2 the planned methodology is shown, divided in several phases: preparation, research and use case prototyping, validation, and evaluation. The work flow followed in this research is as follows:

1. During the preparation the research is started by a *desk research* of the current application programme interfaces (APIs) and standards. The sensor layer in which the assessed standards are grouped can be visualized in the OSI-model. This gives an overview of the general standards infrastructure for sensors. Simultaneously, interviews and meetings are held with stakeholders in the project of Smart Emission.

2. Subsequently, in the research and *use case* phase, the requirements for the application and the use case can be defined, based on user needs, sensor maintainer needs and the needs from project team members. These requirements are used in the following steps and should be carefully chosen. In the use case context the used standards are presented. Additionally the commonly used standards for sensors are determined based on relevance for the use case project and the number of hits on the Internet. Furthermore an alignment of the commonly used standards and the use case specific standards is created, based on the requirements. This is done by a alignment matrix, a table aligning the standards.

3. In the next step, a *prototype* is built, the data structure of the sensor is modelled and given relations with Unified Modeling Language (UML). UML is used, because it clearly shows the relations between phenomena subdivided in classes. Harmonisation is required to link

the different standards. If possible duplication and conflicting terms and classes should be adapted, deleted or renamed. This is done in order to help the team of the Smart Emission project to transform the raw data to comprehensible data and show the possible usefulness of collaboration in the sensor standards in this use case scenario. Shifting from a semantic abstract data model towards an implementation model requires extensive and clear documentation about every decision to provide insight in the process. The basis for the model is Observations and Measurements of Inspire. To successfully finish this step, maintainer requirements are required as well as the knowledge of domain experts.

4. The fourth step is the *validation* using the requirements. The validation can demonstrate the use case applications' strengths and weaknesses in terms of standard usage. In this validation especially the technical restrictions and possibilities will be noted. This is done by going back to the requirements and checking if these requirements are met and by which standards. The method to achieve this is an assessment in a table. The translation from requirements to the data model is done to make the requirements better visible for a developer and to incorporate and visualize the current standards in the use case environment.

5. In the last step, called the *evaluation*, conclusions will be drawn based on the use case to bridge the gaps and evaluate the overlaps in the existing standards. The main question is then answered using the acquired insights to work toward a solution in the form of a more interoperable Sensor Web.

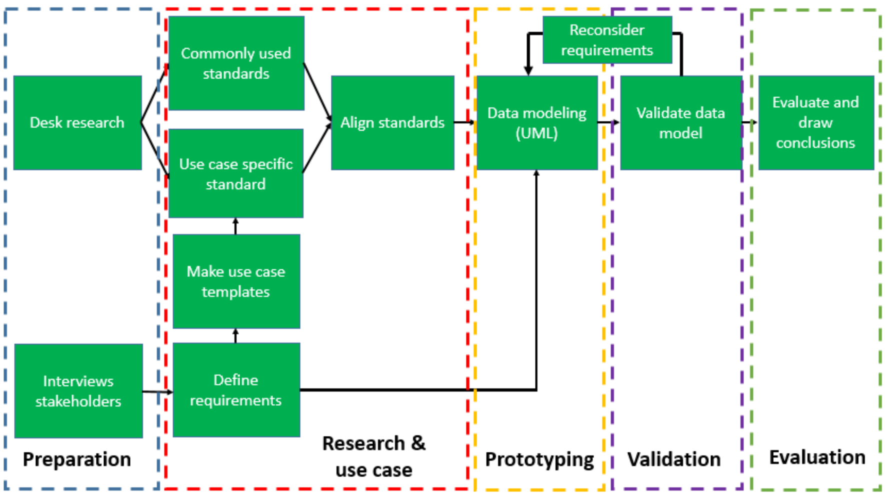


Figure 2.2: Work flow of the used methodology

2.2 STANDARDS ALIGNMENT

Different Standards pursue different goals, because they are made by different institutes for a specific audience. Therefore it is not possible to compare them on every point. There has already been a comparison of the

SensorThings API and the Sensor Observation Service done by OGC [2016f]. However, the alignment matrix included in this research is based on use case requirements instead of general capabilities of the standards and compares more standards than one done by SensorUp. This should give a more complete image of the standards situation. The information in the scheme is from various sources, online documentation of the standards, practical experience of users, and from this earlier standards assessment.

In another situation with a different use case the method might be the same, but the goals are different, so the developer might pick specific standards bases on the requirements, harmonize them and apply them on the sensor data. These standards need to be interoperable, which is a challenge.

2.3 USE CASE TEMPLATE

In the project team there is domain knowledge about air quality, sound and meteorological data, also calibration is defined by the team. This is relevant for this research because then requirements for the implementation can be adequately defined. However there need to be standards for the conversions, units of measurements, algorithms and other components of the process leading to understandable sensor data. A well tested use case can indicate the feasibility of this required standardisation.

A use case can be given in many forms, from text, to using operations, activity diagrams, state-machine to other behaviour description techniques, Coleman gives the example of pre- and post conditions [Coleman, 1998]. These are present in current templates. A template is a predefined form in which a developer can fill in technical requirements for a developed application. The template can be complemented and improved by other stakeholders to achieve full comprehension of the requirements for all the team members that are involved in implementing the use case. It makes it easier to survey the needs of users and translate them into a prototype. Using such a template can also help achieve standardisation, because one template can be compared to another template to see the differences and similarities in implementation. This is done for example in a smart city project in Gottschalk et al. [2014]. The applied use case template for the Smart Emission project can be seen in chapter A.

So, a possible solution to the aforementioned problem of lacking standardisation is the use case template. They are used more often to help explain use cases, such as in the case of M2M [M2M, 2016]. According to Cockburn use case templates show the scope and goal of the use case [Cockburn, 1998]. The template can give examples of how the sensor data will look, this can be in table form or in plain text [Coleman, 1998]. In this study there will be examples of such a template in the appendix and every step will be explained.

The template found in chapter A can help in the Smart Emission use case. This can work in the following way: as has been explained in the use case description, there are different stakeholders involved in the use case and these stakeholders all make their own demands from the application and thus indirectly from the standards. Creators of standards should translate the requirements into standards. The goal of such a standard can be clearly stated, all the actors are defined and tables can display the chosen format in one glance. Scientific we can learn from it how requirements can be used to change standards and how to deal with standards in a dynamic world where changes are taking place in a rapid pace.

2.4 REQUIREMENTS FOR THE USE CASE

Technical requirements for the Smart Emission project use case for user-focused time series can be found in the appendixes and are based on consultation with project members and on a translation from user needs derived from several meetings with citizens from Nijmegen. In 2016 several citizen meetings were held where they could voice their opinions on the application. In this period also interviews were held with two workers of Intemo, the maintainer of the sensor network and with the person who is responsible for the calibrations of the sensors and the algorithms used to translate the raw sensor data to more meaningful sensor data. Furthermore during this year within small groups the data infrastructure was discussed with the technical data experts of the team, the developer and the person responsible for the standardisation. More details on the interviews can be found in chapter A.

In this case, the template shows that the primary actor is the citizen of Nijmegen, researchers and students. In other use case templates the maintainer of the network can be the primary actor. The sensor gives time series data about many variables. Not all of them are included in the application, because that is currently technically not possible. Meteorological data, air quality and sound are included in the application. Furthermore there are a few pre-requirements that have to be met for the use case to be successful. The requirements have to resemble the needs of the primary actor as much as possible. Therefore this template is not written in one version, but several times a review was done based on new insights. Initially, the template was written by the group responsible for the standardisation and the developer. Later it was revised based on an interview with a project member responsible for the data analysis. Additionally, the template was changed after input from the project leaders. This versioning helps to achieve a use case description where all the pros and cons of a choice have been considered and the stakeholders will benefit from the final choice. The knowledge about requirements for the maintainer of the network use case templates comes from meetings with Intemo, the maintainer of the sensor network for the Smart Emission Project. The shared knowledge about the users is from meetings with a member from the project who studies specifically the user and made his own case study based on their needs. Bundling this knowledge increases the credibility of the use case.

Finalizing the use case template of the user and maintainer will make it possible to define the requirements that are going to be implemented in the model.

The requirements are the general technical needs from the user and produces combined. It is a best case scenario. It is possible that some of them can not be implemented. That will be considered later in this research in chapter 6.

Furthermore it is possible that a specific question from a citizens implies having to use different standards and different applications. This possibility will be explored in this research as well. It will follow the use case for air pollution in which case a citizen is interested if the air pollution in his street is too high.

The requirements are the red line throughout the methodology. They are used for the data modelling, for the standards assessment, and also for the validation.

2.5 DATA MODELING

In this step the requirements that have been created are translated into a logical model which visualizes the relations. This makes the requirements more clear and a user can see in which of the existing standards these classes appear and see the requirements in more detail. The most efficient way to create a data model is to use the already existing models as the basis and harmonize them. Introducing new terms might confuse users of this model. If old models are reused it is not required to create a whole new concept. Different classes and parts of existing standards should be brought together. in figure 2.3 this can be seen. However there can be situations that models have the same class or the same components. This duplication needs to be solved. This can be done by deleting one of the double classes. This can be seen in figure 2.5. In this example, it can be seen that the class Sensor exists in both models, so one of the classes should be combined. Also irrelevant classes in the models can be deleted, to prevent to extensive models and keep them compact thus comprehensible. Sometimes information in the data model is missing as can be seen in figure 2.4. In this figure it can be seen that in contrary to figure 2.3 the WiFi Network class is not in any of the models. The logical action that needs to be taken is to add this class to the harmonized model. The result should be a compact, clear and complete model. The advantages of using old models is that it is more efficient to use parts of working models and users of the models are used to the terminology.

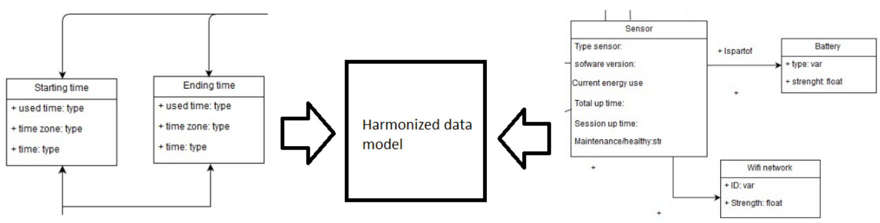


Figure 2.3: Modeling data model, ideal situation

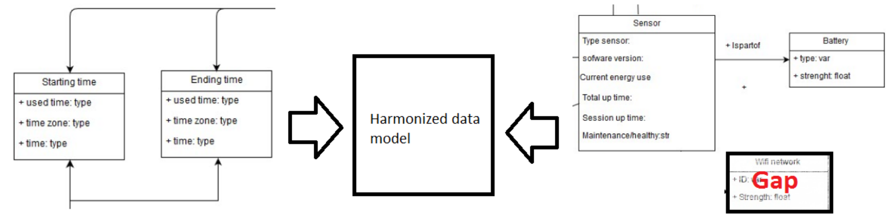


Figure 2.4: Modeling data model, gap

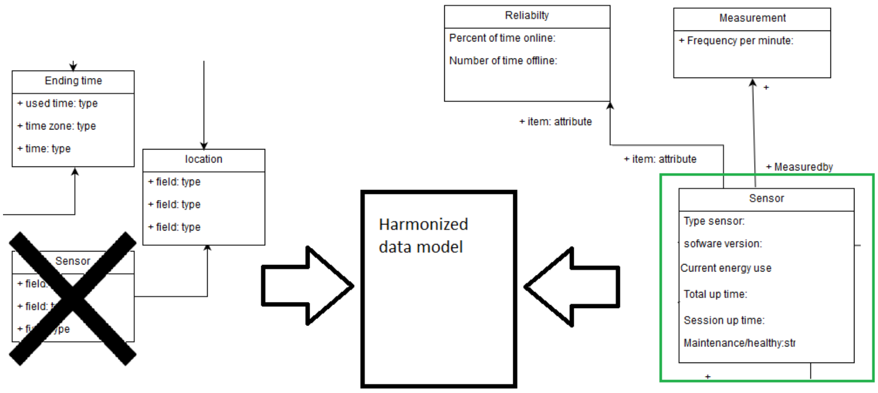


Figure 2.5: Modeling data model, duplication

The basis for the model is the Observation and Measurements Model. The start of the model is a model that fits all the requirements as much as possible. Then the next step will be to implement the possibilities that are available in the existing standards.

In the created model that sketches the ideal sensor situation, it can be seen that the sensor and observation are important. The sensor is important for the maintainer of the sensor network and the observations gives essential information to the citizen.

2.6 VALIDATION

The data model that is created in this research needs to be used in a certain way. In another study using a data model is explained by showing the steps that need to be taken.

1. Create the Data Model and the XML Schema
2. Create a Physical Data Structure and Accredited Datasets
3. Create a Relational Database Management System (RDBMS) XML Interface
4. Security and Information Assurance
5. Develop CBRN Discovery and Web- Services

[Snee, 2016]. It is possible to translate semi-structured data to Extensible Markup Language (XML). XML has already been a standard for data exchange on the web since 1996. There is a specific order in both languages. Therefore it is possible to link data, make relations and translate semi-structured data to XML. [Goldman et al., 1999]. However there are a lot of standards in the fields of XML. So many that the XML environment is filled with too many XML-enabled systems, which is caused by their creation by an abundance of software retailers and their new ideas. [Abiteboul et al., 2000]. So in the data exchange of the project there are already a lot of standards only based on XML, which is only a fragment of all the data and procedures that need to be done for a working application with meaningful data. This abundance is one of the causes of non-interoperability in the sensor web.

3 RELATED RESEARCH

In this chapter there will be an overview of sensor standards and on standardisation. Furthermore, there will be an example of how standards can be ordered using the OSI-model. Additionally, this chapter will elaborate upon the commonly used sensor standards. Finally this chapter will be ended by the current solutions for the interoperability and ordering problem within the Sensor Web and their limitations and indicate the directions toward a better solution.

3.1 STANDARDISATION

Before starting to think about solutions for the two related problems defined in the problem statement, namely the lack of interoperable standards and the problem of non-understandable data from the sensor, caused by not using the suitable standards, it is necessary to consider the societal and economic relevance of standardisation.

A major reason to use standardisation within and between companies is to speed up market expansion, because a lack of interoperability is a bottleneck for economic growth. There are also other non-economic advantages, including reuse of software and quick adaptation to changing technologies [Percivall, 2010]. Kim et al. [2004] states that having one universal standard is useful but there are also difficulties of using one universal standard in the geo-domain. There are so many different standards that have been proposed, therefore it may take a long time to agree on a universal standard. The following consequence in a rapidly developing sector such as the sensor technology is that standards cannot be introduced quickly enough. This is disadvantageous for the working field.

Another issue related to standardisation that should be mentioned is stated by Chen and Helal [2008]. His point is that standards are used in a wide variety of fields and that mentioning them in a wrong context can confuse people. For example, sensor standards can mean something different to a data analyst than to a software developer for sensor data. An example of research where standardisation proved useful outside the sensor working field is the research on standards in health care by Memon et al. [2014]. In his work, the feasibility of standardisation in another field than the sensor world is explained. Key factors for interoperable solutions are inter-organizational collaboration, user-centered studies, increased standardisation efforts, and focus on open systems. Standardisation between organizations can provide semantic interoperability by different methods such as Darpa Agent Markup Language (DAML), Resource Description Framework (RDF) and Ontology Working Language (OWL) [Bandyopadhyay and Sen, 2011].

There is a vast amount of literature available on standards, because both the Dutch government and the European Union have set the goal to standardize geographical data and the rules that have been made to exchange data, such as for air quality according to directive 2011/850/EU. Various organizations are working on sensor standards including W3C, NIST, OGC, M2M and Geonovum. Furthermore standardisation is a topic that is linked to many fields of work and these fields all require excellent standards. Due to legislation the publication of this geographical data including sensor data are directed [van der Schaaf and Herzog, 2015].

There are European regulations for standardisation. This is defined for the Sensor Web in the guidelines for Observations and Measurements. This document requires via 2007/2/ec common implementing rules by giving regulations for the meta data, implementation, and interoperability between datasets and services. This is what members states must implement. There is also a optional implementation specification document which is not legally binding. This is what member states might implement [Inspire, 2016e].

An example of how standardisation works in practice might shed more light on the phenomenon. There is a whole official trajectory before a standard is de jure an official standard. The process to accept a standard is done in cooperation with involved experts from a specific domain. If the standard is mature enough it can be accepted as official standard by International Organization of Standardisation (ISO) [Woolf, 2009].

Sometimes a standard in development is too similar to one that is also in development. Then an organization such as OGC can decide to stop its development and to continue with the other. In other cases a standard is rejected because of concerns of members such as in the case of the Geoservices Rest API [OGC, 2016c]. This way the system should regulate itself. However this system does not always work as intended. As what occurs more often in the standards, there are islands of standards, made by companies, that comply with requirements, defined by the same company. There are also standards that are broadly supported and new technical documents are reviewed by a range of standards experts and users [Brentjes and Grothe, 2016]. It can be observed that clusters of islands such as the Sensor Web Enablement are a right development for the Sensor Web.

3.2 THE OSI-MODEL

One of the problems that must be solved is the unclear situation of the standardisation of the Sensor Web. Some decades ago the Internet was in the same situation as the Sensor Web now. The problem was that there was no order and no appropriate overview of the available standards [Zimmermann, 1980]. The OSI-model attempted to solve this problem by ordering the existing Internet standards in a layered model. This model can be a solution for the unclear situation in the Sensor Web.

That is why it will be used in this research to prove that it can be used in an revised version to order the commonly used standards.

The wireless sensor network is made up by different layers conform the Open Systems Interconnection Model (OSI-model). The OSI-model is an ISO standardised reference model for data communication standards [Stallings, 2007]. If layers are reusable it is more efficient for this research, therefore the layers of the OSI-model will be explained. The OSI-model contains the following layers:

1. Application layer: Dominant layer. The other layers support this layer. A set of application supporting information systems physically distributed over multiple locations, which are connected using a communication network.

2. Transport layer: Regulations for the transport of data within the system

3. Network layer: Defines the settings and maintenance of the network in the sensor system

4. Data link layer: Regulates how the data is linked. The data frames from the physical layer are checked and transfered from one data hub to another.

5. Physical layer: Overview of the transport of data consisting of the low level reliability, contention access control, encodings, and modulation issues

[Alkhatib and Baicher, 2012].

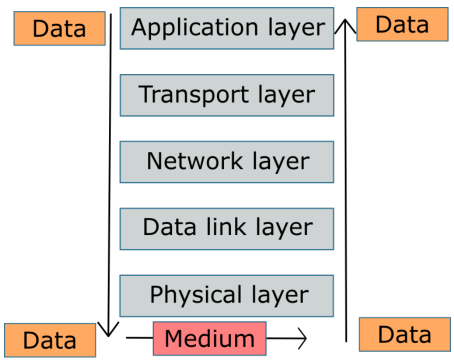


Figure 3.1: OSI-model

In figure 3.1 it is shown that the OSI-model is built up by layers. The interoperability is the capability of n heterogeneous devices to communicate and cooperate in a correct way. All the layers in the OSI-Model can have their own standard and need to communicate. So one of the reasons why the amount of standards is so high is the diversity of devices. From the lowest level, the physical layer on which the mechanical rules are set for the network up to the highest level, the application layer, where the products is created, there need to be rules to make the network interoperable. However interoperability of the Sensor Web on all layers is not accomplished yet. However there are test available to test the interoperability of sensor systems. There are no iso-standardised interoperability tests yet, but there are some non-standardised methods that were used. After testing the interoperability of platforms, it was concluded that resource capabilities, temporal constraints and internetworking all are important to make systems interoperable for the user

[Benkhellat et al., 1993]. There is also a slightly different concept for the OSI-model advised by Zimmerman, which changed the second layer into upper later(s): [Zimmermann, 1980]

1. Application: similar as in OSI-model

2. Upper layer(s): Object standards, global naming, standards for semantic content in user to user message passing.

3. Transport: similar as in OSI-model

4. Network: similar as in OSI-model

5. Physical, Media and Data Link Layers: transport of data consisting of the low level reliability, contention access control, and modulation issues

[Maier, 1996]. This model has been used by other authors looking at standard level. Currently there are five levels in it. According to Sleman and Moeller [2008] the model is not even completed yet incorporating five layers, but should contain six layers, bridging the standards. The sixth layer is called the Adaptation layer. Another suggestion by Zimmermann [1980] is to make seven layers adding to the original OSI-model the presentation layer and the session layer. The presentation layer is a service layer adding the option to interpret the meaning of the data. The session layer supports interaction between presentation entities.

There are several gaps in the Sensor. Rani et al. [2013] looks at the Internet of Things and his conclusion is to look at the networking gap and not at the sensor data. Bröring et al. [2011] did research on the Sensor Web and works on sensor things. His conclusion on the current Sensor Web is that due to a large amount of varying standards for sensors, needs of sensor software are still using old methods. He recommends to use a well-defined and commonly used integration layer. Havlik et al. [2011] wrote an article on how to achieve an Observation Web where data is given semantics using the Future Internet PPP. Giving semantics with this kind of standards can also help in the future for other projects such as for the use case. Standards aiming on the semantic web also need to be included in a Sensor Web overview. Liang [2015] states that the Internet of things is irrelevant and that it is better to speak about Service Enablement instead, which will transform the user experience and he also states that within this sensor environment, there is not enough interoperability. The importance of interoperability is confirmed by other authors such as Eriksson et al. [2009] adding that testing of interoperability is necessary.

In this research the OSI-Model can be used as an ordering system. However the names of the layers should be well chosen to change the model for web technologies to the Sensor Web [Postscapes, 2016]. The lowest level of the OSI-model is called the physical level. Here the electric signals are defined. The maintainer of the network profits from a well-defined physical layer. Web services such as Web Feature Service and Web Map Services are in the application layer.

The new categories of the OSI-model will be scaled from sensor-focused to data-focused. The layers that will be in the new model can be found in chapter 5.

For maintainers of the wireless devices the lowest layer, the physical layer is the most relevant. Here technical sensor standards such as the Zigbee and IEEE can be found [IEEE, 2016c].

3.3 HARMONISATION OF STANDARDS

Harmonisation of standards is necessary to solve identified technical and legislation conflicts between standards. Technical conflicts can mean the sensor data from different types of sensors. For instance one sensor provides the user with other types of data than another sensor and it's not yet possible to make these types interoperable. Legislation conflicts can mean following different rules during implementation, often solved by European laws. An example is that some standards favor one milieu above another, for instance industry above user or trade liberalization above the protection of the environment. Harmonisation means rewriting standards languages, so it is a necessary step towards standardisation [Mutersbaugh, 2005; Pelkmans, 1987]. An example of legislation within sensor standards is the legalConstraints property of SensorML, based on ISO 19115. This property specifies whether such legal and ethical considerations as privacy acts, intellectual property rights, copyrights, or scientific publication ethics apply to the content of the process description and its use [OGC, 2016b]. Therefore it makes sense to apply this method in this research. On the other hand harmonisation does not mean a better perspective in every situation, because bringing together all the stakeholders and coming to a consensus can be quarrelsome and might take a long time [Mutersbaugh, 2005]. Many components within the Geo Web are already depending on other components and are harmonised. For instance, SensorML is dependent on the common data models, and has an association with Observations and Measurements but on contrary to Common Data Models, no dependency [OGC, 2016b]. This is because all the components have their own role in the Sensor Web. This can be seen in figure 3.2. In general components in the OGC Sensor Web Enablement have been harmonised, but the non-OGC standards are not harmonised yet, such as the Semantic Sensor Network.

3.4 OBJECT MODELING

To understand interoperability between standards better, more detailed explanations of the models behind these standards are required. There is one method, The Object Modeling Technique that will be explained through a model from Warmer and Kleppe [Warmer and Kleppe, 1996]. This model is chosen, because it uses the same approach, and also works with requirements and a use case.

System development can be done by the Object Modeling Technique. in figure 3.2 it is displayed how a developer of systems can translate any use case to an object model as code. This is relevant in the case of data modeling. This process is divided in several phases, of which some are also found in this research: the conceptualization, analysis, system design, object design and implementation and there are three kinds of input: functional requirements, domain knowledge and non-functional requirements [Warmer and Kleppe, 1996]. The first phase, the conceptualization is characterized by a domain analysis, which means both looking for generic building components that can be reused as well as modeling the problem domain [Grothe, 1998]. This is done in this research too. The analysis of the domain is done by consulting domain experts and appropriate literature on sensors.

One of the reason that developers, system and information designers model is to reduce complexity for a better understanding [rajanib handari, 2016]. The link with standards is that this procedure can be standardised according to standards and models can be reused. In the model there are functional models, object models and dynamic models. The object model incorporates the static and most stable phenomena. This model can include classes and associations, having attributes and operations. The phenomena originating from the functional description receive their meaning in the object model. The Dynamic model represents the state on the model, including the states, transition of one state to another actions and events. The functional model shows everything that happens with input values until they are output values [rajanib handari, 2016; Grothe, 1998]. In figure 3.2 it can be seen which segment of the OMT modeling model by Warmer and Kleppe is used. Not everything is in there what is covered in this research. The blue tiles are included, the red are excluded.

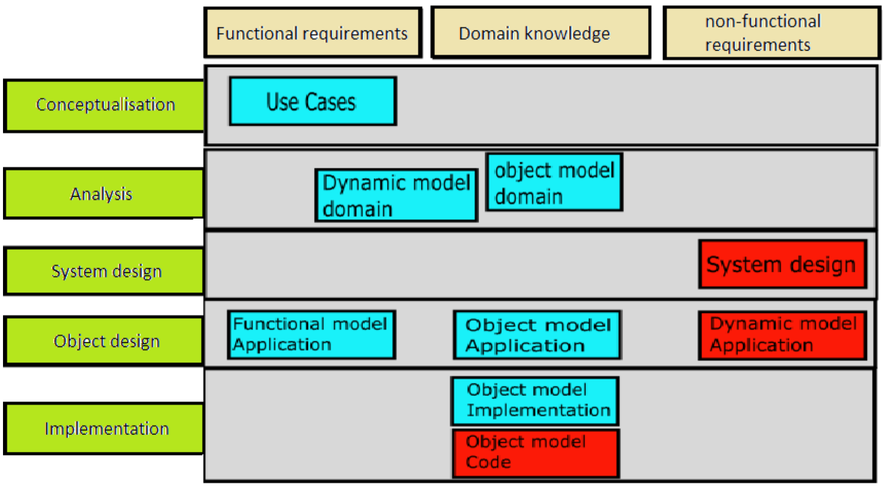


Figure 3.2: OMT modeling

The procedure to create this kind of models as following:

- Define the classes of the used objects
- Create a dictionary including the data for classes, attributes and relations
- Include relations between the used classes
- include object attributes and links
- order object classes by using inheritance
- order classes assorted by modules based on closed coupling and similar functionalities

3.5 GROUPING OF SENSOR STANDARDS

Now it is explained how object modeling for standards is done, it is Necessary to explain how standards can be grouped. The sensor standards can be grouped based on the kind of service it offers. OGC standards offer data services, portrayal services, processing services, encodings, catalogue services and multi-source and integrated application clients. These services form the basis for the sensor standard framework and can be used to create a Sensor Web. However there are more organizations that can enrich the framework with standards, such as IEEE and W3C. IEEE offers standards for data linkage and unit of measurement symbology. However the networking standards, which are made not primarily for sensors, might be the most relevant of the 1300+ standards offered by IEEE. IEEE standards can deal with the sensor information flow from the physical sensors to the network [Lee, 2007]. W3C has standards aimed on the device, and sensors. Ordering the framework gives developers the option to choose a standard that satisfies their requirements. How the OGC standards are supplemented by other standards can be seen in figure 3.3. This overview looks now very hard to understand. There are too many groups, if standard groups such as semantic standards are added.

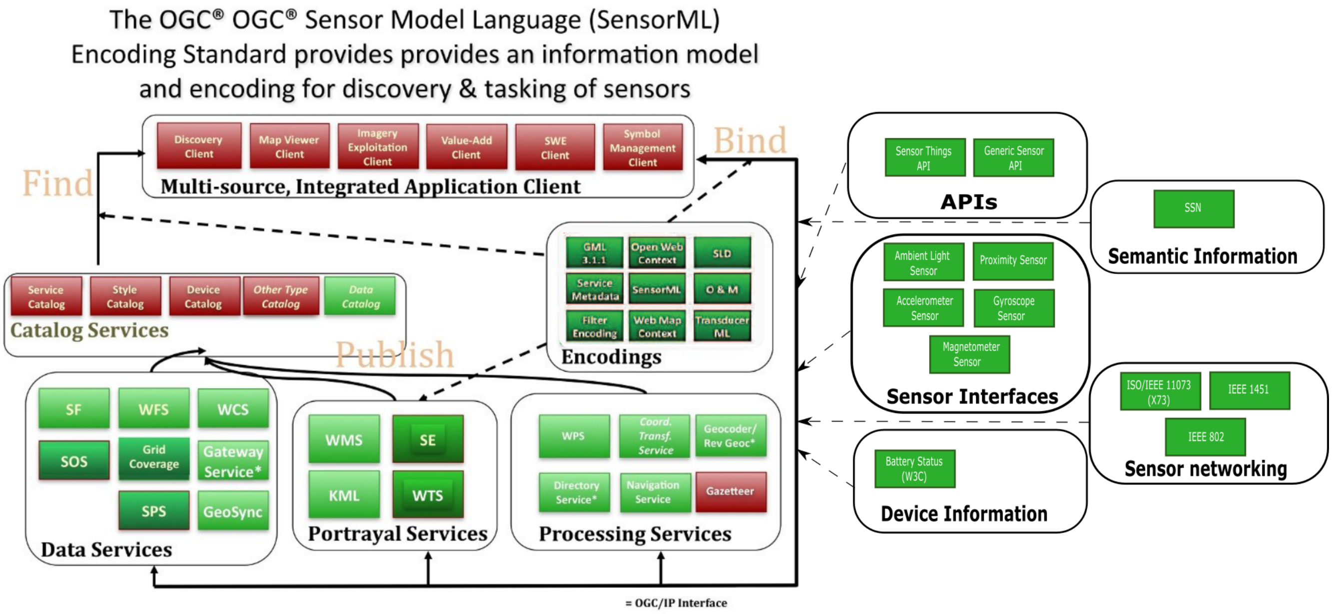


Figure 3.3: Grouped sensor standards according to OGC

The developer's choice of standards depends on several criteria:

- The aim of the sensor network that is created.
- The audience of the sensor data and their requirements

Aloisio et al. [2006] states the characteristics of sensors that influence the type of standard that is chosen.

- The data format and information that sensors provide

- The ownership of the sensors and how the owners wish to share the sensor data

However as can be seen in figure 3.3 grouping by service quickly makes the overview confusing and unnecessarily complex. As can also be seen standards that are not from OGC form their own island and are hard to integrate in the framework.

Later in this research within chapter 5 another way of grouping based on creation method and data layer will be explained. One aspect that needs to be mentioned is the discussion about sensor-focused data and observation focused data. Sensor focused data is data in which the device is the core of the data. Observation focused data aims to serve the user with measurements and observations and its meta data. According to Sugumaran and Storey [2002] the observation-centric side seems to be winning. This is clearly visible in the standards such as O & M and Sensor Observation Service which are focused on observation data and are commonly used for user oriented implementations, where values and observation data are more important than device information.

3.6 SENSOR STANDARDS

Next to OGC, W3C is also working on sensor standards. Besides Semantic Sensor Network, one of the standards that might be relevant for this study is the Generic Sensor API. This standard is still a working draft according to the documentation, but can help on technical aspects of the sensor. Another W3C standard that can be useful for the device side of the data is the Web of Things, which is still in the development phase [W3C, 2016b].

When focusing on WIRELESS ad hoc sensor networks there are several standards that are commonly used. Two different types of IEEE are discussed by Garcia-Hernandez, the IEEE 802 series IEEE 1451 family [García-Hernández et al., 2007]. The Institute of Electrical and Electronics Engineers (IEEE) makes standards for electronics. The IEEE is producer and maintainer of nearly 1,300 standards and projects under development [IEEE, 2016a]. Currently, in the electronics standards the most prevailing standard is IEEE. However there is so much information on IEEE standards and it is too extensive to compare hundreds of standards, they will not be individually assessed. The goal of their standards vary from symbols for unit of measurements to broadband LAN cabling. In the current situation these standards do not fit in the frame of the research which is focused on the data standards and not on the electronics standards, however they remain relevant in the future of the Sensor Web. The reason that this group of standards is mentioned, is because of the influence of IEEE on the sensor technology development is too extensive to neglect.

The IEEE offers the maintainer of the sensor network a set of tools that makes it much easier to create the sensor network. For instance the transducer Interface Module(TIM) offers descriptive information about transducers. The descriptive information about the sensor replaces all the information that used to be paper data. Part of this discoverable information can be relevant for the maintainer of the network such as the sensor type, calibration data and user information. Therefore it is important to incorporate the relevant IEEE standards in a grouping of the Sensor Web.

The relative position and relations for the standards are displayed in the red circle in figure 3.4. In that figure the location of Sensor ML is shown, as well as the the Sensor Observation Service and the Observations and Measurements and how they are all depending on each other. The IEEE 1451 is proposed as a universal solution to connect sensors within networks. However the IEEE 1451 is best suited for application adaption. There is a supplement proposed on the IEEE 1451 for interpretation of the data and adding meta data, namely the Sensor Web Enablement. The main aim of SWE is to make sensors and other devices that are accessed through the Internet web accessible and controllable [Botts et al., 2008]. SWE's sub-encodings inclusive Observation and Measurements, SensorML and Sensor Observation Service [Hu et al., 2007]. These last three will be assessed in this research. Classes in OGC's standards are based on the Common Data Models of Sensor Web Enablement, such as SensorML. SensorML adopts for instance medadata for input output and parameter (SensorML).

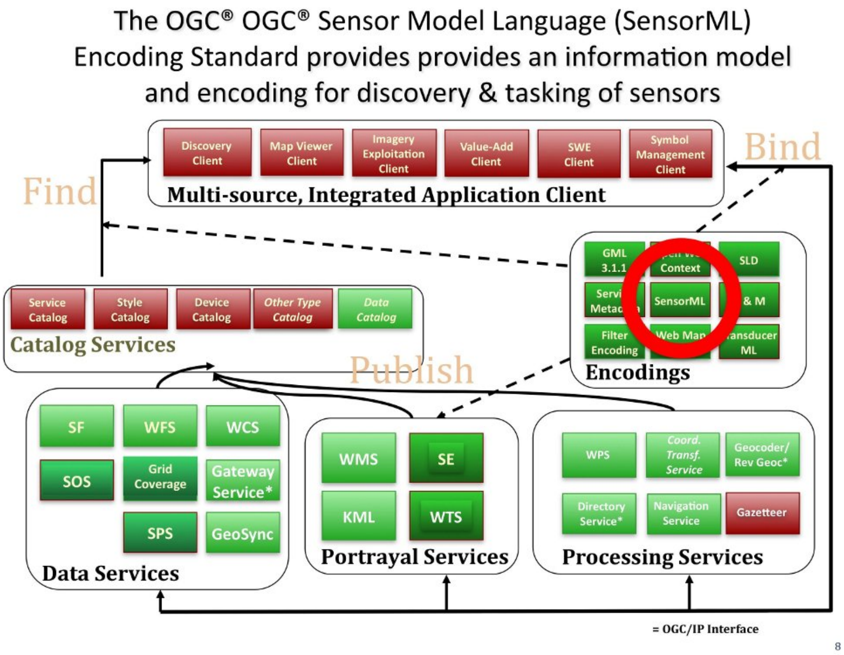


Figure 3.4: Overview of OGC-standards(SensorML)

Some of the current sensor standards are well developed and commonly accepted. On the other hand there are also sensor standards that are still in development. An example of those standards that are already mature is SOAP based standards. Soap is a XML-based standards that is used as a messaging standard and to make remote procedure calls. Other examples of mature standards are web feature services and IEEE 802. Services that were defined in 2006 being in development are the Sensor Observation, planning and alerting services [Lee, 2016]. Continuously there is work going on in the standards. In the time this study is done there can be another sensor standard that is approved by OGC. OGC is a big player in the sensor standard working field. They developed the Web Map Service (WMS), Web Feature Service (Web Feature Service), Web Coverage Service (Web Coverage Service), Catalogue Service for the Web (CSW), Sensor

Observation Service (SOS), Sensor Planning Service (SPS), Sensor Alert Service (SAS) Geography Markup Language (GML) Web Map Context and KML (keyhole Markup language) [Percivall, 2010]. NIST is more focused on standards for calibration, security and technologies on lower levels in the OSI-model which will be explained later [Lipe, 1996; Ross, 2007].

There are different types of interoperability between standards. There is syntactic interoperability and semantic interoperability. Syntactic interoperability is standard formatting for machine-to-machine exchange of data, semantic interoperability is interoperability of meaning [Compton et al., 2012].

Currently Inspire has 34 themes and several of them are relevant for sensor data. One of them is Atmospheric Conditions and Meteorological Geographical Features. This theme is based on Observations and Measurements. It introduces different types of observations, namely:

- Point observation: A single observation at a point in time at a certain location
- Point Time Series Observation: Various points in time at a fixed location also known as time series
- Multi Point Observation: observations made at one point in time and at different locations
- Grid Observation: Observations made in a coverage of a grid made out of similar spatial units at one point in time
- Grid Series Observation: Observations made in a coverage of a grid made out of similar spatial units at different points in time
- Profile Observation: A spatially vertical profile at one point in time. An example is wind speed at different heights
- Trajectory Observation: Observations at a meandering trajectory in both space and time.

Not all of the observation types are relevant for this research. For the last value the point observation is relevant. For the time series the Point Time Series Observation is relevant. If there is a bounding box in which the sensor data is requested, the multi point can be chosen. Both the grid observation and the grid series observation are not relevant. The profile observation is not relevant and the trajectory observation is also not relevant. However this can be different per use case.

In this theme inserting meta data of the sensor is an option in resultQuality:DQ_Element of the generic class OM_Observation. Other meta data can be inserted as well in the ISO 19115 class MD_Metadata.

For clear observations unit of measurement is important. This is adapted in Inspire from the UCUM, a code system setting agreements on the use of symbols for units of measurement [Inspire, 2016c; Umuc, 2016].

The overview of OGC's standards demonstrates the relevance of non-sensor specific standards in sensor applications, such as the Web Map Service, Web Coverage Service and Web Feature Service. Later in the use case it will be explained which of these standards are used and how.

The semantic web is a potentially relevant area for the Sensor Web where still steps are taken in a fast pace to improve it. For example if rules need to be defined for sensors and observations W3C's SWRL can be used.

Especially in the case of sensors there can be certain threshold within which there could be some kind of consequence, which can be seen by the users [Sheth et al., 2008]. An example is when gases are too high for a certain amount of time. There can be a term to refer to this situation that can be understood by the users, such as medium danger for the health.

OGC is currently working on standards that can be relevant for the sensorweb such as the TimeSeriesML [Inspire, 2016a] .However this standard can not be used yet so will not be included in the research.

3.7 COMMONLY USED SENSOR STANDARDS

There are more standards that can be analysed in the time span of this research so the commonly used sensor standards will be studied and explained most extensively. This is done to limit the amount of data in the assessment plus it will give the opportunity to study the commonly used standards into more depth. The meaning of commonly used standard is set to a standard that is accepted by official standardisation institutes and thus in general also adopted and exploited by the corporate users, and institutes. Furthermore it should be relevant for this use case to be applicable on that setting. Relevance means having a link to the use case, being used in the use case or mentioned and/or used extensively in similar sensor project. To avoid a too narrow scope some other significant standards will be mentioned. They will also be plotted in a ordering system, but will not be thoroughly assessed nor explained. The choice for the commonly used standards is based on the number of hits on Google scholar, as a search result on Google, on relevance for this research as well as on their appearance on the official websites of OGC, W3C, CEN, NEN, Inspire and ISO. The research that has been done to find the commonly standards can be seen in figure 3.5 The standards in this overview are picked based on references in the literature and being mentioned in the Smart Emission project. The standards that have more than 500 hits on both Google scholar and Google and are relevant for this project will be further elaborated on. The ones that have less hits on both Google scholar and Google but are relevant for the project will also be further analysed. The standards that have enough hits but have no relevance will not be included in the further research as well as the standards that have less than 500 hits and are not relevant for this research.

	Hits Google scholar	Hits google	relevance research	commonly used standard	Further research
Sensor observation service	sensor observation service standards: 1,980	sensor observation service standards: 17,400	Relevant for: Web service interface to query observations, sensor metadata, and representations of observed features.	Yes, and relevant for project	✓
SensorML	sensorml standards: 2510	sensorml standards: 44,700	Relevant for: Restriction of sensor description, and sensor discovery	Yes, and relevant for project	✓
Semantic sensor network	semantic sensor network standards: 978	semantic sensor network standards: 8,920	Relevant for: describing sensors, observations, and related concepts	Yes, and relevant for project	✓
Observations and measurements	observations and measurements standards: 17,500	observations and measurements standards: 272,000	Relevant for: XML implementation of schemas for observations, and for features	Yes, and relevant for project	✓
sensor things API	sensor things api standards: 1	sensor things api standards: 121	Relevant for: interconnecting IoT devices, data, and applications over the Web	No, but relevant for project	✓
IEEE	IEEE standards: 2,120,000	IEEE standards: 34,800,000	Negligilbe, focused on mechanics	yes, but irrelevant for project	✗
Transducer Markup Language	Transducer Markup Language standards: 3,780	Transducer Markup Language standards: 91,900	Negligilbe: focused on describe any transducer (sensor or transmitter) in terms of a common model	yes, but irrelevant for project	✗
Aireas API	Aireas API standards: 0	Aireas API standards: 2	Negligilbe: focused on aggregation of sensor data	No, and irrelevant for project	✗

Figure 3.5: Commonly used standards

3.7.1 Sensor Observation Service

The Sensor Observation Service which will be abbreviated as SOS is found and described in the OGC SWE specification series. SOS provides the Sensor Web with a web interface aimed on querying measurements as well as other sensor data. [Botts et al., 2008] Jazayeri et al. [2015] draws the conclusion that therefore the SOS is a mediator between the client and the repositories of sensor observations.

Walter helps explaining the SOS by giving a typical example of its concepts. Procedures are data producers, such as sensors and the sensor has a location called the feature of interest. An observation is a phenomenon at a specific time and has a specific location. The observations form groups ordered by semantics [Walter and Nash, 2009].

The Sensor Observation Service model is complying to the Observations and Measurements version 2.0, This means that the SOS reuses terms from the Observations and Measurements such as the Observed Property, Phenomenon time, result time, Feature of Interest and result [OGC, 2016d].

SOS facilitates the interface as a web service in which the user can request, filter and find observations and information about the sensor device and system. Therefore the SOS is a mediator between the client and the repositories of sensor observations [Jazayeri et al., 2015].

There are different servers on which a sos service is running and that have a different performance: 52North, MapServer, PySOS and Deegree. Aforementioned servers all use the same XML schemas, but have their own specific configuration and performance [Poorazizi et al., 2012; 52North, 2016].

These servers use also other open standards. For example Deegree uses Web Map Tile Service, Web Map Service, Web Feature Service, Catalog service web and Web processing service. An example of a SOS server using the 52 north server can be seen in figure 3.6.

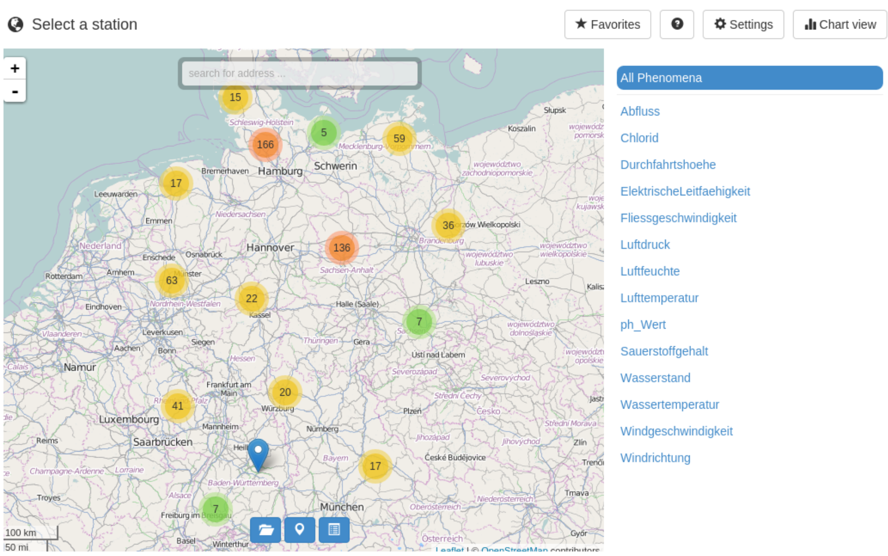


Figure 3.6: Example of the 52north SOS viewer

However the SOS servers can be used and adapted for every topic ranging from species count in biology to flooding of roads in risk management.

3.7.2 Semantics Sensor Network

The Semantic Sensor Network has been chosen as only non-OGC SWE standard, because it can show how additional semantic data can be added. Before the introduction of the Semantic Sensor Network, the Sensor web lacked semantic discovery of sensor data. According to Neuhaus and Compton [2009] the Semantic Sensor Network offers the option to do semantic queries on the Sensor Web using ontologies. de Liefde [2016] created an solution that made it possible to discover, retrieve and process sensor data in the Sensor Observation Service. This improves the performance of the Sensor Web and makes it better usable for users.

The Semantic Sensor Network serves two goals for the Sensor Web: the development of ontologies for describing sensors, and the extension of the Sensor Model Language (SensorML), one of the four SWE languages, to support semantic annotations. Using ontologies is a method to represent the knowledge originating from the real world in creating designs for databases.

Corcho and García-Castro [2010] defined five issues that can be handled by semantic web applications.

- Quality of sensor data
- Level of abstraction of the sensor data
- Integration and fusion of sensor data
- identification and location of relevant sensor-based data sources
- rapid development of applications

It can be seen that the Semantic sensor Network is essential in the development of the Sensor Web. The SSN is currently the standard that is mainly used to work on semantics for sensors and observations. However as has been aforementioned, there are also other standards that are applicable such as the Semantic Web Rule Language (SWRL).

The SSN works with ontologies. An ontology is a domain representation, represented by concepts and relations [Sheth et al., 2008]. In other words it is a natural means of representing real world knowledge for the development of database designs [Sugumaran and Storey, 2002]. Next to the SSN ontology there are other ontologies relevant for the Sensor Web, which can be seen in figure 3.7. According to this figure the ontologies all have similar data semantics, namely sensor data, sensing processes and acquisition policy but they lack some types of semantic data such as data quality.

	Sensor	Observation	Data								
Ontologies	8 facets	5 facets	Data	Data Stream	Sensing process	Communicating process	Tranforming process	States	Data Quality	Acquisition policy	Communication policy
SSN [3] ontology	8/8	4/5	*		*					*	
CESN otology [6]	2/8	1/4	*		*						
CSIRO ontology [9]	8/8	4/5	*		*					*	
Sensei O&M ontology [3]	N/V	N/V(not available)	*		*						
OOSTETHYS ontology [5]	2/8	2/5	*		*						
MMI [4] ontology	5/8	N/V			*					*	
SWAMO [5] ontology	3/8	2/5			*						
SEEK ontology [14]	N/V	N/V	*		*						
SDO ontology [12]	2/8	2/5	*		*					*	
SeReS O&M ontology [15]	N/V	N/V	*		*						
OntoSensor ontology [16]	5/8	5/5	*		*					*	

Figure 3.7: Available ontologies for sensor data

The data model from SSN originating from the SSN ontologies can be seen in figure 3.8. In red the main concepts are visible which are adapted from O&M, the sensor, observation, property and feature of interest. However there are also other terms such as system and platform.

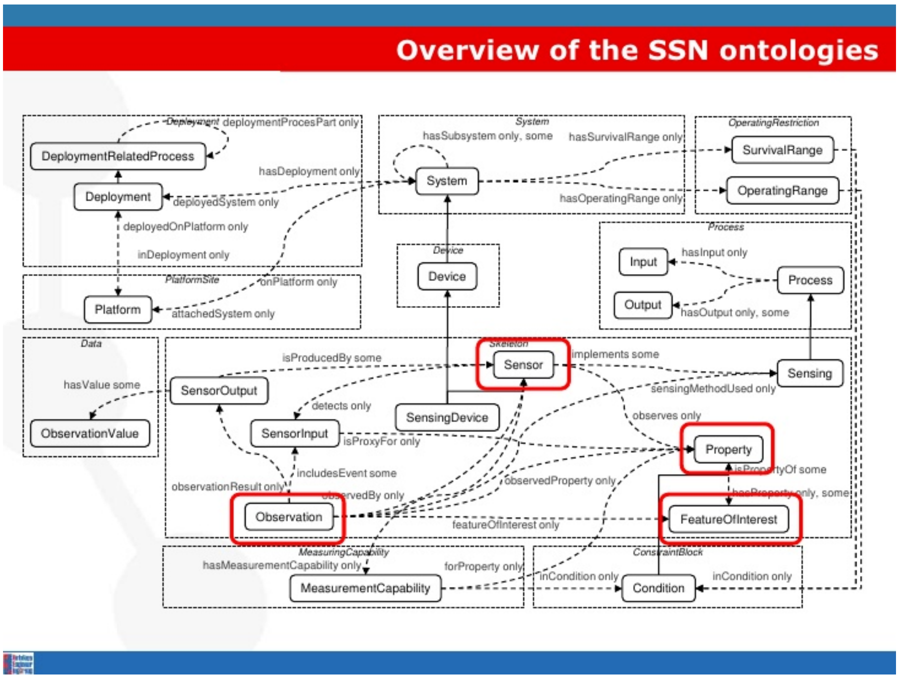


Figure 3.8: Datamodel from SSN ontologies[?]

3.7.3 Sensor Things API

The Internet of Things is much intertwined with sensor standards. In the Internet of Things there is a growing number of standards, also used in the Sensor Web such as the Sensor Things API. The reason of this growth is the pace in which the Internet of Things grows as well as the expectations that this growth causes [van der Schaaf and Herzog, 2015].

Sensor Things API is a relatively new OGC standard, based on Observations and Measurements and offers an open manner to connect devices, sensor data and resulting applications on the web. The standard works well even if the amount of resources for devices are limited [van der Schaaf and Herzog, 2015]. Things in the SensorThings API are the sensing devices in the sensor network, have a location, described as a geometry object and a time, to support mobile things. Things also have a description other arbitrary meta data [van der Schaaf and Herzog, 2015]. The UML model that clearly shows how it works can be seen in figure 3.9

The sensor things API has been applied in several cases to achieve interoperability, such as in the case of Senviro. Senviro is a sensorized platform [Trilles et al., 2015]. The procedure to publish the data is straightforward. This is explained online and can be seen in figure 3.10.

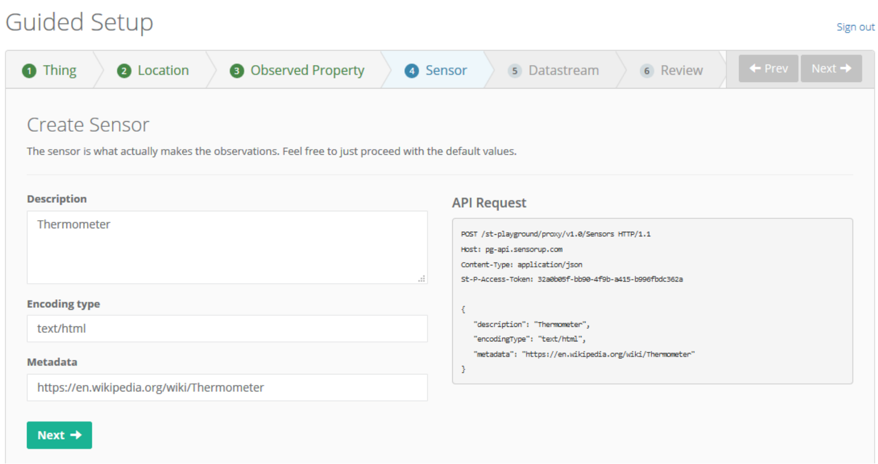


Figure 3.10: Setup sensor things API

Even though the Sensor Things API is relatively new, there are already a couple of implementations for the Sensor Things API respectively: Whiskers, GOST and Fraunhofer [Wikipedia, 2016]. That means there certainly is interest in its functionalities.

The data model for the sensor things is composed of a data stream linked to an observation at a feature of interest, The data stream is also connected to a thing. Things are important in the SensorThings API. The thing has a location and can have a historical location. Furthermore the data stream is connected to the sensor and has an observed property.

3.7.4 SensorML

OGC has stated the following goal for SensorML on their official website : The goal of SensorML is to set up a rich way of process definition and component processing linked with both the measurements and post-processing of observations. Both semantic and syntactic

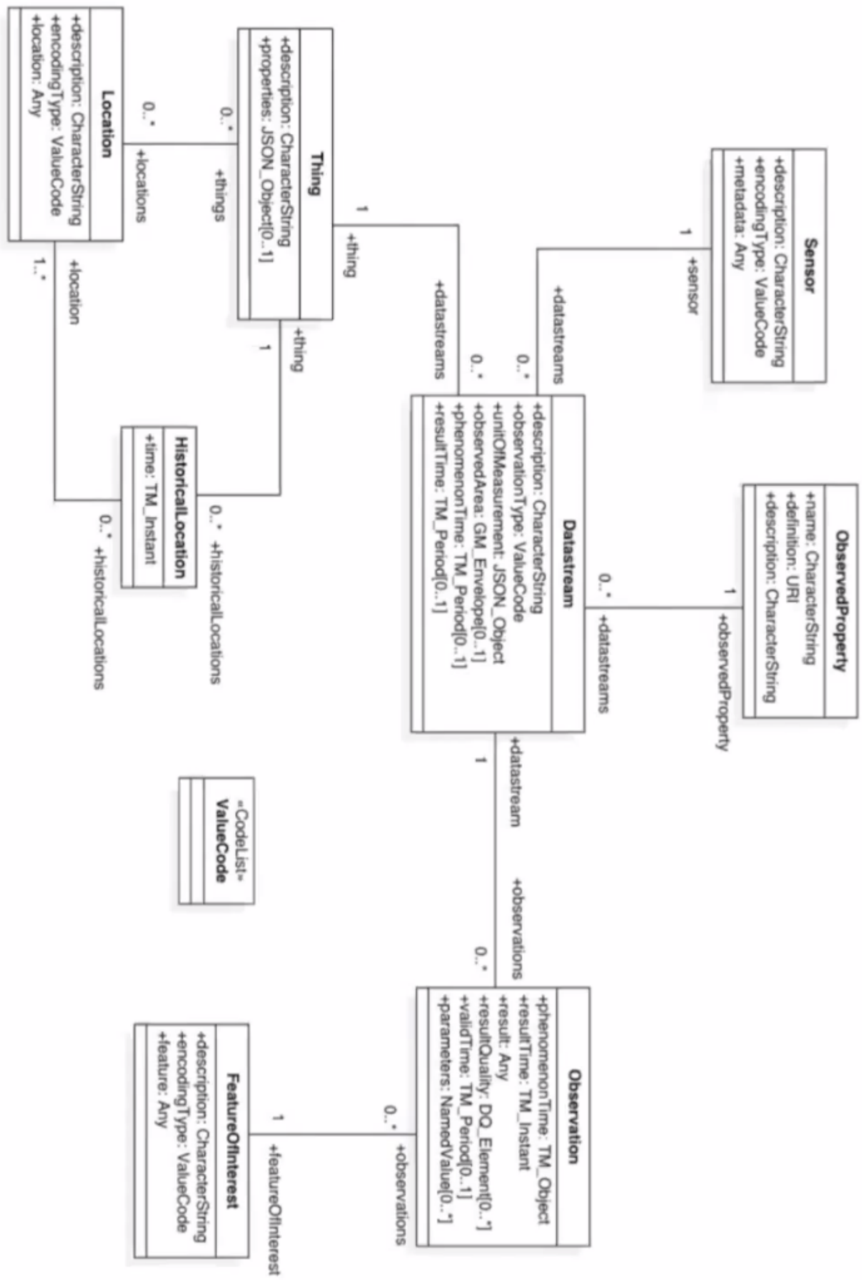


Figure 3.9: Sensor Things API according to [Liang, 2016]

interoperability are represented in SensorML [OGC, 2016b]. SensorML offers models for standards and for XML encoding to describe sensing procedures [Aloisio et al., 2006]. In SensorML sensors as well as other components are modelled as processes [O'Reilly et al., 2009]. SensorML's description has the option named Measurement By Sensors, the request to acquire high-level observation data [OGC, 2016e].

SensorML 2.0 is capable of producing meta data both real time and of past intervals [OGC, 2016b]. Examples of meta data that can be provided can be seen in 3.11

In the example below, the metadata provided includes:

textual description

unique identifier

name

keywords

identifiers

classifiers

valid time constraints

security constraints

legal constraints

characteristics

capabilities

contacts

documentation

Figure 3.11: Meta data SensorML

A further advantage of SensorML is that meta data can be shown such as the health of the sensor, as can be seen in the data model there is a device class, where such variables can be added. This is relevant for the maintainer of the sensor network.

3.7.5 Observations and Measurements

Inspire's Observations and Measurements is a standard that is commonly used and harmonized into other standards [Cox, 2006]. The goal of Observations and Measurements is an XML implementation of schemas for observations, and for features. It is closely linked to SOS, because according to OGC it is an dependency for the OGC Sensor Observation Service (SOS) Interface Standard [OGC, 2016a].

O&M's models are uttermost relevant for the following themes of Inspire:

- Geology
- Atmospheric conditions and Meteorological geographical features
- Environmental monitoring facilities
- Oceanographic geographical features
- SeaRegions
- Soil
- Species distribution

Furthermore the O&M models are partly relevant to some other themes, such as Human Health and Safety and Land cover.

The core for a new sensor standards is generally the conceptual model of Observations and Measurements. The concept of Observations and Measurements that is adapted is that an observation is an activity which result is an estimation of the value of a property of a feature of interest. This observations is collected by a particular procedure [Woolf, 2009]. The concepts that are the basis for Observations and Measurements and that are adapted in other Inspire themes and standards are Feature of Interest, Observed Property and process. How these concepts are related to each other can be seen in figure 3.12

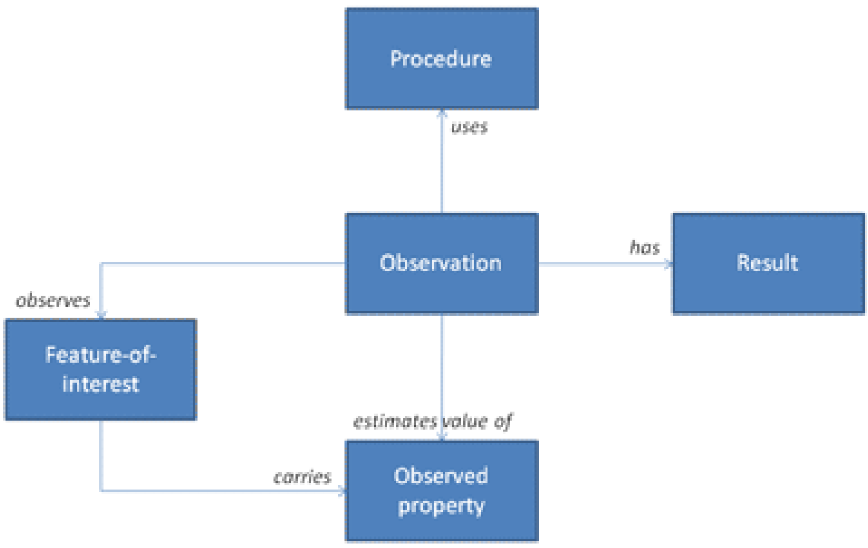


Figure 3.12: Basis concepts Observations and Measurements, [Woolf, 2009]

It can be seen that the observation is the core of the model. In the case of the maintainer that requires specific data about the sensor the sensor should be the core. Therefore Observations and Measurements is not suitable to function as the standard for maintainer. Since many other standards use the Observations and Measurements conceptual model, this also accounts for these standards and all the themes related to Sensors in Inspire. However for the user the sensor data is the most important component of the model and because observation is focused on Observations and Measurements, its model is better fitted [Cox, 2006].

3.8 CURRENT SOLUTIONS

There are currently several pieces of research aiming for a better organized standards infrastructure and more interoperability within this infrastructure.

- The Sensor Web Enablement and the SWE common data models were created to achieve interoperability as main goal [Inspire, 2007]. However using only the Sensor Web Enablement is not enough to achieve an interoperable Sensor Web on all the layers. There are studies that suggest using combinations of standards to add more capabilities [Hu et al., 2007].

- NOSA is one of the currently offered solutions. It is a new standard based on SensorML, Observation and Measurement, Sensor Collection Service, Sensor Planning Service and Web Notification Service. In this work this set of standards constitutes a layered model similar to the OSI-model [Chu et al., 2006]. This model can be seen in figure 3.13.

- Furthermore there has been a study making a meta data model for sensor discovery, including a alignment matrix comparing the capabilities of several standards [OGC, 2016f].

- In the field of plug and play there has been a call for adopting commonly used standards. For example in the research of Hu et al. [2007]. Hu states that their research can assist in other system integration research incorporating sensors. The suggestion that is proposed is a IEEE standard combined with Sensor Web Enablement encodings. The IEEE can then be used for sensor description and SensorML to model the sensor descriptions. Additionally, Observations and Measurements and TransducerML can be used to describe observation properties. the limitations of this method is that harmonisation is not working due to missing mappings of terminology between standards. Additionally the author is concerned if the standards can be used for maintenance of the sensor and can practically be adopted by manufacturers of the sensors.

- Lee [2016] mentions a proceeding about harmonisation of standards involving the stakeholders and evaluating the current situation of the Sensor Web. In this proceeding possible solutions for the future were offered. In one of these meetings it has been mentioned that the requirements for sensor data will evolve in the future. If technical evolution will result in different requirements for this data, standards should also be dynamic and will change in a fast pace. Therefore

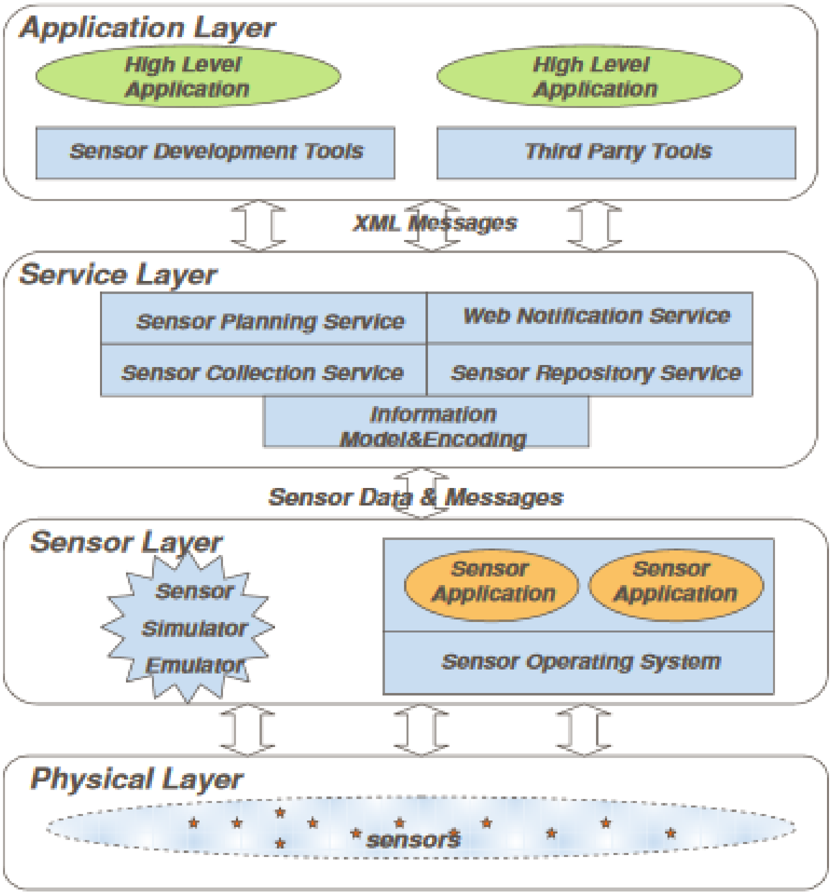


Figure 3.13: Layered model[Chu et al., 2006]

creating standards is not the end stage of standardisation. Standards need to be maintained [Jackson et al., 2003]. In the same workshop harmonisation for the Sensor Web including six components has been suggested. The advise was to use a combination of TransducerML (TML), ANSI 42.42, IEEE 1451, the CBRN Data Model, EDXL using CAP and, SensorML/OGC. All these components together form the Sensor data model. The author mentions different standards because every standards contributes in its own specialism [Lee, 2016].

- Another suggestion offers a similar solution namely Lee [2007]. This proposed solution combines IEEE 1451, SensorML, TransducerML, the CBRN Sensor Data Model, MIMOSA, and OSA-CBM. This combination of standards is especially useful if a user would like to discover sensor meta data. Semantics through ontologies is used to find similarities in the standards and so to harmonize them. NIST and OGC, two organizations that work on sensor standards claim to have a collaboration planned for the sensor standards, however this is disputed by Hu [Hu et al., 2007]. On the other hand in 2007 there was a sensor standards harmonisation work group where NIST was mentioned as a active member of this meeting, which proves steps have been made towards harmonisation [IEEE, 2016b].

- There is a study that attempts to couple wireless sensor networks and the Sensor Observation Service that tries to solve the interoperability problem by accessing the data standardised in a SWE infrastructure [Walter and Nash, 2009]. Another way to make heterogeneous sensor network interoperate is to combine Peer2Peer architecture and the SWE standards. Liang et al. [2008] used Geoswift 2.0 to achieve this. This gives the option to find sensors in a certain area. Geoswift 2.0 is different than other sensor standards such as SOS in the way that it is Peer to peer constructed and solves centralized ontologies.

- The standardisation approach which Elloumi [2015] applied is similar to the approach used in this research and is also divided in several steps. First the use case is defined. The second step is to set the requirements, then following step is to use existing standards/API, combine them or make a new one and the last step is to validate the used standard or API.

- The aforementioned first way to group the standards is the OSI-model. Another way to group the standards is given by [Postscapes, 2016]. Their proposition is to group standards from the Internet of Things in 8 groups:

  - Infrastructure
  - Identification
  - Comms / Transport
  - Discovery
  - Data Protocols
  - Device Management
  - Semantic
  - Multi-layer Frameworks

- Even though not all Internet of Things standards are relevant for the Sensor Web and the ordering done by [Postscapes, 2016]. is using too many standards irrelevant for the Sensor Web, a similar way to order the sensor standards is plausible, because the Sensor Web also needs standards to discover sensor data. The Sensor Web needs standards for device management and there are semantic standards such as Semantics Sensor network. It is possible to enrich a SOS service with Semantics. This is done in a project named SemSOS. They use SOS in combination with Observations and Measurements, SensorML and RDF [Henson et al., 2009b]. It is an example where the required standards are taken and used in such a way that the requirements of the research are met.

3.9 LIMITATIONS OF CURRENT SOLUTIONS

The problem of the current standards is that for some people in the geospatial world the SWE-standards are clear. However according to Walter and Nash [2009] it is not immediately clear to everyone how to apply them. For some users they might seem too complex and technical. Furthermore the combination of Observations and Measurements and other existing sensors standards was concluded in the context of the Smart Emission project to be not suitable enough for the maintainer. This is not solved in the current standards. Standards are used to achieve interoperability. However use cases are not generally part of these researches. So there is not a practical implementation to support interoperability. The possibility to request meta data from the sensor is depended on the capability of the sensor to output this data. Currently creating a heterogeneous sensor network with different types of sensors is still hard, because the sensors often have their own standards [Bröring et al., 2011]. The fact that there are so many solutions proposed, shows that one comprehensive solution is still far from reality. However it also demonstrates that many researchers are working towards a solution.

3.10 NEW SOLUTION

The current solutions do not fulfil the requirements of the primary actors. Therefore another solution is required. Combining several standards as has been done in earlier studies such as Walter and Nash [2009] Chu et al. [2006] and Liang et al. [2008] is therefore the basis for the new solution. However, more standards should be considered and explained to give a better image of which standards are optional.

Giving other names to the layers in the OSI-model such as in Postscapes [2016] is a relevant option. However the situation is not similar, so other layers should be defined.

A combination of standards for more interoperability such as suggested by Hu et al. [2007] is a fitting concept. It is possible to test the feasibility of this idea by trying it in the use case. To achieve the suggestion by Lee [2016] bringing together the stakeholders and coming to a mutual agreement about how to handle sensor data is a sound solution to make interoperability in real life possible and show the usefulness of standardisation in the Sensor Web.

In research on the sensor web use case were included, this will also be done in the new solution. It should be a use case that can prove standardisation in a realistic situation that is not an isolated case but can possibly happen more often in the future in the same or similar context.

Furthermore, the requirements of the users and maintainers for standards and the Sensor Web are essential for the future of the Sensor Web. Their needs should be clearly translated and visible in the standards. This translation not been done for the Sensor Web. This research attempts to incorporate those requirements. The efforts of the creation of sensor standards by EU organized institutes should be reimbursed to the users and maintainers in the form of an clear and accessible Sensor Web.

Adding semantic annotations to sensor standards such as in Lee [2007] or has been explained for the Sensor Observation Service by de Liefde [2016] is a useful idea. In this way it is possible to add semantic knowledge to an open standard [Henson et al., 2009a]. If that is done, it is possible to query sensor services on the web and retrieve this data as a user. de Liefde [2016] It would be useful to include semantic annotation to the use case sensor data. This can be done when the applications are running and providing the sensor data. However this will not be part of this study.

Not only will there be a data model made and a grouping, but to show the usefulness of such models, there will also be a visual online design to help developers in their standards choices and to demonstrate best practices. This will be shown in chapter 5.

4 USE CASE

The goal of this research is to pinpoint the gaps and overlaps in existing sensor standards and find a solution towards bridging the gaps. The use case to reach this goal is a project focusing on publishing smart city sensor data for citizens. In the project there are participants that are familiar with standards and there are those that are not yet familiar with standards. It is an excellent situation to involve all the parties and raise awareness about sensor standards. In this chapter first the context of the use case will be given and then the applications that are created are illustrated and explained.

4.1 CASE DESCRIPTION

Initially, the problem that has led to drafting the use case was the construction of a new road and the renovation of the current bridge over the river the Waal in Nijmegen. There was need for a digital sensing system that would collect data about the air quality of the city and publish them as open data. This can be done by sensors measuring gases such as O3, CO2, O2 and NO2. However, Sensors can collect more than only air quality data. So more measurements will be included in the use case of Smart Emission. The air quality measurements are complemented with meteorological data, sound and other measurements. However to keep the use case simple, this case study will focus only on the air quality.

In the end of 2014 the Smart Emission was started as a pilot that combines research and development of a citizen-sensor-network. It takes place in the city of Nijmegen, monitoring physical and environmental qualities with the help of citizens using innovative sensing and ICT technology [Nijmegen, 2016]. It was initiated by the municipality, cooperating with the university of Nijmegen, maintainer of the sensor networks and organizations that create geo-standards. The data from the sensors is available via the web. A GIS-application will be made for the project with the goal to monitor and display the data from the sensor. This research only deals with the time during which the internship at Geonovum takes place, which started at November 2015.

The Smart Emission project depends heavily on the cooperation of companies and institutes, but the target group for the application that is created are the citizens of the city. It is both a technical and a sociological project, because it can demonstrate how the citizens will respond to the sensor data and if they will use environmental data and also if they will benefit from standards. Even though a well functioning sensor standard is not directly visible for the citizens, the creation of the current sensor applications will turn out better much better with an interoperable standard.

Through publishing sensor data online, the municipality is able to objectively prove that certain values of air pollution in the city are within a certain threshold. If law directs health rules, depending on a maximum degree of air pollution, a citizen can report threshold exceedances.

To investigate sensor standards the real life use case is the following: The user of the application, being a citizen of the Dutch city of Nijmegen, needs clear sensor data that is self-explanatory, and specifically wants data about air pollution. The maintainer of the sensor network, in this case the same as the maintainer of the sensors, is also subject in the use case, because that is something not so much researched yet. The raw sensor data needs to be transformed into comprehensible data and this procedure has to be in the data model. To do this in an ordered way every type and variable should be discussed with the experts of the different topics. The innovativeness of the Smart Emission project in combination with this research is that the producer and maintainer of sensors is introduced in standards testing and modeling. The goal for the use case is to assess the use of a sensor standard in a real-life situation by exploring the used system, applying commonly used standard in use case and defining steps to align systems

The information architecture that is currently used for the project can be seen in figure 4.1. It can be seen that the spectrum of used standards is still unsure. A couple of them are chosen, such as the sensor things API, the Sensor Observation Service and the Web Map Service, Web Feature Service and Web Coverage Service, but there is still room for improvements and recommendations. That is why the conclusions of this research are required for this project in this point in time. The study will give these recommendations for the project, but will be also exemplary for how the Sensor Web can be ordered in a better way and how to choose a single standard or a set of suitable standards for a possible sensor project.

The use case is a demonstration of the complexity of sensor data and how to handle it, where possible by standards. Sequeda and Corcho [2009] sums the types of data possibly coming from sensors, being geographical data for data aggregation and data selection, numerical data being the observations, the element time which specifies when a measurement was done also used to aggregate data, and data quality.

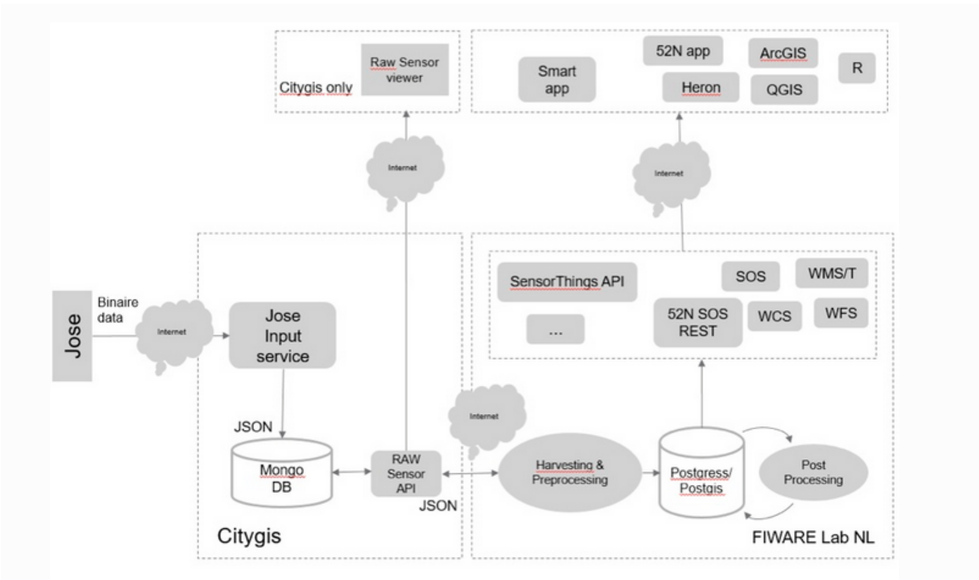


Figure 4.1: Architecture Smart Emission project [Project, 2016]

4.2 USE CASE SMART EMISSION APPLICATIONS

Currently there are three applications for the Smart Emission project. Later there will be a fourth application which uses the Sensor Things API. The citizen needs to know which application serves which goal. Therefore standardisation is required to limit the number of applications and define which functionalities can be found in them. The aim of the project group is to limit the number of applications for the citizen and offer only the application that fulfils the minimum of requirements agreed upon by the project team, which will be the prototype that will be tested through validation using the data models based on existing standards. The project is planned to finish at the end of 2016. Therefore the universal application is not finished yet. The assessments of the use case are based on the current applications.

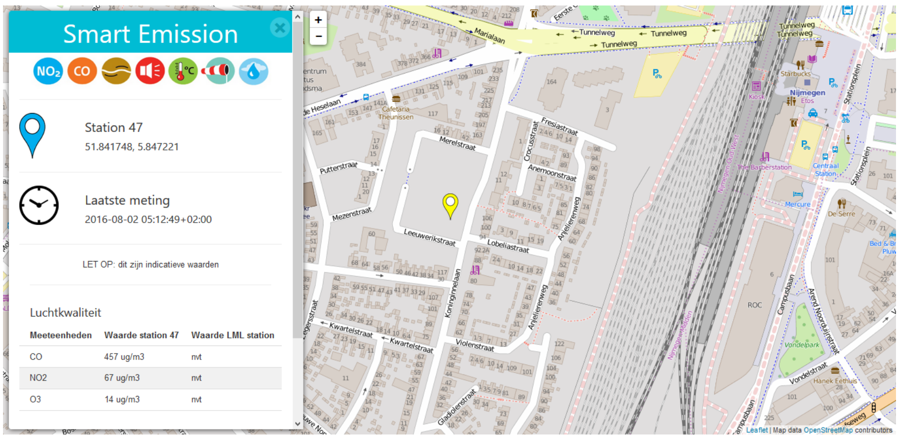
The three functioning applications that will be included in the Smart Emission project that will be assessed on interoperability and for which the sensor standards can be relevant are the Heronviewer, the Smart App and the SOS-viewer, which will be explained in more detail.

Both the Heronviewer and the SOS viewer are based on the SOS 52 north server. The Heronviewer uses WMS-Time [van den Broeke and Brentjes, 2016].

4.2.1 Smart Emission app

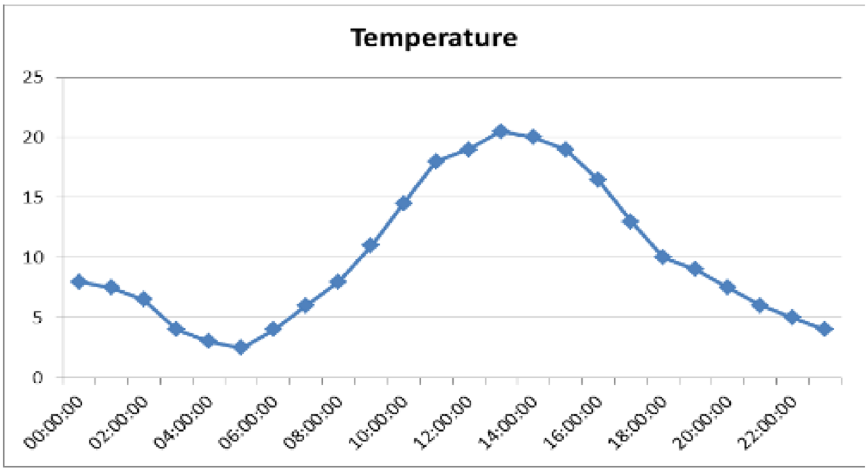
The Smart App is made by Giel Vermeulen, Just van den Broeke and Robert Kieboom and is made as a leaflet application. It is called smart, because of its capabilities to provide the user with relevant information and because it can intuitively be used on a smart phone.

Figure 4.2: Smart Emission App



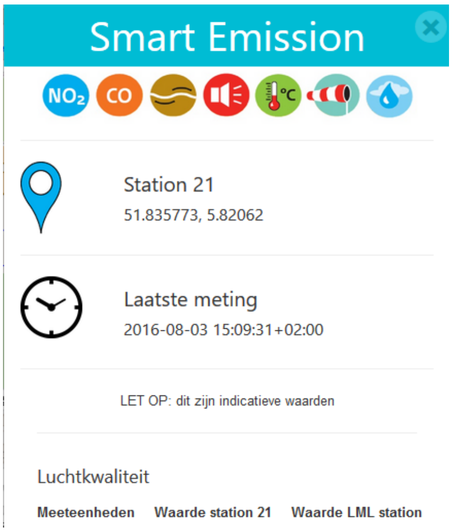
The three applications that are now available serve two temporal goals: time series and last value. An example of time series according to Inspire can be seen in figure 2.

Figure 4.3: Time series example [Inspire, 2016c]



The last value means the last observation from a certain sensor. This does not automatically mean that if the current time is 12:15:00 it gives the measurement of 12:15:00. It means it gives the last observation given by the sensor. An example of how the last value and the current time are two different things can be seen in figure 4.4. In this situation the sensor had not given any sensor data since August the 3rd, so the last value for this sensor was from August the 3rd, even though the application was accessed and some days later, for the data query.

Figure 4.4: Last value



4.2.2 SOS viewer

The second application is the SOS viewer, which is using the 52north SOS implementation. It is an exemplary case that proves the usefulness of the SOS standard. As can be seen in figure 3.6, the version from 52 north looks very similar to the one created for the Smart Emission project depicted in 4.5. That is the advantage of a standards such as the SOS. It saves a lot of time. It can be considered as a framework that can be reused. The SOS-viewer supports the downloading of historical sensor data. This is shown in a graph which can be seen in figure 4.6.

Figure 4.5: SOS viewer

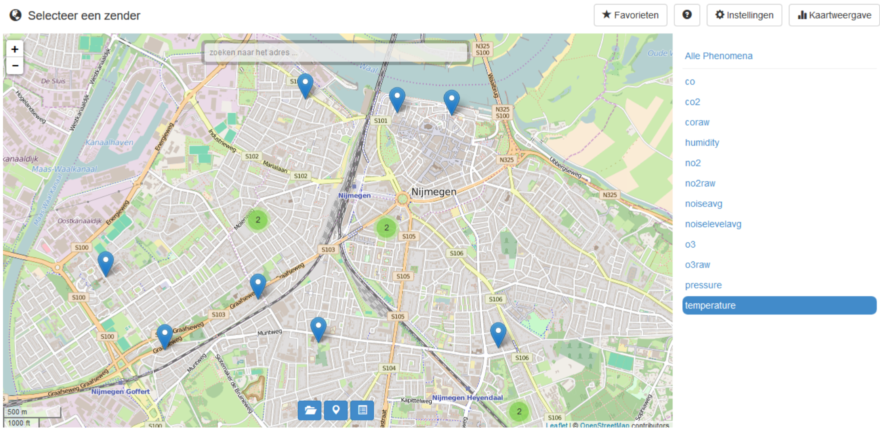
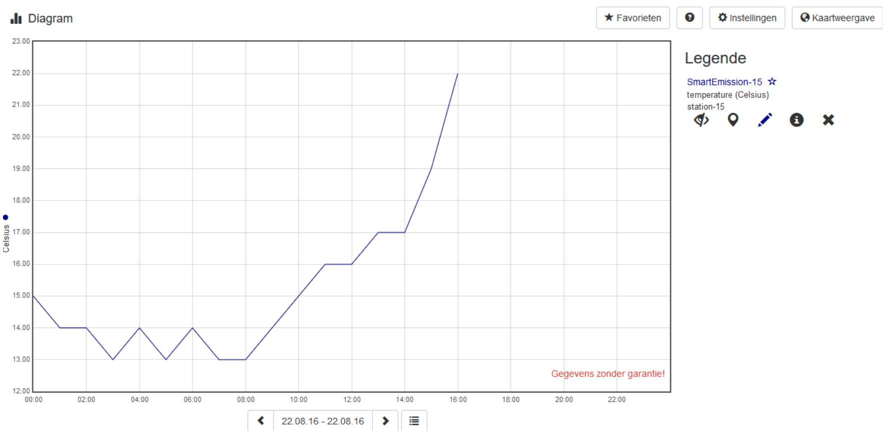


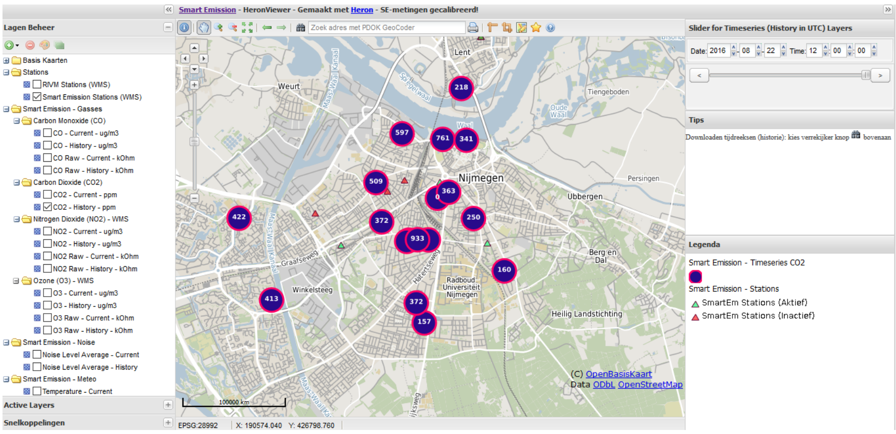
Figure 4.6: SOS historical data



4.2.3 Heron App

The third application that has been created for the Smart Emission project is the Heron App. In figure 4.7 this application can be seen. The heron app is made in Heron, an open source mapping client and supports downloading of time-series data.

Figure 4.7: Heron App



5 RESULTS

This chapter will list the requirements, show the data model that is created based on existing standards and give recommendations for improvements on current data models. Furthermore it will give an example on how to use the results on a web page environment to bring together technical information on the standards, and use cases experiences.

In the situation of the use case, harmonisation was done on six standards, because those turned out to be the most relevant commonly used sensor standards earlier in this study. The commonly used standards SensorML, SOS, SSN, Sensor Things API and O&M are combined in the data model. In the case that these standards do not meet the requirements, the criteria for the application have to be reconsidered and possible redefined, which is also a step in the work flow of this study. The standards used for the applications within the project are chosen heuristically and based on past experiences. The model will show that there is a better more intuitive way of choosing standards. The model that will be shown in this chapter is designed for a public that is familiar with the terms used, such as developers and sensor builders and aims to be also indirectly useful for the user in a later stage in development.

5.1 USE CASE REQUIREMENTS

The requirements specifically for the citizens in the use case are the following:

- The user should be able to view and download calibrated values for every sensor on meteorological data, gases and sound
- The data should be both real time (last value) and historical (time series)
- The historical data should be requestable for a specific moment in time and for an interval in the past
- The sensors should be able to be spatially visualized in a map
- There should be a specified set of units of measurement related to the values, which should be clear to the users, including scales
- There should be the option to select multiple sensors per geometry such as a bounding box and see their associated values
- It should be possible to view tables and charts visualizing the sensor data

There should also be meta data for the sensor containing the following data specially relevant for the maintainer of the network:

- Battery status

- WiFi status and network
- Sensor health
- Sensor name
- Last maintenance
- Frequency of measurement

5.2 THE ADAPTED OSI-MODEL

The adapted OSI-model can be seen in figure 5.2. In the model the five selected sensor standards are placed as well as the generic sensor API and the IEEE series to demonstrate how the model works for the more device-focused standards. The more data-focused standards are more relevant for the users of the sensor data and the more device-oriented standards are more relevant for the maintainers of sensor devices. However a balanced choice of standards is required to satisfy both groups. As can be seen there are standards that only fit in one category such as the SOS, but there are also standards that fit in more categories, such as the SSN. This is because the SSN is a solution as standards for devices and data. That does not mean that this kind of standards solve all problems regarding a missing universal standard, because the SSN does not include phenomena such as time and location. SSN acquires these phenomena from other ontologies [W3C, 2016a]. That is why besides standards also ontologies should be interoperable.

The five categories are Physical, Interfaces, Data linkage, observations and semantics and they all tell something about what is standardised.

- The physical layer standardizes the way the lowest most technical layer of the sensor is defined. Examples are how the resistance of the sensor is displayed and how the status of the battery is shown.
- The interface layer standardizes the interface of applications, which buttons, how to download in which format etc.
- The Data linkage layer represents the link between observation and sensor
- The Observation layer represents the values and meta data for the observations
- The semantics layer represents the rules and typical sensor specifications that could be reused in other similar projects, such as formulas, translations of real life phenomena, requirements for the data quality. This is a way to make datasets and the Sensor Web really interoperable.

This separation in layers and the kind of data is in them can be seen in figure 5.1. The flow of information starts at the bottom, where the raw sensor data is accumulating, then the layers communicate through interoperable standards and in every layer more information is added.

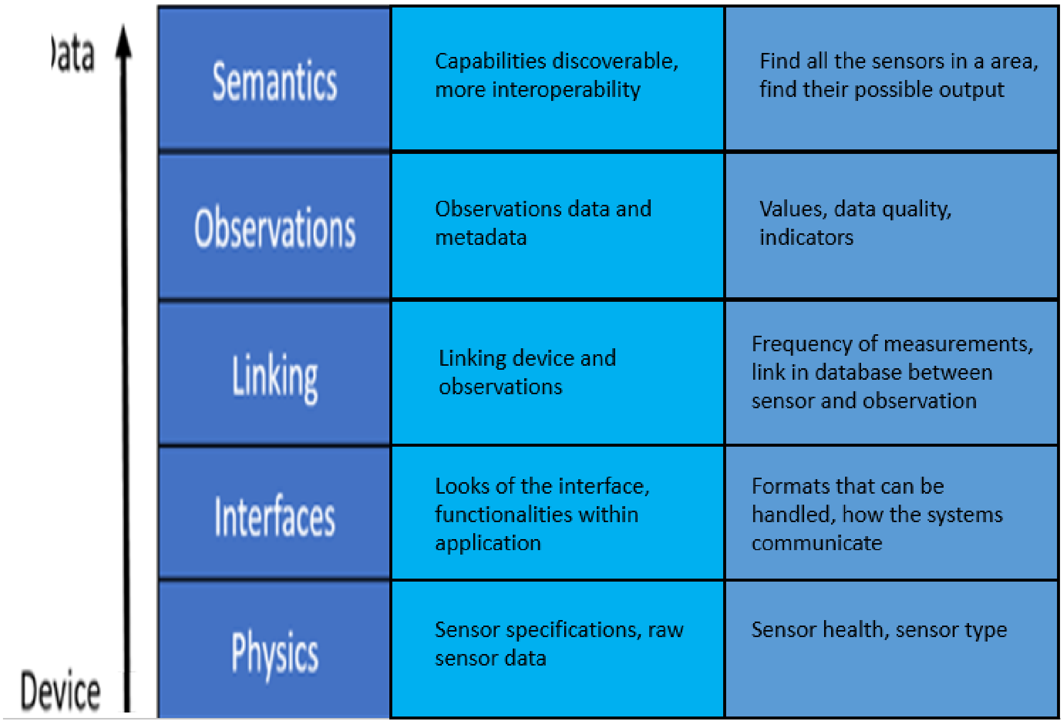


Figure 5.1: Layers of the Adapted OSI-model and included information

If the data ends up in the semantics layer, data is available for the user from all the layers underneath. If data is extracted from a sensor, just like in the original OSI-model in every layer more information is added, which can be queried. This is used in the same way as in the original OSI-model [Zimmermann, 1980]. This model can be used and moderated to fit other standards research, such as in the medical standards. It is possible to categorize them also on method, such as they were grouped in figure 3.3. Applying this on the OSI-model can be seen in figure 5.2. It can be seen that every layer already has at least two standards. This means that the developer can choose standards based on what kind of method of implementation he uses. This also means that there are overlaps and/or the standards use the same approach and goal. It is possible to add many more standards if the Sensor Web will grow in the future. This is possible because for every field in the model there can be more than one standard in it. If there are gaps in the model it means there is space for improved or new standards as long as they are unique and contribute more intuitively to the Sensor Web. Developers using the adapted OSI-model can easier choose the appropriate standard(s). If none of the standards is sufficient or the standards are not extensive enough, this can be drawn as a conclusion from the model. The standard organizations that use the model can look where their standard is in the model and discuss gaps, interoperability and overlaps with other standard organizations. Furthermore this model is a method to inventory and order the Sensor Web standards.

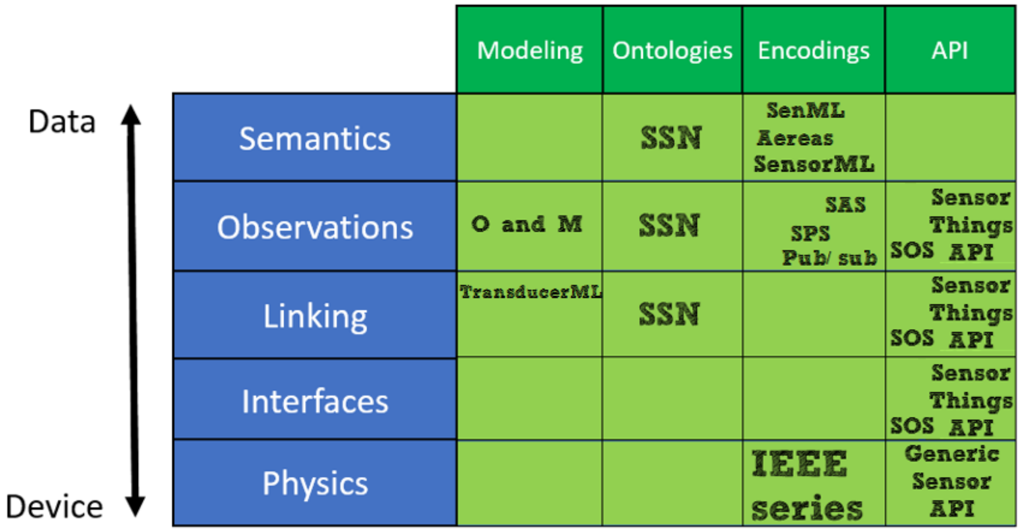


Figure 5.2: OSI-model for sensor standards categorized

It is not recommended to make the model too complex by adding too many categories, because then the overview becomes unclear. As can be seen there are certainly overlaps for the standards in both categories. However an overlap in a certain category does not mean that choosing one of the standards is always the solution. Often the situation is more complex in the Sensor Web and then the other tables should be consulted to discover if the requirements of a project or an application can be achieved through a certain standard. The OSI-model is a first consultation and requires those more extensive tables.

There are several advantages of using this adapted OSI-model. Developers can choose the fitting standards more easily. They can be picked based on preferences of the users of the standards. Furthermore the standards are ordered and an inventory is made of them. Furthermore it is possible for standard organizations to adapt their standards to other standards that are similar or work in the same field.

5.3 ALIGNMENT MATRIX

Some standards cover such a broad spectrum of the Sensor Web that they fit in more than one layer or category, such as for example the IEEE family and the SSN. Therefore the OSI-model is not enough to select a fitting standard. The user also needs a more in depth overview of the sensor standards. Figure 5.3 shows that capabilities for the commonly used sensor standards are given against the criteria formulated in the requirements.

This schema can help the users to choose the appropriate standard or standards. The checked boxes in the figure mean that the standard is able to meet this requirement. An unchecked box means that the standard does not allow this. It can be seen in this figure much better than in the other assessment that the SensorThings API and SOS have a lot of capabilities in common. Furthermore the most semantic standard, the Semantic Sensor Network can fulfil the most requirements related to the meta data for the sensor. The other two standards, Observations & Measurements and

SensorML can be used as a basis for the SOS and the SensorThings API. This is possible because except for the SensorThings API all the other standards have been made interoperable within the OGC Sensor Web Enablement framework. It has to be noted that this can be different for non-OGC standards such as the IEEE standards. The last conclusion that can be drawn from this alignment matrix is that sensor standards are quite heterogeneous, because they all are created with a different goal.

5.4 DATA MODEL

The data model that is created using UML and incorporating the set requirements can be seen in figure 5.4 and has entities represented in the boxes also called classes.

This model has harmonized all the thematic models created per use case template and its minimal requirements and also incorporates the maintainer requirements. Therefore this model is the complete image of the requirements in an ideal situation. Both temporal and spatial settings can be adjusted via this model. The model uses terms from several standards. For example historical location comes from the Sensor Things API. Observations procedures are from Observations and Measurements. The term Feature of Interest comes from the SOS. The maintenance component in the model is new. Furthermore it can be seen that there is a constraint for the value in the observation class. There is no trigger yet for the health of the sensor and the last maintenance, because this part is not in any of the standards applied in the use case. It is however possible to implement such a trigger on it in the future. One of the SWE standards that could help achieve this goal is the Sensor Event service, that can send messages to a forum about measurements, sensor management and expiration information [north, 2016]. This can be used if there is a problem with the sensor, if the temperature is unrealistically high or low, pointing at a dysfunctional sensor. However this is currently not included in the requirements so will be not in the data model. In the model it can be seen that sensor, location and observation are the most linked classes. They are relevant because all the other classes give meta data about the sensor and observation. There it can be seen that both for the user and the maintainer meta data is produced. Furthermore the location is important because the user and maintainer want to know where the measurement has been done and every thing has a location, just like in the Sensor Things API data model. The thing has been left out of this model, because it was not relevant, but a sensor can be seen as a thing.

Standard	Observations & Measurements	SensorML	Sensor things API	Semantic sensor network	Sensor Observation service
Sensor data					
View sensor data	×	×	✓	×	✓
download sensor data	×	×	✓	×	✓
Last value data	✓	✓	✓	×	✓
Time series data	✓	✓	✓	×	✓
Data requestable interval	×	✓	✓	×	×
Data requestable point in time	×	✓	✓	×	✓
Sensor spatially dispersed in map	×	×	✓	×	✓
Clear units of measurements	×	✓	✓	×	✓
Scales if required for measurement	×	×	×	×	×
Select sensor by clicking	×	×	✓	×	✓
Select sensor by geometry	×	×	✓	×	✓
Charts for sensor data	×	×	✓	×	✓
Metadata sensor					
Battery status	×	✓	×	✓	×
Wifi status and network	×	×	×	×	×
Sensor health	×	×	×	✓	×
Sensor name	✓	✓	✓	✓	✓
Last maintenance	×	×	×	×	×
Frequency of measurement	×	×	×	✓	×
Comments	Used in combination with other standards	Used in combination with other standards	Still in development	Adds a semantic layer	

Figure 5.3: Matrix sensors assessed based on the requirements

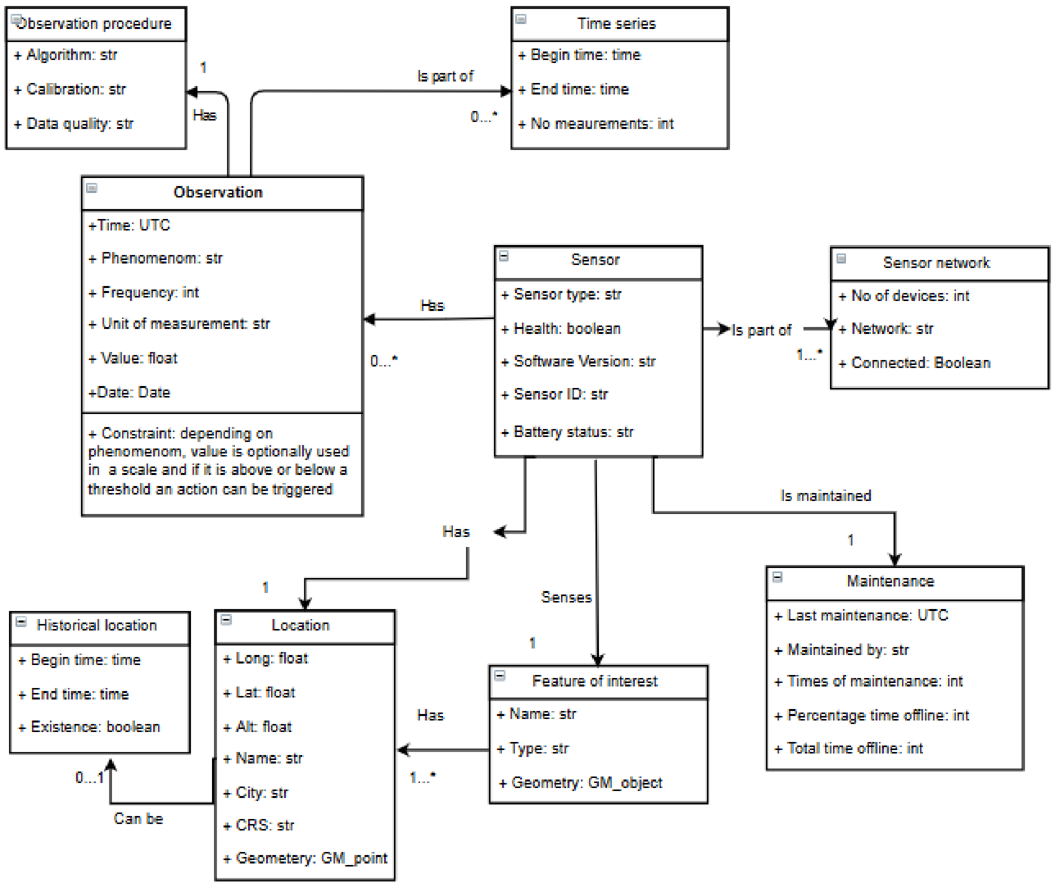


Figure 5.4: Harmonized sensor data model

There are certain requestable aspects of the measurements that are missing in the application. One of them is the altitude, also known as the Z coordinate. The reason of its absence is the lack of precision on which this can be sensed. However, a relative imprecise Z-coordinate is better than no Z-coordinate at all. Manufacturers are suggested to work on addition of this type of data in the standards for, for example 3D sensor data.

Currently there are no ontologies used for the creation of the data model or in any of the use case standards. This means that there is still improvement possible if semantics would be used. More interoperability between systems and applications could be achieved, making them able to communicate.

5.5 WEB VISUALIZATION

Contemporary developers would benefit from overviews, reviews and examples of sensor standards. A categorized overview had been made and explained in this thesis. Reviews can be made based on project experiences, but they are not discoverable yet. Examples where the standards are used in projects are also not discoverable in a convenient way. Therefore a visual example of a web portal on sensor standards has been made to show how such a website would be working. This can be seen in figure 5.5. The suggestion is that the Adapted OSI-model would be on the website as a tool and if a developer is interested in one of the standards and clicks on the Sensor Observation Service he is directed via deep linking to the situation as seen in the figure. Here the visitor can immediately see a finished or ongoing project which uses this standard. In the left down corner it can be seen that the standard is reviewed on practical use by verified users. This is a way to find the available sensor standards and simultaneously explore their practical use and see which other standards are used in combination with it. Via this website it is possible to be linked to the technical documentation of the sensor standards.

For people involved in the sensor standards, it is also important that the goal of the standard is clearly stated. This will vary per standard. Some standards pursue a specific goal and others are applicable in a whole range of goals.

Not only the existing sensor standards need to be visible through this portal. Ongoing development on new sensor standards need to be included as well to offer the option to a visitor to see what the future will bring. It will also demonstrate if these standards will be helpful for their application.

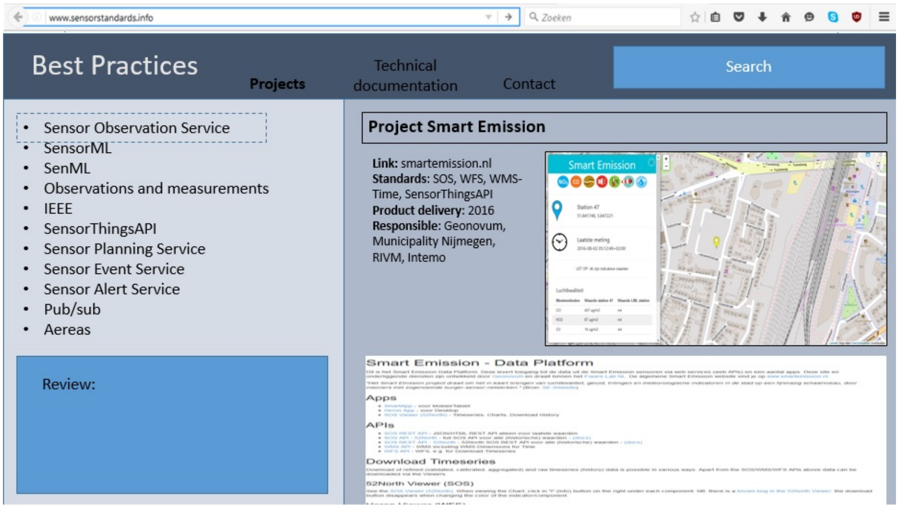


Figure 5.5: Example of best practices and reviews of sensor standards

6 VALIDATION

In this chapter the standards will be analysed and it will be tested if they fit with the requirements. This will be done based on the current state of the three applications made for the use case, the SOS viewer, the SmartApp and the Heron viewer. The SensorThings Viewer that is planned for the Smart Emission Project is excluded in this validation.

In figure 6.1 the test results can be seen in which the requirements are checked individually. Every requirement is checked for the current three applications if it is fulfilled, which standard is used to achieve the requirement and comments are given if applicable.

Analysing these results yields some useful conclusions. The first conclusion is that not a lot of standards are used at the moment. The SOS is primarily used as well as WMS-time. It needs to be noted that using more standards does not mean a better sensor web.

This model can be divided in two sides, the maintainer and user segment. In figure 6.2 the yellow classes represent the information relevant for users and the green classes representing data relevant for maintainer of the sensor networks.

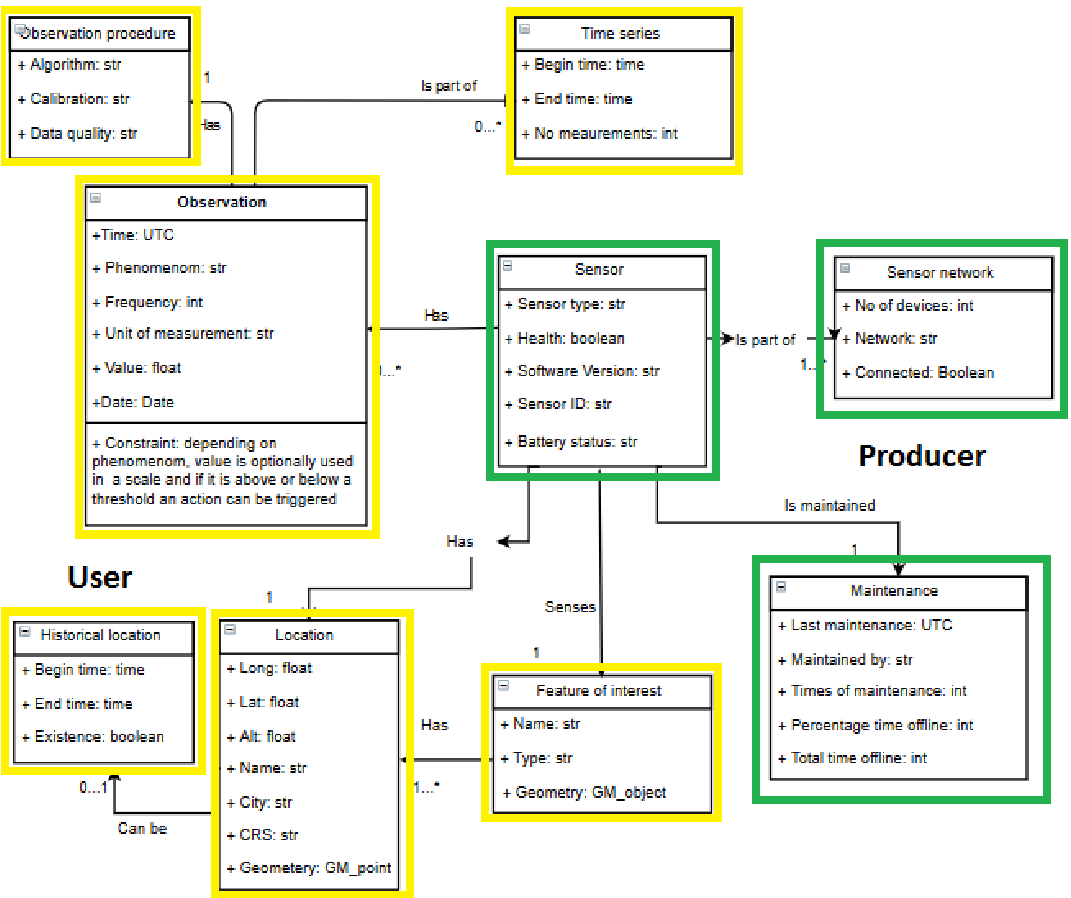
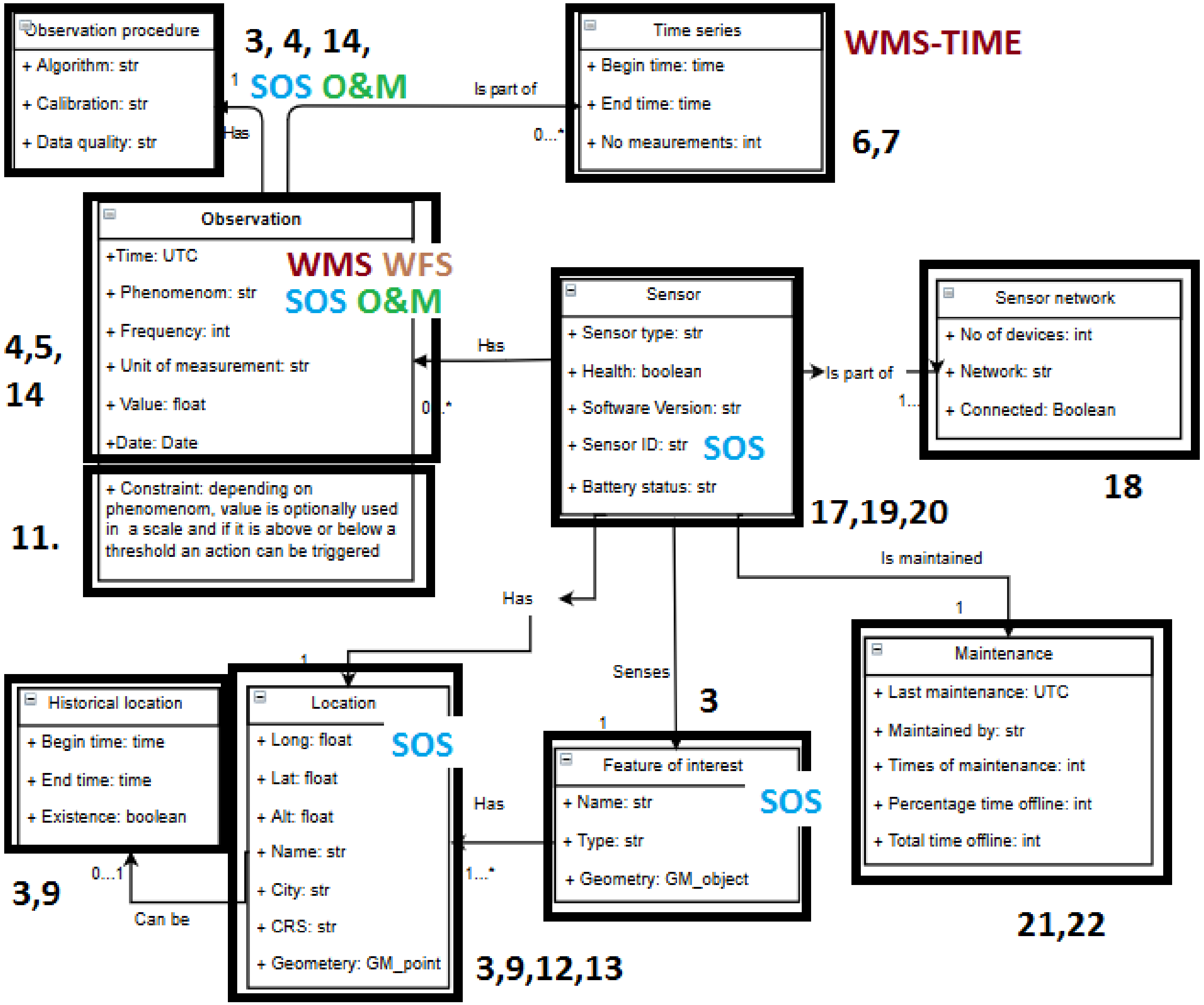


Figure 6.2: Data model users and network maintainer

Requirements	Fulfilled	Standard used	Application	Comments
Sensor data				
View sensor data	✓	SOS, O&M	Heron viewer, SOS viewer and Smart app	×
download sensor data	✓	SOS, WMS, WFS	Heron viewer	×
Last value data	✓	SOS, O&M	Smartapp	The other applications gave older data +- 2 hours
Time series data	✓	WMS-Time	Heron viewer and SOS viewer	All the data is stored in a database
Data requestable interval	✓	WMS-Time	Heron viewer and SOS viewer	Slider which can only slide one way, SOS viewer only per day
Data requestable point in time	×	×	×	Two sliders are required
Sensor spatially dispersed in map	✓	SOS	Heron viewer, SOS viewer and Smart app	×
Clear units of measurements	✓	none	Heron viewer, SOS viewer and Smart app	Not always clear how much one unit is
Scales if required for measurement	✓	none	Heron viewer, SOS viewer and Smart app	Scales depending on threshold, both color and text used
Select sensor by clicking	✓	none	Heron viewer	Takes long to process
Select sensor by geometry	✓	none	Heron viewer	Takes long to process
Charts for sensor data	✓	SOS	SOS-viewer	Work in progress
Metadata sensor				
Battery status	×	×	×	Is possible through Battery Status API or Sensor Things API
Wifi status and network	×	×	×	×
Sensor health	×	×	×	×
Sensor name	✓	SOS	Heron viewer, SOS viewer and Smart app	×
Last maintenance	×	×	×	×
Frequency of measurement	×	×	×	×

Figure 6.1: Requirements assessment

The UML-model can even be subdivided into the specific requirements. This division into requirements is shown in figure 6.3. The requirements have been linked to standards, therefore it is now possible to show where in the model the standards play a role. For the observations segment of the model there are four different sensor standards used, namely the SOS, Observations and Measurements, WMS/WMS-TIME and WFS. It can clearly be seen that there are no standards used in the project for the maintainer aspect of the Sensor Web. However there is a request from the maintainer of the network to have remote access to the sensor and do this in a standardised way. Here the more sensor-focused standards such as IEEE or new Internet of Things lightweight standards can play a role. Furthermore there are other standards that can improve the model such as the Sensor Things API, that will be added in the future. It has a focus on devices so, can help in the middle of the model, the sensor class or for instance for the battery status.



2	**Sensor data**	
3	View sensor data	SOS, O&M
4	download sensor data	SOS, WMS, WFS
5	Last value data	SOS, O&M
6	Time series data	WMS-Time
7	Data requestable interval	WMS-Time
8	Data requestable point in time	x
9	Sensor spatially dispersed in map	SOS
10	Clear units of measurements	none
11	Scales if required for measurement	none
12	Select sensor by clicking	none
13	Select sensor by geometry	none
14	Charts for sensor data	SOS
15		
16	**Metadata sensor**	
17	Battery status	x
18	Wifi status and network	x
19	Sensor health	x
20	Sensor name	SOS
21	Last maintenance	x
22	Frequency of measurement	x

Figure 6.3: Data model indicating requirements

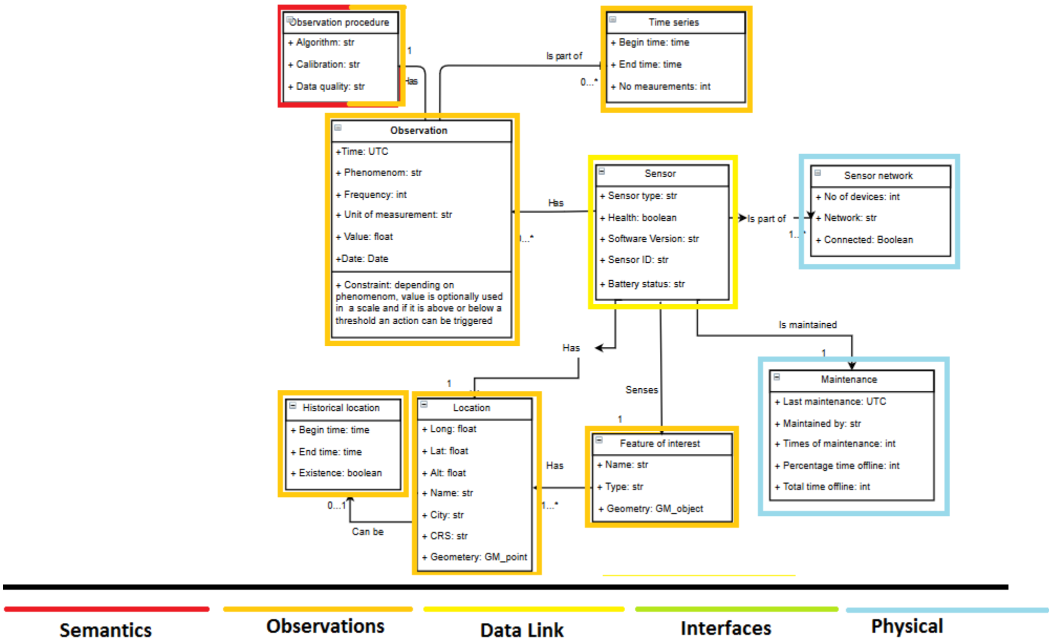


Figure 6.4: Data model indicating requirements and categories from the OSI-model

An example of how in the situation of the use case the models can be used can be seen in figure 6.4. It is clearly visible that the model is following the line of the adapted OSI-model having the physical layer to the right and the semantic layer to the left.

To test if the models that are created work as intended the model will be tested with real data examples from the use case. This is done in a instance model also known as a object diagram. As example data from one sensor will be used from the gases in Nijmegen. The explicit data stream can be seen in figure 6.5.

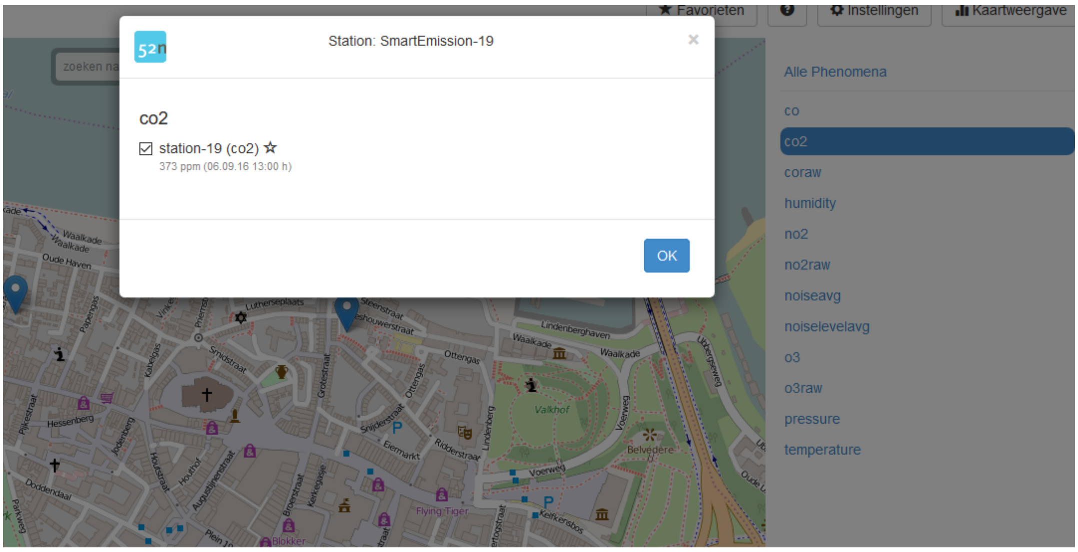


Figure 6.5: Example data station 9 Nijmegen

After looking for the right data in the applications it can clearly be seen that all of the applications were required to find the appropriate data. For instance the altitude and longitude were not mentioned in the SOS viewer and the frequency was also not found in any of the applications. Here it can be seen that this is not visible to the user as meta data.

The instance model can be seen in figure 6.6. A green circle indicates that this requirement is met in the applications. Red means that it is not implemented and can also not be found as meta data. It can be seen that some of the elements from the model are well represented in the application, such as the observation class. Other classes are not represented yet, such as the maintenance

The algorithms that are used to translate raw sensor data into meaningful data are made using a MLPRegressor via Scikit Learn, so they are standardised. It is not directly a sensor standard, but it is a example of standardisation over the whole process and multidisciplinary standardisation. The preprocessing is very device-depending and is therefore hard to standardize. If the heterogeneous devices can be treated like homogeneous devices, it can be possible to achieve interoperability in this part of the process as well. The SensorThings API is promoting this interoperability in the Internet of Things and is therefore a suitable candidate.

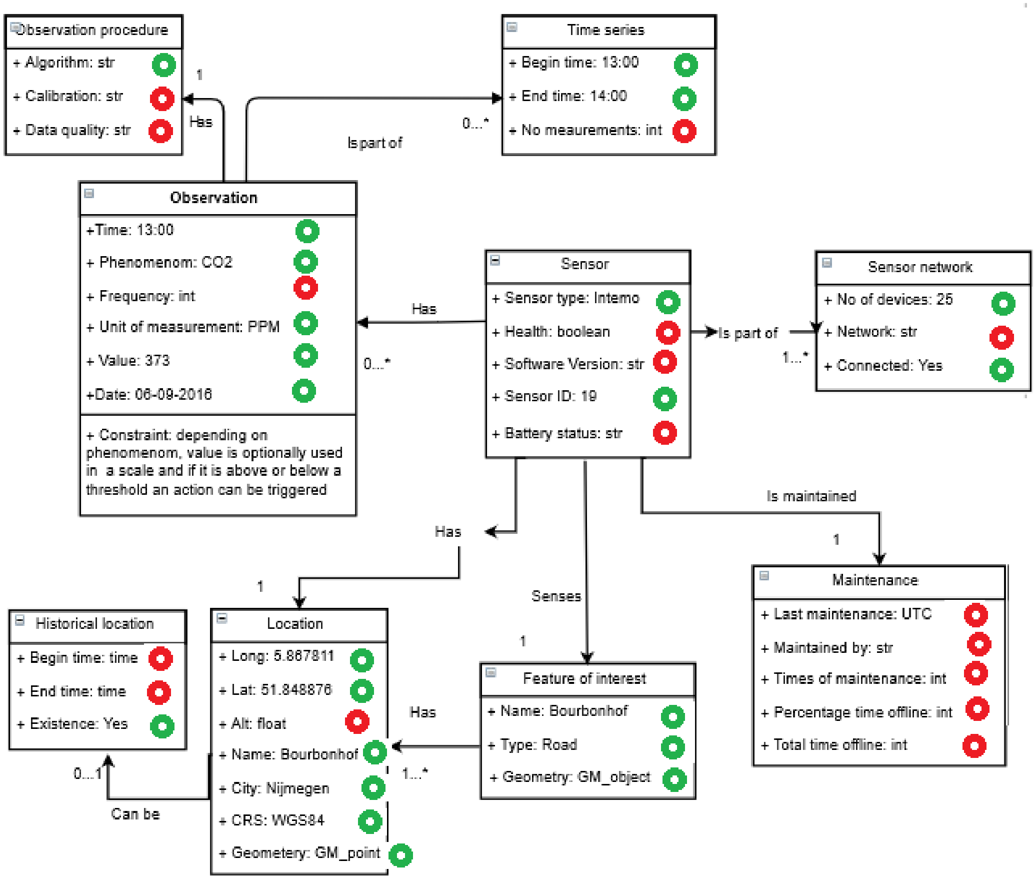


Figure 6.6: Instance class model validating the current situation of the use case, red = not found in use case applications, green = found in the use case applications

What can be concluded from this model is that the applications can still be improved on two levels, namely the semantics and the physical level. To avoid this situation the appropriate standards can be picked from the adapted OSI-model. Doing so will result in a multi-layer-covering application, fitting the chosen requirements.

A practical example of the usefulness of this model and website is the quest of the maintainer of the sensor network and the network maintainer for a missing standard for a lightweight sensor standard. Within another company they are working on exactly this. However, the maintainer of the sensor network in our project had no contact with them, so if this standard will end up in the model, the maintainer can simply contact the creator and cooperate to create the fitting standard.

7 CONCLUSIONS AND RECOMMENDATIONS

In this chapter the conclusions are drawn based on the research findings. Additionally, recommendations will be given to improve the Sensor Web. The answers to the research questions that were given in the introduction will be used to draw the conclusions. The conclusion will prove if the tested methods succeed to solve the two problems stated in the problem statement namely the problem with lacking meaningful sensor data and the second problem where there is no universal standard and no order in the existing sensor standards. Lastly there will be an evaluation if the results support the hypothesis.

The main research question is:
To what extent is there an alignment of existing sensor standards for describing observations and sensors, and how can they be further harmonised?

The sub questions are:

1 What steps can be distinguished to align the use case standard to the commonly used standards?

2 What are the commonly used sensor standards?

3 Which standard or standards are used in the Smart Emission use case?

4 To what extent do commonly used standards align?

7.1 CONCLUSIONS

To be able to answer the main question, the sub questions must first be answered. The answers to the sub questions can be found in the same order as the questions in the chapters. The first sub question can be answered based on the findings of chapter 2 The steps that need to be taken in the suggested method to align the standards are successively:

1. Define the requirements for the project/use case
2. Find the relevant standards through research
3. Choose the suitable standard(s) for the project/use case in consultation with the involved stakeholders
4. Align the standards by assessing if the defined requirements are met and comparing their capabilities and goals

Those steps are chosen after consultations with the Smart Emission project team members and after studying methodologies of earlier work on data modeling such as Warmer and Kleppe [1996].

After creating a model for the standards, the second step can be skipped and the standard or standards can be chosen from the OSI-model instead of through cumbersome extensive literature research. Chapter 3 examined the sensor standards into detail and checked which of them are generally used and which ones are not. Eventually five commonly used sensor standards are chosen based on the frequency they appear in on the Internet and relevance for the use case. The Semantic Sensor Network, Sensor Observation Service, Sensor Things API, SensorML and Observations and Measurements.

The third sub question can be answered using the information flow from the Smart Emission Project and the extensive answer can be found in chapter 4. In the current situation there are a couple of standards used: the SOS via the 52 North server, the WMS-Time, the WFS and WCS. The Sensor Things API will later be applied as well. Picture 4.1 shows that this might not be the final version of the standard usages. No new standards were created, however the use case produces best practices of a fitting implementation of sensor standards.

The last sub question can be checked via table 5.3 defining specifications and capabilities of the five commonly used sensor standards in chapter 5. The table shows that there are similarities between the SOS and the O&M. There are also similarities between the Sensor Things API and the SOS. This makes sense, because SOS is based on the O&M model and the Sensor Things API and the SOS both have the goal to request data about the observations. On the other hand the fields that are left white demonstrate that there are also a lot of differences between the standards, because they are all designed with a specific goal and most of them are OGC standards. It would cause redundancy in the Sensor Web if standard organisations would create overlapping standards, therefore there are relatively few similarities. A better ordering method is to categorize them on more general specifications, on their goal and the way this goal should be reached. The sensor standards that were assessed in the alignment matrix do not align enough to state that they overlap. However there are some similarities between the SOS and the Sensor Things, but the Sensor Things Api also has unique capabilities. This diffusivity can also been observed in the OSI-model. The standards almost all are all grouped in another category and serve other goals. There are no big gaps. On all levels there are suitable sensor standards. There is clearly a line visible in the sensor standards that goes from the top left to the right under corner. This has to do with the fact that API's are more technical and semantics is based on relating phenomena. It can also be concluded that the Sensor Web is a complex system of connected standards, which all serve a specific goal. Some of them are overlapping and have therefore similar goals. Within the Sensor Web Enablement the goals are clear, because the standards are made by one organization. Other organizations work on sensor standards as well or their if their standards are not focused on sensor data their standards can still contribute to the Sensor Web. Not even their abundance is the problem, but rather the missing overview of the existing sensor standards and the sensor standards in development.

After having answered the sub questions it is possible to answer the main research question.

To what extent is there an alignment of existing sensor standards for describing observations and sensors, and how can they be further harmonised?

In the current Sensor Web there are sensor standards on all levels and for different goals. However the organizations that create the standards do not always harmonize their standards sufficiently. Most of the standards focus on a small sector in the Sensor Web, for instance semantics or units of measurement. The existence of organizations such as the OGC is necessary, because it can promote standards and harmonize them. Sensors and observations should have both equal importance, because the maintainers of sensors are interested in sensor meta data and the users of the sensor data are interested in the observations. Having one universal standard for the Sensor Web currently limits the flexibility to choose and make the application that fits the requirements. However that does not mean that limiting the number of standards would not benefit the Sensor Web. The steps required for standardisation in the Sensor Web are alignments of standards through Unified Modeling Language and capabilities, definition of the project requirements, harmonisation based on a so efficient possible model where the minimal requirements are met, and for grouping the adapted OSI-model.

In the beginning two problems were brought forward:

- There was not yet clear data origination from the sensor
- The absence of a commonly used well-functioning standard for sensor data

The findings of this research prove that the first problem can be solved through using suitable sensor standards. By means of the used standards the applications were able to spawn the required meta data. However for some of the data in the use case still some work is required and this will be achieved in a couple of months, especially on semantics still work is required as well as on creating the fourth application and fulfilling the maintainers and citizens requirements.

The other problem is harder to solve and has not been solved completely in this research but steps have been taken toward standardisation and the following recommendations will be beneficial for the Sensor Web on the long term.

Now that the research questions haven been answered and the conclusions have been drawn it is possible to accept or reject the hypothesis. The hypothesis for this research that has been proposed is that the OGC sensor standards are a steady basis to describe both observations and sensors for the use case. However there are still steps to be taken before harmonisation of the existing standards is achieved. The results endorse this hypothesis. The research on the use case showed that if OGC standards are used to describe the sensors and the observations, most requirements are met for the observations. However some requirements are not met in a standardised way, because no standard was used. For the sensors almost none of the requirements are met. Furthermore the steps that need to be taken to describe the sensors and observations more efficiently is harmonisation and ordering of the available sensor standards.

7.2 DISCUSSION

This research focused heavily on the use case from the Smart Emission project in Nijmegen. It is a use case which specifically representing smart city projects. However it is not one-to-one representative for other sensor projects. More use cases are required to support the research. The layers in the Adapted OSI-model are defined broadly to include various heterogeneous standards, this is an advantage. The disadvantage is that for example semantics can be understood in different ways. Furthermore the order of layers can be a point of discussion. The layers are ordered this way because the ordering represent the device data versus observation data arranged organisation divided by the link layer. The data model has been specifically made for the use case, limiting its use. On the other hand, this does not mean it is useless. Other disciplines can take over parts of the data models and re-harmonize it. The requirements of the user have been defined specifically from a relatively homogeneous group of citizen volunteers. It would be useful to incorporate also other citizens requirements. It might be useful to look at the topic of privacy. If a sensor is placed it can sense also people that do not want to be sensed. Furthermore, some of the older people who participated were not able to make it to the meetings and thus had less saying in the development of the applications. It is useful to also hear these citizens. Furthermore it is necessary to keep track of the progress of the project, especially after the project is finished and the sensors are still measuring. It would be possible that the requirements change over time. There is a vague boundary between geo-standard and sensor standard. As has been concluded in this research many terms are used for standards, because the concept standard is very broad and can be used in many disciplines. In this research many so-called geo-services have also been considered standards. They have not been designed primarily for the Sensor Web, but are in this case considered an usable standard, but have not been included in the Adapted OSI-model, because they have not been designed for the Sensor Web, but as a geo-service. The whole process to find, analyse and order sensor standards has not been automated. It would be preferrable in the future. This means there should be a programme running that looks on the web for standards, validates the standards, based on some specifications, and order the standards. This needs to be checked by an sensor standard expert to make sure the model does not become erroneous or incomprehensible.

7.3 RECOMMENDATIONS

The recommendations for standardisation in the Sensor Web that are the result from this research are:

- Further research should try to establish an equilibrium in the sensor web of standards focused on devices on one hand and on observations on the other hand. This way both the user that is interested in the observations and values and the maintainers of the sensors can benefit from the Sensor Web. As long as both are equally represented in the adapted OSI-model this requirement for the Sensor Web is met.

- Attempting to use SSN ontologies for more interoperability between applications and datasets will benefit the Sensor Web.

- Use of the adapted OSI-model as basis for sensor standard grouping and adapting it according to needs of the stakeholders will result in a more clear sensor standards system.

- The use case template is an excellent way of defining the requirements and to communicate them in a clear way to other stakeholders. The requirements are essential in almost every step, therefore they should be clear to everyone that is involved and there should be a translation from the users needs to formal requirements, filtering what is relevant and technically possible and what is not.

- Try to use sensor standards on all levels and for every goal. There are enough standards to pick from and it is more time-efficient to reuse standards.
- On the long term some of the sensor standards can be neglected, because they are redundant. This will result in a more clear Sensor Web and more interoperability.
- If something is not yet implemented in some standard, it is better to not start creating a new one immediately, but to look first if it is in another standard and on the long term the step that needs to be taken is to point this out to the creator of the standard to improve the standard. There are work groups, conferences and forums to give suggestions to the creators. These are opportunities for users of the standards to have an influence on standardisation.
- The use case that is illustrated, explained and validated can be used as a example for best practices. This use case and various others can be listed in an overview where future developers can discover the use cases and take over recommendations.
- when using an overview, it should stay up-to-date. OGC is working on standards that are not included in this research because they are not finished, such as TimeSeriesML. These can be included in the Adapted OSI-Model, when they are accepted by OGC and ready to use. The pace of sensor standards creation is currently so fast, that it needs to be updated regularly, otherwise it is not useful.

7.4 FUTURE WORK

This thesis has made a step towards a more interoperable Sensor Web, but even better would be if the next steps would be followed in the near future. Future work that needs to be done is:

- Incorporating other use cases in the the data model to bridge interdisciplinary gaps in the Sensor Web.
- Extending the data model with more semantics.
- Creating the website where best practices are featured.
- Make sensor devices more interoperable and remotely configurable.

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A APPENDIX

A.1 DOWNLOADED SENSOR DATASET

To show what downloaded sensor data from the Smart Emission Project looks like it is included in this appendix in figure A.1. It is downloaded from the SOS viewer on 14 September 2016 at 4 PM.

station;phenomenon;uom;date;value
SmartEmission-32;co2;ppm;2016-09-14T00:00:00.000+02:00;463
SmartEmission-32;co2;ppm;2016-09-14T01:00:00.000+02:00;477
SmartEmission-32;co2;ppm;2016-09-14T02:00:00.000+02:00;474
SmartEmission-32;co2;ppm;2016-09-14T06:00:00.000+02:00;488
SmartEmission-32;co2;ppm;2016-09-14T07:00:00.000+02:00;490
SmartEmission-32;co2;ppm;2016-09-14T08:00:00.000+02:00;475
SmartEmission-32;co2;ppm;2016-09-14T09:00:00.000+02:00;442
SmartEmission-32;co2;ppm;2016-09-14T10:00:00.000+02:00;441
SmartEmission-32;co2;ppm;2016-09-14T11:00:00.000+02:00;459
SmartEmission-32;co2;ppm;2016-09-14T12:00:00.000+02:00;461
SmartEmission-32;co2;ppm;2016-09-14T13:00:00.000+02:00;455
SmartEmission-32;co2;ppm;2016-09-14T14:00:00.000+02:00;444
SmartEmission-32;co2;ppm;2016-09-14T15:00:00.000+02:00;426

Figure A.1: Downloaded data set

It can clearly be seen the downloaded data set is similar to the data shown as raw data in figure 1.1, but it is data reduced to the simplest form, containing only the observation data but it has still more meaning than the raw data, because the unit of measurement (UOM) is added, which was not visible in the raw data and the algorithms are applied to translate the raw data values to values that make sense for the user.

A.2 REFLECTION

The topic sensor standards was chosen in October 2016 and this was followed by a first orientation with the project leader from Geonovum of a case study that was relevant for my topic, namely Michel Grothe. The graduation internship and Smart Emission project started almost simultaneously. Therefore it was possible to follow the project from the beginning. This gave unique insights in the process and it was a perfect way to meet all the involved actors. The group was changing a bit in composition over the time, but they key players, the University of Nijmegen, the RIVM, CityGIS, the municipality of Nijmegen, Geonovum and Intemo, were from the beginning involved. Therefore it was easy for me to communicate, because the group was not too big and most people kept being involved and it was easy to contact them and ask them specific sensor or standard questions.

Furthermore, several other students worked within the project and achieved useful results. Two of them worked on citizen participation, another student worked on the Smart App and the third one will analyse the sensor data and make useful visualization from them. Working with them inspired me to make something relevant and useful and we had something in common, our scientific goal.

Within a couple of months the citizens were invited to join the pilot and they themselves offered a location for the sensors including an energy socket and WiFi. Most of these citizens had a certain reason to participate. Some of them were only interested in the use of sensors and/or the sensor data. Others were also interested in the data to show a specific problem in their environment. Through the sensor data they had the opportunity to actually prove that for instance there was too much air pollution. On the other hand if this was proved wrong, the municipality can also show this in the same way. My conversations with the citizens were useful and showed me that there is a practical use for the sensors in the public domain. More importantly here there was a platform to demonstrate the usefulness of standards to a broad public including scientists, corporate participants, the municipality, the government and citizens.

My own contribution to the project was assistance with the use of standards and the handling of the sensor data. I did a couple of presentations during the project and was present during most of the meetings, with both the project members and the ones with the citizens. In the beginning it was hard to find my role within the project and within Geonovum. Michel Grothe helped me by taking irrelevant work out of my hands.

Initially it was hard to separate the goals from the project and Geonovum from what I had to do for the university. Therefore my research goal during my P2 was not clear to the attendants of this presentation. After useful feedback the goals were more realistic and delimited in a new P2 moment later in the year. The supervisor at Geonovum helped greatly to achieve this separation of tasks.

For the research on sensor standards itself, it was necessary to dive deep into the scientific sources and for a relative starter in this field it is a lot to comprehend and master in a short while. The best way to understand the Sensor Web is to be part of it. Therefore viewing, downloading and analysing the data is an essential part of the research. Meeting other researchers working on Sensor standards during the 52North conference in Munster was a unique chance to verify my research conclusions and to discuss them. On one hand the moment of this conference at the end of my research was useful, but obtaining more knowledge through lectures on Sensor Web and following tutorials on how to use them would have been a great start for the research, because then you can ask the experts where the gaps are and what research is going on.

In the course of the summer working almost every working day on the research drove the research in a rapid acceleration. Therefore a internship really forces you to come to work and starts working on the research.

The help that was offered by the both supervisors was clear. Sometimes textual advises were contradictory but in general the two mentors agreed on what needed to be done. Furthermore the help offered by Michel Grothe was useful and helped me progress.

In the beginning of the year a planning was made to make sure the deadlines would be made. The first planning had to be revised, because the P2 was not a go the first attempt, but the second planning was more realistic and kept me on track.

The research provided a start towards an ordering model. It contains the current standards but without further work it will be quickly outdated, so it needs maintenance. It was neat to experience that the result was appreciated by the involved parties, but it is hard to explain to someone that is not involved in sensor standards. Explanation requires a lot of context.

Overall the thesis was a great experience and I learned much about sensor standards, Geonovum and myself. I really liked working on it and if possible I would like to keep working on the topic.

A.3 USE CASE TEMPLATE

The following pages show one out of four use case templates. This template is created to display the requirements for the user for time series. The other three are templates for users last value data, maintainer of the sensor networks real time and maintainer of the sensor network last value data.

Use Case Template

Versie 0.2

Revisie Historie

Datum	Auteur	Wijziging
03-07-2016	Matthijs Kastelijns	Alle velden zover mogelijk ingevuld.
06-06-2016	Just van den Broeke, Michel Grothe en Matthijs Kastelijns	Eerste revisie. Bijgewerkt tot extensies.

Use Case:
Verkrijgen van Smart Emission time series

Id:
UC-SE-004

Beschrijving
Een burger van Nijmegen wil historische sensor data van, meteo, lucht en geluid verkrijgen (optie tot zowel bekijken als downloaden)

Primary Actor
Burger Nijmegen, onderzoeker en studenten

Supporting Actors
Niet van toepassing

Belanghebbenden
Burger die applicatie gebruikt kan in het verleden terugkijken naar de data van de sensor.

Onderzoekers en studenten wenst over een langere periode de data te kunnen analyseren en wil data kunnen downloaden
Noot: burger kan ook een onderzoeker zijn

Pre-Condities

- De Sensor heeft de optie om data te kunnen produceren
- De data kan omgezet worden naar hanteerbare formaten (o.a. json, xml)
- De metadata kan omgezet worden naar begrijpelijke taal voor de burger
- De data kan gevisualiseerd worden
- Elke sensor wordt op de kaart getoond op de juiste locatie
- De data is gekalibreerd zodat de afwijking met de RIVM waarde wordt getoond
- De data moet binnen een bepaalde tijd op het scherm staan

Post Condities
Voorwaarden Succes

- Station: Toont het juiste stationsnummer dat bij de geselecteerde sensor hoort ---- VB: Station 14
- Toont of het station actief is
- Er kan een tijdstip in het verleden worden gekozen
- Er kan een interval in het verleden worden gekozen, d.m.v. begin- en eindtijd

Metingen

- Voor elke meting wordt een waarde van het gekozen station getoond van een type meting.
- Hoofdcomponenten geluid, gas en meteo
- **Geluid**: gemiddeld in DB & level in niveau 1-5
- **Gas**: NO2, O3, CO & CO2
  - Voor CO2 wordt de waarde in ppm getoond
  - Voor O3 wordt de waarde in ug/m3 getoond
  - Voor O3RAW, NO3 en CO wordt de waarde in KOhm getoond
- **Meteo**: Temperatuur, luchtvochtigheid en luchtdruk
  - Voor meteometingen wordt de gemiddelde uurwaarde teruggegeven
- Downloaden: in formaat: csv, gezippede file
- Waarden worden afgerond op heel getal

Voorbeeld:
A
Periode: 15-6-2016 tot 16-6-2016
Tijdinterval: 16:05:15 – 17:05:20
Metingen:
-Meteo
-Temperatuur
16:00-17:00: *17 °C*
17:00-18:00: *16 °C*

B
Periode: 17-2-2016 tot 18-2-2016
Tijdstip: 12:05:00
Metingen
    -Gas
        -NO2
            12:04:55: *0.4 k* Ω

Voorwaarden gefaald:

- Als er niet aan een van de precondities of postcondities wordt voldaan

Minimale garantie

- Er mag maximaal een bepaald aantal uur data ontbreken

Trigger
Een primary actor opent de applicatie en selecteert een sensor

Success Scenario

1. Primary actor selecteert een sensor op de kaart
2. Primary actor selecteer een component
3. Primary actor selecteert een tijdspanne.
4. Applicatie toont de historische metingen van dit component in deze tijdspanne deze sensor.
5. Burger kan doorgaan met een andere sensor en stappen 1, 2, 3 en 4 herhalen zich.

Extensies

2a. Er zijn in die periode geen metingen
2b. Er komt een mededeling dat er geen metingen bekend zijn in de gekozen periode

Variaties

1. De Primary actor heeft al een sensor opgeslagen als favoriet die hij/zij wil bekijken en opent deze direct

Frequentie:
50 keer per dag

Aannames

- De Primary actor snapt Nederlands
- De Primary actor is gemachtigd om de applicatie te gebruiken
- De Primary actor snapt de waarden en parameters die in de applicatie worden getoond.

- De Primary actor heeft de juiste software op zijn computer en krijgt geen foutmeldingen vanwege een fout in die software.
- De hosting en website geven geen problemen

Speciale vereisten

- De website is goed beveiligd tegen hackers
- De juiste tijd wordt weergegeven
- De coördinaten en het coördinatensysteem kloppen
- De conversie van ruwe data naar betekenisvolle data is goed gegaan
- Alle browsers en besturingssystemen kunnen de applicatie goed tonen

Issues

- Hoe wordt alle data opgeslagen? Het wordt al snel een grote hoeveelheid data. Een juist geïndexeerde database kan bijdragen aan goede opslag
- Tot hoever terug wordt de data opgeslagen? Als de data er niet meer is, moet dit wel gemeld worden aan de gebruiker.
- Worden er ook tabellen en grafieken, getoond? Is de API compatibel hiervoor?

Te doen

1. Nagaan of dit technisch mogelijk is zowel aan de software kant in de sensor als aan de kant van de waar deze waarden betekenis krijgen.
2. Applicatie zo inrichten dat alle data overzichtelijk kan worden getoond