AGGREGATION OF SEMANTIC SENSOR DATA

Graduation proposal

by

Ivo de Liefde

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CONTENTS

ACRONYMS

EU european union 1
GIS geographical information system 4
INSPIRE infrastructure for spatial information in Europe 1
IoT internet of things 1
ISO international organisation for standardisation 1
OGC open geospatial consortium 1
O&M observations and measurements 1
RDF resource description framework 1
REST representational state transfer 3
SensorML sensor modelling language 1
SEL semantic enablement layer 3
Sem-SOS semantically enabled sos 3
SOS sensor observation service 1
SSNO semantic sensor network ontology 3
SSW semantic sensor web 1
SWE sensor web enablement 1
URI uniform resource identifier 3
W3C world wide web consortium 1
WPS web processing service 4
XML extensible markup language 3

1 INTRODUCTION

From 2020 onwards all member states of the european union (EU) should provide sensor data to the infrastructure for spatial information in Europe (INSPIRE) in order to comply with annex II and III of the INSPIRE directive (INSPIRE, 2015). For this a number of sensor web enablement (SWE) standards are required to be used (INSPIRE, 2014). The sensor web is a relatively new development and there are still many question on how to structure it. This thesis aims to develop a method to publish and link sensor metadata on the semantic web for discovering, integrating and aggregating sensor data.

1.1 BACKGROUND

In 2008 the open geospatial consortium (OGC) introduced a new set of standards called SWE. These standards make it possible to connect sensors to the internet and retrieve data in a uniform way. This allows users or applications to retrieve all kinds of sensor data, regardless of the type of observations or the sensor's manufacturer (Botts et al., 2008). Among other standards SWE includes the observations and measurements (O&M) which is a model for encoding sensor data, the sensor modelling language (SensorML) which is a model for describing sensor metadata and the sensor observation service (SOS) which is a service for retrieving sensor data (Botts et al., 2007). O&M has also been adopted by the international organisation for standardisation (ISO) under ISO 19156:2011 (ISO, 2011).

Recently OGC has defined the role which their standards could play in smart city developments (Percivall, 2015). Smart cities can be defined as "enhanced city systems which use data and technology to achieve integrated management and interoperability" (Moir et al., 2014, p. 18). Research on smart cities has shown a great potential for using sensor data in urban areas. Often this is presented in the context of the internet of things (IoT) (Zanella et al., 2014; Wang et al., 2015a). The IoT can be described as "the pervasive presence around us of a variety of *things* or *objects* ... [which] are able to interact with each other and cooperate with their neighbors to reach common goals" (Atzori et al., 2010, p. 2787).

Parallel to the development of the sensor web other research has focused on the semantic web, as proposed by Berners-Lee et al. (2001). This is a response to the traditional way of using the web, where information is only available for humans to read. The semantic web is an extension of the internet which contains meaningful data that machines can interpret as well. Rather than publishing documents on the internet the semantic web contains linked data using the resource description framework (RDF) (Bizer et al., 2009).

Sheth et al. (2008) proposes to use semantic web technologies in the sensor web. This so-called semantic sensor web (SSW) builds on standards by OGC and the world wide web consortium (W3C) "to provide enhanced descriptions and meaning to sensor data" (Sheth et al., 2008, p.78). W3C responded to this development by developing a standard ontology for sensor data on the semantic web (Compton et al., 2012).

1.2 PROBLEM STATEMENT

The implementation of the sensor web is still in an early stage.

A number of companies and organisations still use their own custom APIs to connect sensors to the internet.

It is hard to find SOS services on the internet.

It has been argued that it is difficult to integrate sensor data from different sources to perform data fusion (Corcho and Garcia-Castro, 2010; Ji et al., 2014; Wang et al., 2015b). Data fusion is "a data processing technique that associates, combines, aggregates, and integrates data from different sources" (Wang et al., 2015a, p. 2).

1.3 RESEARCH QUESTION

This thesis aims to build on the recent literature by creating a method that uses the semantic web to improve sensor data discovery as well as the integration and aggregation of sensor data from heterogeneous sources. The following question will be answered in this research: *How can the semantic web improve the discovery, integration and aggregation of distributed sensor data?*

2 RELATED WORK

a related work section in which the relevant literature is presented and linked to the project;

2.1 SEMANTIC SENSOR DATA MIDDLEWARE

Henson et al. (2009) and Pschorr (2013) suggest adding semantic annotations to a SOS which they call semantically enabled sos (Sem-SOS). In Sem-SOS the raw sensor data goes through a process of semantic annotating before it can be requested with a SOS service. The retrieved data is still an extensible markup language (XML) document, but with embedded semantic terminology as defined in an ontology model. The data retrieved from Sem-SOS is therefore semantically enriched.

Janowicz et al. (2013) has specified a method that uses a representational state transfer (REST)ful proxy as a façade for SOS. When a specific uniform resource identifier (URI) is requested the so-called semantic enablement layer (SEL) translates this to a SOS request, fetches the data and translates the results back to RDF. In this method the sensor data is converted to RDF on-the-fly. This allows the data to be interpreted by both humans and machines.

Atkinson et al. (2015) have identified that ”distributed heterogeneous data sources are a necessary reality in the case of widespread phenomena with multiple stakeholder perspectives” (Atkinson et al., 2015, p.129). Therefore, they propose that methods should be developed to move away from the traditional dataset centric approaches and towards using linked data for cataloguing. This has the potential to bring together data and knowledge from different areas of research about the same (or similar) features-of-interest. It is also argued that using both linked data services and data-specific services could ease the transition into the linked data world.

2.2 SENSOR DATA ONTOLOGIES

W3C has developed an ontology based on the stimulus-sensor-observation pattern (Compton et al., 2012).

Hu et al. (2014) has reviewed a number of metadata models (including SensorML and **ssno!** (**ssno!**)). They argue that all of the current metadata models are not sufficient for sensor data discovery. Therefore, they propose a metadata model that ”reuses and extends the existing sensor observation-related metadata standards” (Hu et al., 2014, p. 10546).

Cox (2015) has been working on an improved semantic ontology based on O&M.

2.3 SENSOR DATA AGGREGATION

Stasch et al. (2011b) propose to aggregate sensor data based on the geometry of sampling features. Stasch et al. (2011a) proposes a web processing service (WPS) that takes sensor data right from a SOS service in order to aggregate it. The approach by Stasch et al. (2011b) takes sensor data as input that is already published on the semantic web.

Stasch et al. (2014) argue that in order for automatic aggregation to work there needs to be semantics on which kind of aggregation methods are appropriate for a specific kind of sensor data. This requires a formalisation of expert knowledge which they call semantic reference systems.

2.4 CONCLUSION

Sem-SOS (Henson et al., 2009; Pschorr, 2013) as well as SEL (Janowicz et al., 2013) focus on combining the sensor web with the semantic web, but do not address the integration and aggregation of sensor data. Similarly, Atkinson et al. (2015) proposes to expose sensor data to the semantic web in order to find other kinds of related data about the same feature-of-interest. Data that is collected from another area of research for example. Also Atkinson et al. (2015) does not mention the integration of sensor data from heterogeneous sources. Stasch et al. (2011b) and Stasch et al. (2011a) suggest interesting methods for aggregating sensor data based on features-of-interest. However, also these studies use sensor data from a only single source into account. Moreover, Corcho and Garcia-Castro (2010) and Ji et al. (2014) argue that methods for integration and fusion of sensor data on the semantic web is still an area for future research. Data fusion is "a data processing technique that associates, combines, aggregates, and integrates data from different sources" (Wang et al., 2015a, p. 2). This thesis therefore focuses on the discovery, integration and aggregation of sensor data, building on some of the principles proposed by related research discussed in this chapter.

The idea by Jones et al. (2014) of delivering data to users through a service with which they are already familiar is very appealing, because it would enable sensor data to be immediately used in any existing geographical information system (GIS). This is also suggested by Atkinson et al. (2015) to ease the transition to the linked data world. However, current research has mainly been concerned with static geographic data, not with (aggregated) sensor data. Therefore, this thesis aims to provide the service for integrating and aggregating sensor data as a WPS.

3 RESEARCH OBJECTIVES

the research objectives and/or research questions are clearly defined, along with the scope (ie what you will not be doing);

3.1 RESEARCH QUESTION

The main question this thesis will try to answer is:

How can the semantic sensor web improve the discovery, integration and aggregation of distributed sensor data?

To answer the main question a number of sub-questions need to be answered:

- How can sensor metadata be retrieved from a SOS and published on the semantic web with links to features-of-interest in an automated process?
- How can aggregation methods be represented on the semantic web to formalise expert knowledge and prevent meaningless aggregation?
- What are the advantages and disadvantages of integrating sensor data from different sources?
- To what extent can already existing standards for retrieving geographic data be used for a service that supplies integrated and aggregated sensor data?

3.2 OBJECTIVES

This thesis will explore a method that stores metadata of sensors on the semantic web, and links it to real world features of interest and to appropriate methods for aggregation. This should improve the discovery of sensor data through links to other related data on the internet.

To improve the integration of sensor data a middleware architecture will be developed that can return sensor data for features-of-interest. The returned sensor data will be aggregated. Only appropriate methods of aggregation are offered for each kind of observations, based on a formalisation of expert knowledge on the semantic web.

3.3 SCOPE

4 METHODS

overview of the methodology to be used;

5 PLANNING

time planning—having a Gantt chart is probably a better idea then just a list;

5.1 GANTT CHART

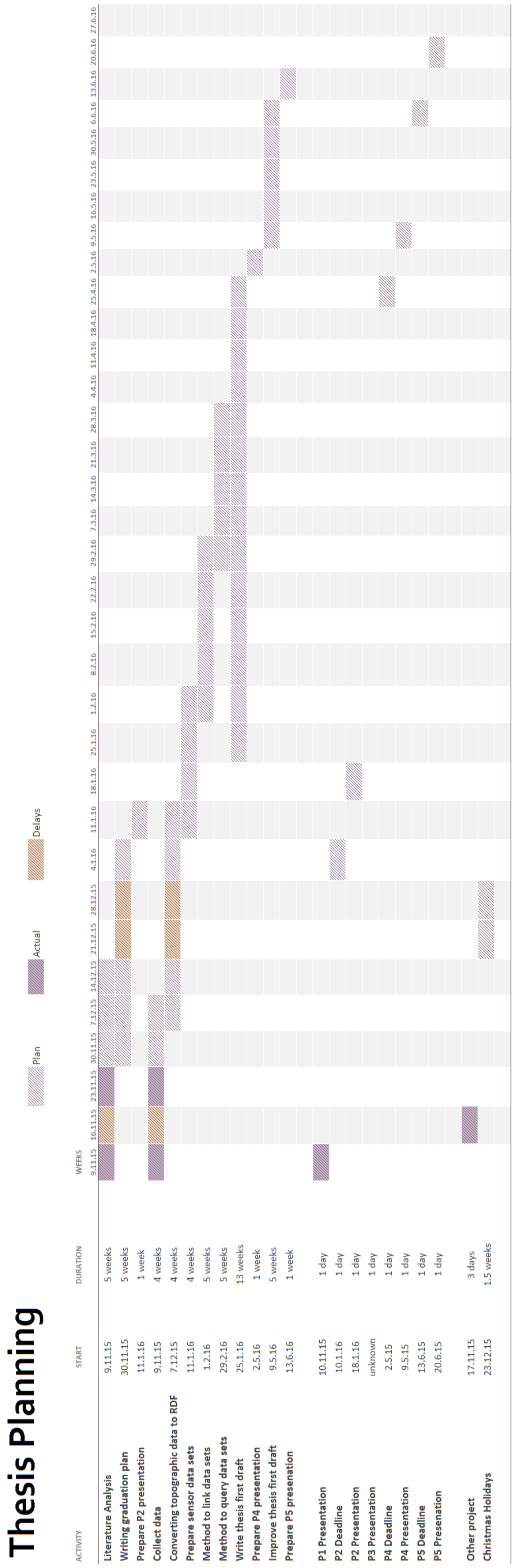

Figure 5.1: GANTT chart showing the planning of the thesis

6 | TOOLS AND DATA

since specific data and tools have to be used, it's good to present these concretely, so that the mentors know that you have a grasp of all aspects of the project;

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COLOPHON

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