Semantic Sensors: A Proposal From Smart Building to Smart City Model.

Oscar Hernández U.
TIEC, CIATEQ AC.
Santiago de Querétaro, México.
oscar.hernandez@ciateq.mx

Domingo Guinea,
LERH,
CAR, CSIC-UPM.
Madrid, Spain.
dguinea@car-upm.csic.es

Matilde Santos,
Facultad de Informática,
UCM.
Madrid, Spain.
msantos@ucm.es

Abstract—Advances in hardware, software and communications have been pointed out as promising tools for building a Smart City. These advances have made possible to face an increasingly complex functionality in different processes that can be found in any city. Applications called "smart" (smart building, smart water, smart energy, smart grid, smart city, smart transport, etc.), start to emerge around the planet. These smart applications are supported by ICT technologies and they connect the physical world and its digital representation, where novel algorithms and knowledge representation provide with information in a user context. This paper presents a smart building approach with multiple sensors and the use of a low enthalpy geothermal system to maintain indoor comfort. We decided to go a step ahead and go from smart building to a smart city model of a real location. A smart city model is build and environment is simulated where semantic web technologies and linked open data play a key role.

Keywords—smart city; smart building; semantic sensor; KPI's; Internet of Things; nZEB;

I. INTRODUCTION

Some concerns from now on to next decades, that are unavoidable to attend are: demographic change -sooner 80% of world population will live in cities-; longevity -life average expectancy is greater-; climate change, and global business. All of them have intrinsic events that in one way or another affect directly economic growth and social live in a country. Events such as migration from town to cities would imply not only to add infrastructure that support population needs but also knowledge to explain how well and efficiently population needs are cover to reduce the gap between rich and poor people [1]. On the other hand, recent years have witnessed a rapid advance in hardware and software technologies, where sensors are more sophisticated and the addition of new functionalities is ever easier. Smart applications start to emerge around the planet and seem an option to face these kinds of problems.

Following Internet of Things (IoT), it is necessary to link data beyond a local system (for example, a smart building), to other entities (cities). That is, it is necessary to pull and push data down and up from WWW to share and reuse knowledge. Embedded sensor systems developed at the Renewable Energy Fuel Cells and Hydrogen Laboratory (LERH), CAR_CSIC_UPM, (http://www.car.upm.csic.es/lerh/index.php/en/) not only generates huge amount of data but they can also enable contextual intelligence. Even more they have all the communications ports necessary to access the web, to account for great amount of data, to link data and interfaces, and to interact with users [2]. This increases the complexity because different entities have to be considered (people, buildings, weather, heterogeneous devices, etc). This point generates new challenges both for governments and citizens. But these systems make cities more “intelligent” by integrating smart water systems with smart transport and smart buildings and so on. It is clearly that a large amount of data is out there, gaining access and being able to process heterogeneous data is a key factor to make possible the generation of smart actions. Here is where ontologies, semantic web technologies and linked data tools, methods and standards are useful. Santiago de Querétaro (México) is going in for the smart city concept to be self-sustainable and to improve citizen’s quality of life [3]. The main idea is that users should start to play an active role and city key performance indicators (KPI’s) such as CO2 emissions must be updated in real time.

This paper is organized as follows. In next section, basic concepts and related works on semantic sensors are presented. In section III, the steps from a smart building to a smart city model is proposed. Some experimental tests have been carried out and results are shown. Finally conclusions and further work are formulated.

II. RELATED WORK: ONTOLOGIES + SEMANTIC WEB + EMBEDDED DEVICES = SEMANTIC SENSORS.

By definition “ontology is a formal, explicit specification of a shared conceptualization” [4]. From a very general perspective, it means to build technical specifications of the desired features and requirements by using a formal language. In fact, the deepness the encoding of these features and requirements is, and how explicitly all of them are formally specified, the ontologies are classified as formal or domain ontologies. The first one is fully described by a set of terms and some specification of their meaning through relationships, axioms and properties, using a representation language to infer knowledge (for instance, DOLCE). The domain ontology is related to relationships, axioms, and properties focus on some specific domain (for example SSNO).
The diversity of computer applications in which the use of ontologies is involved and the need to establish interoperability among multiple representations has favored the emergence of ontological patterns, where FOAF is one example [5]. The use of ontologies has been widely incorporated to the sensor field where also patterns have emerged. For example, W3C Semantic Sensor Networks Incubator Group (SSN-XG) developed an ontology sensor called Semantic Sensor Network Ontology (SSNO). There is also a well-known pattern for semantic sensor observations that is part of OGC’s standards and has been incorporated in SSNO. This is known as the Stimulus-Sensor-Observation (SSO) pattern, presented as a building block for work on the Semantic Sensor Web and Linked Sensor Data [6]. Also, smart applications using ontologies have been carried out where sensors are used [7-11]. This lets know that the web of documents, where primary objects are documents with implicit semantic of content for human consumption is changing. Semantic Web Vision is the web of linked data where primary objects are things with explicit semantic of content and links, not only for human consumption but also for machine. It makes resources accessible to automated machines and allows the use of logic reasoning to find useful information.

The development of languages oriented to the creation of ontologies has been a key priority. One of the initial proposals was RDF/RDFS. Later on, ontology language OWL-DL was preferred; it is based on description logic. SPARQL standard is used to query data that are built according to semantic web vision. There has been a lot of work to create standards such as the mentioned on the famous semantic web layer cake [HEN2009, DECKER 2000, CUENCA 2008] where every piece of information is represented by a tuple: Subject, Object and Predicate (S-P-O), called triple (Figure 1). Semantic Web Vision has been broadly applied to BBC, dbpedia, geonames, and governments such as EU, US and UK [12-14].

Energy consumption in buildings is a global concern. Buildings consume near 40% of energy worldwide and usually the 60% of total energy is spent for heating and cooling to maintain indoor comfort [15-16]. U.S.A. and EU. goals by 2020 are to certify almost all buildings as Zero Energy Building (ZEB) [17-18]. Many papers have been published where ontology for a semantic representation is mentioned [19-22]. Because of that, it is worthwhile to mention that most of the times it is not necessary to start from the scratch to build an ontology, but to make use of some of the existing ontologies or use some of the called upper ontologies as skeleton to develop a new one. For example, to build an ontology of sensors, the first step is to search books, journals, and magazines and attend some workshops to enrich the vocabulary about sensors domain. Second step is to get data and to understand the standards variable the sensors are going to measure (measurement science). Third step would be to search for related ontologies and vocabularies –both SSNO and FOAF could be a good choice-. Finally, to build your own ontology or to extend the chosen ontology, trying to distinguish and formalize atomic concepts, relations and roles found in the sensor domain, it is necessary to use tools such as Protégé, Neon Toolkit or TopBraid [23-24]. Figure 1 illustrates a sensor network ontology for a smart building where the variable is “temperature” showing metadata information around it. In this building it is required to monitor and control many subsystems (Electrical, Thermal, Geothermal, Photovoltaic).

![Fig. 2. OIKOS: A first approach to smart building](image)

The first approach for a smart building was “OIKOS (figure 2) [25-26]. Several challenges where solved using XML files to exchange information between subsystems such as photovoltaic panels (PVP) and Proton Exchange Membrane Fuel Cells (PEMFC), to switch among different strategies of energy flow. This system was presented in Expo2008, Zaragoza and nowadays is at CAR-CSIC-UPM in Arganda del Rey, Madrid.

III. FROM SMART BUILDING TO SMART CITY MODEL.

A. Smart Building.

A project of LERH is about a building with a low enthalpy geothermal system. Here, the smart building concept was embraced. Sensors were implemented and enhanced with more complex functionalities. For example, smartphones were included to enable users to be more active (figure 3, upper part). Many electro-valves, pumps and blowers were controlled. Machine learning algorithms were used to predict rain events (logistic regression algorithm) and faulty sensors (Support Vector Machine). Simulations models were used to understand
heat flow across walls when hot or cold fluid passes through them (figure 3, bottom). Metadata was used to introduce information in a specific domain and context. That is, energy efficient management goes with minimal human intervention. For example, instead of just reading the temperature of the wall metadata that define its location (site, building, and floor), parameters of the wall (thermal conductivity, diameter, and layers), are added. A virtual sensor was built to provide user context (figure 4).

![Diagram](image)

**Fig. 3.** Smart building. Top, the architecture with the sensor network. Solar energy is collected and stored underground. Bottom, thermal barrier is used to change thermal temperature gradient dynamically through the wall in order to adapt it to weather conditions and save energy for heating and cooling.

![Diagram](image)

**Fig. 4.** Virtual sensor was used to fuse several sensor values. This virtual sensor is controlled by a fuzzy engine. Everything is based on XML files, so a parser was needed.

B. **Smart City.**

Santiago de Querétaro (México), also called the “Pearl of the Bajío” has received the distinction of World Heritage City. Like many other cities, it has a lot of events where natural phenomena along a year are included. Same as a lack of information is a major cause of waste energy building during its lifetime, lack of information about annoying events in city is also a waste of energy for everybody. Quite recently a strong storm generated a chaos among citizens which increased the travel time by a factor of almost four what at the same time meant more CO2 emission because of the increase in fuel consumption [27].

On the other hand, in this city water utilities and power companies such as State Water Commission (CEA) and Federal Electricity Commission (CFE), have a supervisory control and data acquisition systems (SCADA). CEA collects information from 60 remote stations around the state to better understand water supply in urban areas as well as in rural areas. CFE has started to install smart meters where data is automatically captured, collected and sent to central servers. They also have weather stations spread around the city to know or predict weather conditions. Public transport at Santiago de Querétaro is connected to Internet to extract useful patterns not only about driving but also about GPS position and time of public transport. This information can be used to find delays between buses stop and to infer events or make predictions about traffic in roads. Smart building can also contribute to this global information system with some data such as water and gas consumption at user level, CO2 generation per day. The use of smartphones with several sensors is continuously growing, and they can be also used to collect or access data from sensors through Wi-Fi connection. With all of this instrumentation, it was aimed to design a smart city model.

C. **Testbed.**

One of the main goals of building a smart city model is to extract relevant information from a large amount of data which are mainly generated by the sensors at different sampling rates. In order to extract relevant parameters and knowledge from this huge amount of information, it is convenient to generate a macroscopic model to work with standards. Each smart application is a macroscopic model that shows relevant parameters (water utilities gives electromechanical efficiency). At a microscopic level we have granular information, such as personal data (user profile or sensor information), figure 1 using SSNO. We have collected sensor information from a smart building for 2 years such as indoor and outdoor temperature and humidity, solar irradiation, presence, etc. Some data from SCADA is simulated but useful to grasp main goal, such as water electromechanical efficiency. Each sensor node simulates a smart application. Data can come from buildings, transport, energy and water utilities. A small ontology is designed by coupling key concepts from existing ontologies in other smart applications.

Figure 5 shows the proposed model1 for a smart city. Four layers are highlighted: perception, network, database, and application. Perception layer will be in charge of acquiring data from sensors or files, where mobile devices redefine the possibilities to connect people, processes and related objects. For example, in our case smart building data is compose of low-enthalpy geothermal system, weather influences, wall properties, etc. Mobile devices not only can access this information and change user behavior but also enable or disable a thermal barrier. Network and database layer are in charge of the transmission and processing of the information obtained in the first layer. They pass through this information to the application layer and vice versa. Finally, the application layer
will allow the users to interact between them and let them make queries to understand the city status. Visualization and data mining tasks are executed. That means to use complex queries and new technologies (i.e., business intelligence, open data, geolocation, web services, contextual applications and augmented reality, etc).

![Layers of the Smart City Model](image1)

Fig. 5. Layers of the Smart City Model.

A large number of weather stations can be used to collect data and then apply some machine learning algorithms to predict locations with a high probability of raining. Because of that, smart water application can close some valves to stop sending drinking water; it has been showed that raining events implies less water consumption. Similarly, Smart transport can reorganize buses to avoid traffic jams because of flooding located at specific paths throughout the city. Figure 6 shows the main idea of this proposal, how concepts and relations are used to connect smart applications and give rise to a Smart City.

![Some concepts and relations used to link smart applications in a Smart City model](image2)

Fig. 6. Some concepts and relations used to link smart applications in a Smart City model.

Nevertheless, some issues still need to be solved. Most of the values computed by sensors are not identified as global parameters, but by processing values at a microscopic level is possible to get global parameters such as CO2 emissions and electromechanical efficiency. Because of that, we use values extracted from sensors located in the building. CO2 is an important KPI for a smart building but is necessary to know how much energy was spent to compute this value each day. Once CO2 is calculated, this data is transformed in a RDF value. Similarly electromechanical efficiency is a relevant KPI for Smart Water and its dynamic and static levels should be displayed by each drinking water well. Finally, neon toolkit and topbraid composer trial have been used to extract information and visualize a Santiago de Queretaro map with some KPis (figure 7).

![Setup topbraid composer to show in a google map main kpi’s from smart building. A sparql endpoint is also available](image3)

Fig. 7. Setup topbraid composer to show in a google map main kpi’s from smart building. A sparql endpoint is also available.

IV. CONCLUSIONS.

The growth of embedded devices where mobiles and smart applications are included provides promising opportunities for real-time and distributed intelligent data analysis. This will make possible for citizens to have access to information about some parameters and conditions of the city and to change their behavior accordingly. Using semantic technologies and machine learning algorithms, it is possible to use huge amounts of data intelligently. There is no reason to wait longer for a Smart City when all the components are ready to be wired. Benefits on the short and long term are clear. First, open data of the city performance derived from sensors and computer systems such as water availability, energy, transport utilities, etc., allow citizens to be more active and to interact with these instruments. Second, public authorities will have a better knowledge about the impact of the new infrastructures, and where it would be more necessary to invest. To summarize, in this paper we have explored the use and advantages of using web ontologies with linked data to build smart cities. A scenario was built to validate ontologies and semantic sensors in a Smart City. Three main goals have been accomplished:

1. Experience gained through smart building and SCADA was used to build concepts, relations and roles through a new ontology.
2. Tests have been show the feasibility and benefits of smart cities designed using ontologies and semantic technologies.
3. Small smart city ontology can be re-used for semantic web applications.

ACKNOWLEDGMENT

Current work was partially funded by Research Grants: MICINN-INNOVA-INNPACTO IPT_2011_1164_920000 and MICINN-INNOVA-INNPACTO IPT_2011_1584_920000 by the Spanish Government. First author thanks to the Alternative Energies Research and Development Foundation (FIDES) for a pre-doctoral grant and also CONACYT-CIATEQ for additional training and economic support.