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A framework analysis approach of an indoor air quality sensor

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Abstract

Killing around 7 million people a year, air pollution is the biggest risk to environmental health in the world. In this paper, we explore the use of structuring knowledge representation in form of a framework approach for an indoor air quality sensor. Applying the main steps to be considered in defining an air quality framework, we discuss each one of them, followed by a particular implementation of the framework in terms of an ontology model to exposure to carbon monoxide and PM10.5 (two of the most encountered pollutants in home life).

Keywords: sensor, air quality, pollution, framework.

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1. Introduction

Integrating sensors and models into computational intelligence, making decisions based on intelligent data analysis to solve, monitoring or predicting problems of any kind in the everyday life, are topics of major interest in the scientific community and of course in the current context of the world we live in (Reis et al., 2015). Thus, sensors play an important role in the field of "Data Knowledge" by extracting essential information from a specific field. Today, most sensors and their uses are managed by the Internet of Things, sensor networks becoming a ubiquitous part of our environment, promising to provide real-time data flows to suit specific purposes such as meteorology, aircraft detection, athlete training, earth observation, smart home monitoring, healthcare, security, surveillance, military, environmental health risks (Meng et al., 2018). Sensors easily interact with computers and smartphones, which connect via the Internet, with monitoring results displayed across various application or website interfaces (Meng et al., 2018).

Uncalibrated (requires filtering measurements for noise reasons) or precalibrated (so that the data is sufficiently reliable for comparison with official air quality standards), sensors should have a web architecture capable of:

- ➔ identify relevant data sources, often by filtering data or reducing noise so that only the necessary information is extracted;
- ➔ access the data (almost) in real-time and combine with the data saved a priori in the form of an existing database so that the system is capable of learning; and
- ➔ combine and correlate data from disparate sources with different ways of monitoring so that the results from different algorithms and different users can be combined and displayed in an application as easily accessible and easy to use (Reis et al., 2015).

The use of detection devices is constantly growing, being mostly implemented to monitor the physical world around us, but even so, there can be mentioned some restraints of using sensors such as increasing the volume of data, increasing the heterogeneity of devices, data formats, and measurement procedures, as well as the difficulty of mounting sensors in certain locations (Compton et al., 2012).

2. General requirements for a framework approach

The main steps to be taken in defining an air quality framework are:

- ➔ purpose identification (its use and characterization of users);
- ➔ key concepts identification (defining and representing the concepts and relations using formal languages);
- ➔ implementation;
- ➔ behavior analysis
- ➔ evaluation and validation;
- ➔ challenges;

2.1. Purpose identification

The link between "Big Data" and public health can be shaped by sensors that try to solve or monitor environmental problems by collecting almost instantaneous data, by improving the collection of environmental data in poorly monitored or rural areas, in urban areas with high concentrations of pollutants, as well as in developing countries where monitoring is virtually non-existent (Reis et al., 2015). In addition to smart sensors, personal sensors also give users the ability to monitor the air they breathe. The basic principle of the functionality of air monitoring sensors is that they measure data (almost) in real-time, with various instruments, such as analyzers, the data being subsequently published to the user through web services.

Meng et al. (2018) describes a geospatial sensor web (GSW) application for ecological public health problems. Human and Ecological health Risks Ontology (HERO) is called the semantic sensor network ontology template and Human and Ecological Health Risk Management System (HaEHMS) illustrates the web-based prototype, which can estimate health risks. Compton et al. (2012) presents a conceptually global ontology of a semantic sensor network incubator group, which describes the sensors and their capabilities, observations, and methods used for detection. Divided into ten conceptual modules, the SSN ontology is designed to support modeling complex projects, like SENSEI or Semsor-Grid4Env project.

Paper (Opera, 2009) describes ontology for air pollution analysis and control and presents its use in two systems, an expert and a multiagent system, both systems being applied in urban regions. There are some meteorological terms used in the created ontology like rainfall, wind, temperature, humidity, or pressure.

In Adeleke et al. (2015), the created ontology implies both the air quality state to which the current concentration value corresponds and thermal comfort in the monitored houses using temperature and humidity values recorded by sensors. For the case study in this paper, the ISO 7730 standard from 2005 was adopted, a standard that defines as pollution the concentration levels that exceed certain critical values. Using a W3C standard ontology language, the authors in Riga et al. (2018) developed both an ontology schema for representing the status of the environment and its impact on citizens' health and a rule-based reasoning mechanism for generating personalized recommendations, based on air quality conditions.

In Dahleh et al. (2016), it is defined a pollution, a sensor, and a species ontology for the representation of ISO37120 Environmental theme indicator definitions. Using Global City Indicator Foundation Ontology to express the units of measure of each pollutant concentration, W3C Semantic Sensor Network Ontology to identify the sensor used in each measurement, the ontology allows the automation of the analysis of a city's performance. The description of an indoor air quality sensor is influenced by the complex interactions of several different phenomena, including natural sources (e.g. weather like tornadoes or wind), indoor activities of occupants (cooking, burning fossil fuels, candles, incense), proximity to industrial centers, burned bushes, characteristics and/or structures of the building (number of windows in a room, type of ceiling) (Adeleke et al., 2015).

Nowadays, when air pollution and health issues reach top searches and concers, there are many monitor air quality sensors, for both indoor and outdoor environment. Different from the point of view of number of sensor, costs, display, particular pollutant, many producers present top air quality devices for the current present (reviewsofairpurifiers.com).

2.2. Key concepts identification

A conceptual framework is based on several layers, like measurement and monitoring, classification and analysis, action and control. For example, by observing air pollutants like SO_2, NO_2, PM10, CO, O_3, or PM2.5 we can know the "potential" air quality (Meng et al., 2018). Starting from this idea, an indoor air quality should meet air quality standards, so once the sensor connects to the power supply, the sensor controller starts an auto-adaptation algorithm that ensures the value of indoor air quality is similar to the index of healthy air quality. The principle of a proper sensor should aim to monitor, measure and record room conditions, turn on the ventilation or purification system when needed, and even send alerts based on measured concentrations if any change appears in the optimum pre-settled conditions.

Exploiting sensor network data can be greatly facilitated by ontology-based modeling (Meng et al., 2018). An ontology example of indoor air quality sesnor in case of measuring concentration values of two pollutants, PM10.5 and carbon monoxide (CO), and what actions should be taken in case of risky values is presented in Figure 1.

PM-type particulate pollution consists of a mixture of solid and liquid droplets. The particles come in a wide range of sizes, but the one with a diameter of 10.5 micrometers (less than the width of a human hair) representing fine dust particles, smoke, or various allergens have been linked to cause or aggravate several serious health problems like heart or lung disease (airnow.gov). Carbon monoxide is an odorless, colorless gas that forms when carbon in fuels does not burn completely. Massive concentrations of pollutants may occur in case of damage to a home stove or gas plant. Entering the blood through the lungs, reducing the amount of oxygen that reaches the organs and tissues, carbon monoxide can cause from mental or vision disorders to people intoxication, having various cardiovascular and respiratory symptoms to even death (airnow.gov).

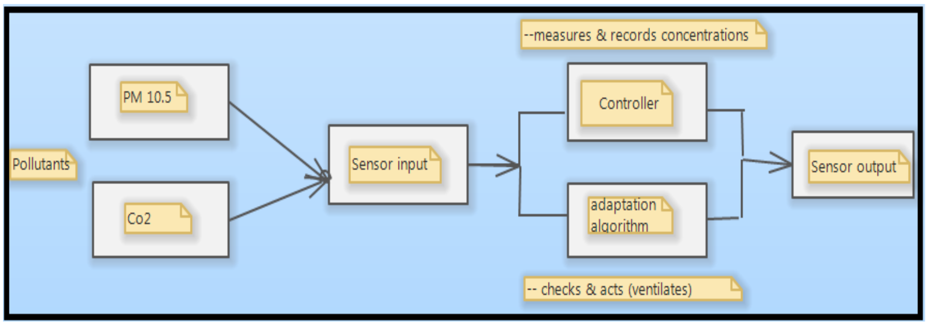

Figure 1. Structure exemple of an air monitoring sensor

We can see both PM 10.5 and CO pollutants applied as inputs for the sensor logic, which through controller and adaptation module, creates specific outputs. This sensor model is thought to measure the concentrations of two of the most encountered pollutants in home life (airnow.gov), the level of PM10.5 and carbon monoxide, so in case of any kind of operational problems of the heaters or simply if any activity in the house increases the rate of pollutant concentrations, the tenants to be informed about the level of pollutant concentrations and about what actions should be taken depending on their values and the logic of the software.

2.3. Implementation

According to Saad et al. (2014), 57% of the indoor air quality monitoring systems are based on microcontrollers, 53% of the systems use the Internet of Things, and 33% are based on Wireless Sensor Network architectures. Traditional sensor network platforms (eg Hourglass, Global Sensor) focus on composing wireless networks for collecting and distributing observed data (Meng et al., 2018). For instance, Intel Research's IrisNet provides a software infrastructure for a platform that allows users to query distributed data collections from sensors globally and proposes a two-tier architecture consisting of detection agents that collect and pre-process the sensor data and organizing agents that store sensor data in a hierarchical, distributed XML database (Gibbons et al., 2003; Compton et al., 2012).

Tzoa is a sensor that measures air quality, allowing users to receive instant feedback on their environment and air quality, by detecting two types of particles in the air, including noxious substances found in the exhaust or various types of dust (Reis et al., 2015). Detailed data is available through a mobile app, which combined with the GPS system contributes to an air quality map, making suggestions for the best routes and neighborhoods for outdoor activities. The sensor also joins other air quality monitoring projects for citizens' health (eg AirBeam, Air Quality Egg, AirBoxLab, or Smart Citizen Kit), which each build air pollution databases (postscapes.com). For example, Air Quality Egg is an air quality detection system designed to allow anyone to collect high-resolution readings of NO_2 and CO concentrations outside the home, using an RF transmitter and an ethernet base station. The data can then be shared to create a network that can be used by the general public (Reis et al., 2015). Dumini DustDuinos is another device that measures the concentrations of harmful particles in the external environment and then uploads the data to a public website (postscapes.com).

Devarakonda et al. (2013) presents a mobile approach for measuring fine-grained real-time air quality in the form of a Mobile Sensing Box (MSB) assembled unit. Consisting of a microcontroller, dust, and carbon monoxide sensors, GPS, and cellular modem, it can be mounted on any vehicle and powered by its battery. In Sherin et al. (2016), there is designed a wireless indoor air quality sensor network system using the Digi XBee module, while (Opera, 2009) describes a wireless sensor network system developed using Arduino and Raspberry Pi open-source hardware platforms. Ho et al. (2020) presents both a “Smart-Air” device and a web server that creates an IoT-based indoor air quality monitoring platform. By measuring concentrations of aerosol, VOC, CO, CO_2, and temperature-humidity, the device composed of a microcontroller, pollutant detection sensors, and LTE modem efficiently monitors the air quality anywhere and anytime.

The challenge of all these projects is the integration of disparate data sets, with those of municipal and academic monitoring stations (if any), and making all data available to the public, in a way that is as compact, transparent, and useful as possible (postscapes.com).

2.4. Behaviour analysis

For the chosen example, it can be explored how different parameters influence the air quality monitoring ontology behavior. Using the Protégé software package, a framework for representing basic and open source knowledge (protégé.standford.edu), we gave examples of PM10.5 and CO_2 measured values and defined rules and commands for the adaptation and control parts of the air monitoring sensor, in case thresholds are crossed (Figure 2 and Figure 3).

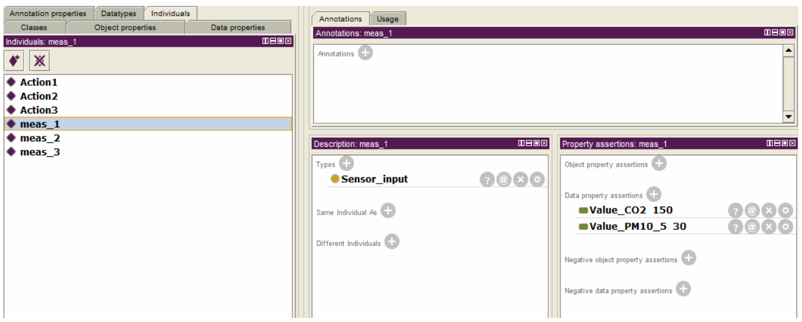

Figure 2. Measurement example for the air monitoring sensor

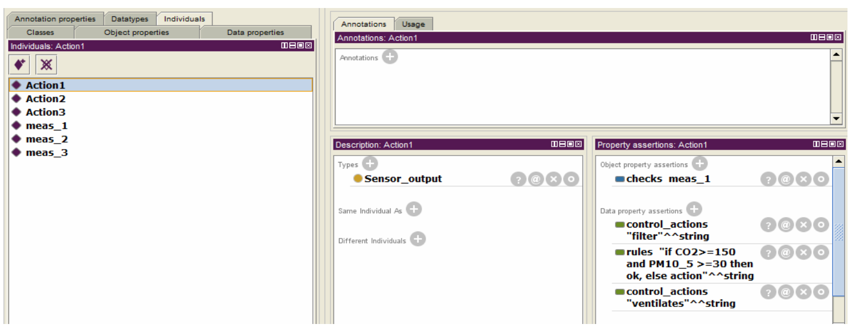

Figure 3. Action example of the air monitoring sensor

2.5. Evaluation and validation

We present a simulation solution approach for an indoor air quality monitoring sensor in form of an ontology. To evaluate it, we assigned different data to the sensor, resulting in scenarios that allowed the analysis of quantitative observations of the sensor (pollutants) to produce abstract qualitative situations. Figure 4 shows an example of SPARQL which queries the values for both pollutants for each measurement in a time interval.

	Sensor_input	Value_PM10_5	Value_CO2
1	:meas_1	"30"^^xsd:integer	"150"^^xsd:integer
2	:meas_2	"150"^^xsd:integer	"30"^^xsd:integer
3	:meas_3	"100"^^xsd:integer	"100"^^xsd:integer

Figure 4. Queried PM 10.5 and CO2 values for each assigned measurement

An example of a SPARQL query that shows the rules of the actions modeled for the ontology by the software side of the sensor is presented in Figure 5, while Figure 6 shows a SPARQL case showing which are the control actions assigned to the Sensor_output.

Figure 5. Queried action rules for the sensor ontology

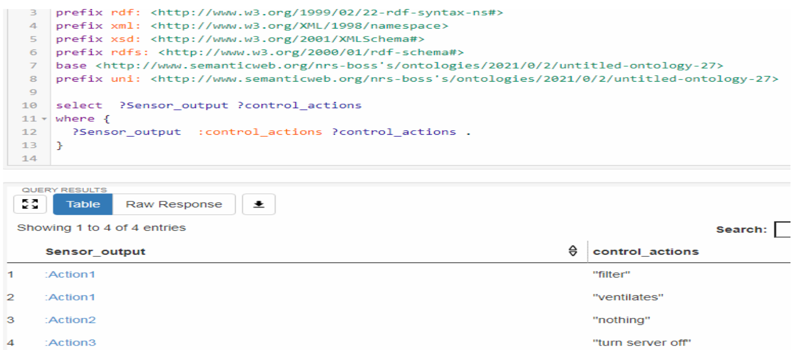

Figure 6. Queried actions applied to the Sensor_output

Even if the evaluation is made via simulation values, just for "proof of concept", this relational schema contains sensor measurements and provides representation and reasoning to analyze the indoor environmental quality situation. For example, if we want to see which values exceed a specific crucial limit (e.g. which are the values for the CO2 pollutant higher than 100), we can interrogate like in Figure 7.

	Sensor_input	Value_CO2
1	:meas_3	"100"^^xsd:integer
2	:meas_1	"150"^^xsd:integer

Figure 7. Output showing which measurements have concentrations values of CO_2 higher than a certain number

For this case, the validation part is inexistent due to the simulating and not real values, but the model could be integrated with real sensor platforms with official air quality standards, where concentrations are measured through physical sensors, which aims to monitor, measure and record room conditions, turn on the ventilation or purification system when needed, and even send alerts based on measured concentrations if any change appears in the optimum pre-settled conditions, ensuring the values of indoor air quality are similar to the index of healthy air quality.

2.6. Challenges

The use of air pollution sensors to collect data to guide what, when, and where the sensors should measure is vital for reducing the concentrations of hazardous elements in the atmosphere and therefore for the health of all those who coexist on this planet. Based on these ideas, as many resources as possible are needed to monitor air pollution, which kills around 7 million people a year. Support for the environment through information science plays an essential role in improving the health of each individual. While the global sensory network has become a very useful monitoring technique, the full potential of the sensory network has not yet been revealed, the integration of several sensor technologies and the implementation of heterogeneous sensor data quality processes are essential for monitoring as accurately as possible.

3. Conclusions

In this paper, we have proposed a framework approach that provides an efficient perspective for describing and understanding how air quality sensors can monitor and control the air quality inside a house.

We provide an ontological framework for the analysis of an indoor environment in terms of air quality. Quantitative and qualitative conditions for environmental pollutants (PM 2.5 and CO) were defined, which allowed the assignment of a series of actions and rules for the microcontroller and the sensor adaptation algorithm to maintain the indoor air quality at an optimal level. Classes, subclasses, class attributes, class actions, and examples for ontology were defined. To obtain relevant situations and different scenarios, the ontology was queried based on the concentration levels of the two pollutants and the control and adaptation actions. Applying the advantages of using Protégé environment and SPARQL queries to evaluate and analyze the air quality state, the model approach achieves the purpose of creating a semantic for a problem related to exposure to carbon monoxide and PM10.5, operating with control actions to mitigate harmful situations, for both pollutants.

Future work to extend this framework approach includes the development of a more complex software modeling required to validate this formalism, by using real air quality protocols.

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