WEB GEOSERVICES FOR MONITORING THE ENVIRONMENTAL IMPACT OF LARGE STRUCTURES

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ABSTRACT:

Environmental monitoring is a fundamental process in design, construction, operation and decommissioning phases of large structures, as highways, roads, bridges, airports, railroads, dams, and reservoirs.
In general many different actors are involved in the process; between them: the owner (public or private) of the large structure; the planning, construction and operation managers; the environmental teams executing the environmental monitoring; the government department or agency which is which is responsible for protecting the environment and the health of the population and finally the policy-makers.
The environmental agency itself is composed by various domain experts dealing with different aspects (air, water, soil,…). The most of collected information refers to space and time and therefore GISs are the natural tools to be used for storing and processing the data. Nevertheless instruments, people and communications are involved throughout the process and many potential cases of failure, waste of time and unnecessary cost can appear.
A web platform based on OGC geo-web services and allowing for sharing and processing the sensor and geographic information greatly improves the all process. The presentation will discuss and show an example of such a kind of solution, where it is possible to mash-up geodata (maps and orthophotos) from different sources and to visualize and analyze the sensor data both with respect to time and space. The platform, built by Politecnico of Milan and ARPA Lombardia (the Lombardy Regional Environmental Agency), is completely based on open standards and open software.

1. INTRODUCTION

Since the appearance of the first webGIS (Putz, 1994) internet has been deeply influencing the usage of geographic information. From desktop GIS, where we must have both data and geographic functionalities on our own computer we have been rapidly moving towards distributed GIS (Peng and Zsou, 2003). Through internet maps, aerial and satellite ortho-rectified imagery and more in general every geo-referenceable phenomenon are collected at one level of government and shared between all levels (INSPIRE, 2007). This allows GI users to better contextualize their projects, mashing-up information in ways original data owners had not considered before.
The trend is a general one as it is testified by the increasing demand and usage of geographic data through services provided by Google, Yahoo and Bing (just to mention the most popular). But it is particularly helpful in cases, like that presented in the paper, where experts of specific domains can exploit updated data collected by other agencies responsible for their maintenance.
Different services have been developed in the last years for offering in different ways different typologies of data: from simple images of geographic data, provided by WMS (Web Mapping Service), to data themselves provided through WFS (Web Feature Service) for vector and WCS (Web Coverage Service) for raster data. Thanks to specifications that were made available from organizations, like for instance OGC (Open Geospatial Consortium), we witness a day-to-day spring of these new services.
At the same time, there is a growing interest to better exploit in a synergic way the existing networks of (remote, in-situ and proximal) sensors to pulse the status of the Earth.
The Earth dons an electronic skin consisting of millions of embedded electronic measuring devices. We can use the Internet as a platform to support and transmit its sensations (Murray 1999).
At the beginning (1997) the "Sensor Web" term was used for defining the concept of "developmental collections of sensor pods that could be scattered over land or water areas or other regions of interest to gather data on spatial and temporal patterns of relatively slowly changing physical, chemical, or biological phenomena in those regions" (Delin et al. 1999).
More recently, the OGC introduced a new definition: "a Sensor Web refers to web accessible sensor networks and archived sensor data that can be discovered and accessed using standard protocols and application program interfaces" (Botts et al. 2006).
The goal of OGC-SWE (Sensor Web Enablement) initiative is to enable all types of Web (and/or Internet) compatible sensors, instruments, and imaging devices to be accessible and, where possible, controllable via the Web.
Based on such a definition, the OGC SWE framework was designed as a suite of standard model encodings, usually given

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in eXtensible Markup Language (XML) and standard web service interfaces; the web is the glue that allows the real time integration of heterogeneous sensor into the information infrastructure.
The concept of Sensor Web can be summarized saying that it aims at simplifying the publication and access to sensor resources, just as the web has done for documents (Woolf 2009) Sensors are spread all over the world and their location, joined with their acquisition time, is the basic information to interpret the observations they make available.
Geographic information systems, allowing users to visualize and analyse the relations among measurements and between measurements and the built and the natural world where they are collected, are the hubs of these new systems.
The analysis of geo-referenced data leads to another interesting development in the GIS world mentioned at the beginning of this paragraph. As said, the new vision of internet GIS brings not only to sharing data but also functionalities, i.e. geographic operators improving in that specific case the ability of validating data, of spatiotemporally synthesizing the huge amount of observations collected by different sensor networks, of modelling fields, of scenarios predicting and risk monitoring.
The WPS (Web Processing Service) is the standardized OGC interface providing geospatial processes, i.e. algorithms, that can be simple calculations or sophisticated models operating on spatially referenced data (OGC 2007a).
WPSs are of particular interest in cases of collaborative platforms (specifically when they have to be used also by non GI experts) or in cases in which the time to process data locally is greater than the global time needed to send the data, process it remotely and download the results. A practical example could be the case in which users are equipped with handheld devices (such Smartphones and PDAs) with low processor performance and limited persistent storage and ROM. To avoid waste of time data are stored on server(s) and processed according to the user's specific requests.
In the next paragraphs all the concepts before introduced are applied to a specific case study: the monitoring of the environmental impact of large structures. The choice has fallen on this example because it is a typical case where sensors play a great role and various domain experts are involved. The rationale of the paper is the following. In paragraph 2 the problematic, the actors involved and the typical workflow is presented. Paragraphs 3, 4 and 5 introduce the Sensor Observation Service (OGC 2007b), the database and the client implemented. Paragraph 6 shows an example of processing (through WPS services) to analyse measurements. Paragraph 7 briefly concludes with some discussions of lessons learned and future developments.

2. MAGO SOS PROJECT

ARPA Lombardia is the Lombardy Regional Environmental Agency. One of its basic objective is to gather information about every change in the quality of natural resources, especially when large structures are built. Even if new highways, high-speed railways and airports are needed for economic development, population living beside them worries about environmental degradation, and the only possible answer is a sustainable development.
To this aim, the first step is the accurate knowledge of the actual state of the environment and of its resources (air, water, underground water, soil, vegetation, noise, …) before every structure has been built: this is called the *ante-operam* monitoring, and it is conducted by the structure's builder. After the structure has built up, monitoring is used to assess the environmental impact: this is called the *post-operam* monitoring. Indeed, during the building phase the monitoring of resources is used to minimize impact and to prevent possible problems as soil and water contamination, increasing of noise pollution, excess of dust, and so on.
ARPA is involved in the whole process by means of its twelve departments: it is the public auditor of the monitoring tasks conducted by several subjects, each one concerning a specific environmental issue of the specific large structure under control. For harmonizing the work of the different people involved, ARPA needs a tool to gather data, to represent them in a geographic context, evaluating not only the impact of a specific structure but the composite impact resulting from each of them.

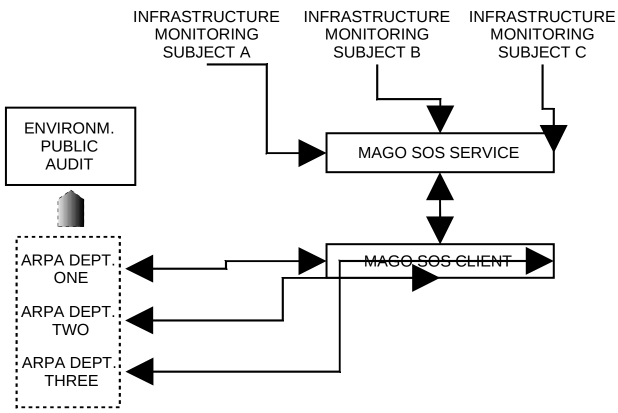

Figure 1. ARPA's role in the infrastructure monitoring issue

The use of SWE tools and standards fits completely these objectives; as shown in Figure 1, the SOS can store almost any environmental issue and every subject can use the SOS to feed the observation database. By means of OGC XML structures, and with a SOS client the data access is easily obtained through any computer connected to the ARPA intranet.
These features were explored in a prototype project dedicated to airport noise monitoring. The first service has soon been evolving in the MAGO SOS Project: the acronym means "Monitoraggio Ambientale Grandi Opere", which can be translated "Large Structures Environmental Monitoring"; but "MAGO" is also the Italian word for "wizard", used for stressing the easy resolution of a complex process.

3. SENSOR OBSERVATION SERVICE

The standard specifications about SOS (Sensor Observation Service), in its current version 1.0.0, were published in 2007 by Open Geospatial Consortium. This standard belongs to the Sensor Web Enablement (SWE), a set of standards dealing with the treatment of sensors and their related data.
Currently several SOS software packages are available or at different phases of implementation: 52°North's 52nSOS (http://52north.org/), UMN Mapserver SOS (http://mapserver.org), deegree (http://www.deegree.org), gvSIG SOS extension (http://www.gvsig.org), istSOS (http://istgeo.ist.supsi.ch/software/istsos/).
We decided not to develop a new SOS product, but we preferred to work with an existing software in order to evaluate its performances about our needs. The software package 52nSOS was used to build up the SOS server because, at the beginning of the project, it seemed to be the most comprehensive product. The software was developed by 52° North (http://52north.org/), an international research and development company, based in Munster (Germany), whose declared mission is to promote conception, development and

application of free open source geo-software for research, education, training and practical use.

This software implements the SOS standard basic version, supporting the mandatory requests:

- GetCapabilities which provides the service description,
- GetObservation which provides the requested observation,
- DescribeSensor which gives the sensor description, following the Sensor Model Language scheme (OGC 2007c).

It also implements the optional transactional functions RegisterSensor, to add a new sensor, and InsertObservation, to add a new observation.

In addition, it supports other non mandatory requests, like GetObservationById (to obtain an observation based on its identifier), GetResult (for periodically polling of sensor data) , GetFeatureOfInterest (to request the GML encoded representation of a feature) , etc.

52nSOS is a Java based software, which uses the following framework:

- DBMS PostgreSQL (http://www.postgresql.org/) with PostGIS extension (http://postgis.refractions.net/), to store and to manage sensor and geographic data,
- XMLBeans (http://xmlbeans.apache.org/) for the XML analysis and coding of requests and responses,
- Java Topology Suite (JTS - http://www.vividsolutions.com/jts/jtshome.htm), an implementation of fundamental 2D spatial algorithms,
- Log4J (http://logging.apache.org/log4j/), to support log information for the application,
- Apache Maven (http://maven.apache.org/), a build manager for Java projects.

4. DATA AND DATABASE STRUCTURE

The data used in the design phase have been provided by ARPA Lombardia, directly interested in the development of a system for monitoring, validating and publishing the observations collected by environmental sensors.

In the web-service prototype a small set of data related to noise pollution monitoring in the Malpensa, Linate and Orio al Serio Lombardy Region's airports, was published. Other data concern Brebemi, a new highway under construction that will connect three cities in the Northern part of Italy: Brescia, Bergamo and Milan.

The database for the data management has been created following the standard structure compliant to 52° North. It is organized into six main tables linked with more bridging tables, for a total of 25 tables. In details, in order to store data related to environmental monitoring of large structures, the database is organized as follows (Figure 2): each structure (highway, airport, etc.) has a one-to-many relation with its monitoring points; each point has a one-to-one relationship with the sensor responsible for the measurements and a one-to-many relationship with the collected observations. Points, sensors and observations are linked, with many-to-one relationships, to the environmental matrix they are part of. The environmental matrices which must be considered for the environmental monitoring of large structures are: surface water, groundwater, air, noise, vibration, flora and fauna, soils and agronomy, landscape. Finally, each environmental matrix has a one-to-many relationship with the measured physical quantities (pH, ozone, Leq, etc.).

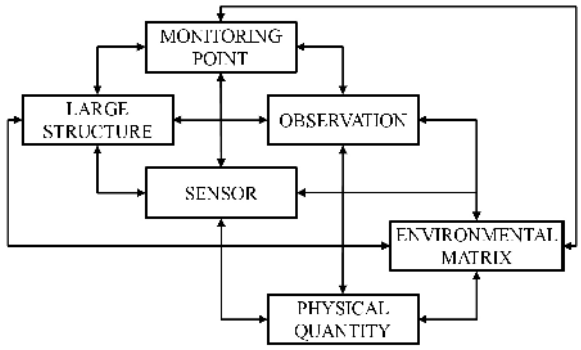

Figure 2. Description of the database structure

For example, the monitoring plan of Brebemi highway concerning only the groundwater consists of 34 sensors dislocated on the territory surrounding the structure. Each sensor measures different physical quantities: aluminum, arsenic, cadmium, calcium, chlorides, chromium, iron, hydrocarbons, magnesium, manganese, nickel, nitrates, oxygen, lead, pH, conductivity, groundwater flow, potassium, redox potential, copper, sodium, sulfates, water temperature, air temperature, non-ionic surfactants, anionic surfactants, zinc, Total Organic Carbon (TOC). Moreover, the monitoring plan of the noise pollution involves 39 sensors to measure: daylight and nocturnal equivalent sound level (Leq), environmental and residual Leq, daylight and nocturnal limit. Therefore we have to deal with a large number of sensor showing great dishomogeneity each other.

It follows that flexibility is a crucial factor because, once the service is fully operational, it will have to support the entire environmental information related to large structures. Thus, in a single database, observations on all environmental matrices and physical quantities will be reported. The structure implemented in the software provides the necessary flexibility to store and subsequently to handle all the different typologies of data.

Despite its simplicity, this database design fits the basic need of observation recording: however, for a best exchanging data feature, a shared phenomenon dictionary could be implemented as a public resource.

5. MAGO SOS CLIENT

A web portal, called MAGO SOS, a Sensor Observation Service for the environmental monitoring of large structures, has been created for consulting the data. Within the portal sensors, observations and cartographic resources necessary for the contextualization are published: ortophotos and administrative boundaries obtained by connecting to Lombardy Region's WMS, shape file depicting structures and the elements connected to them (monitoring points, construction sites, etc.).

For the MAGO SOS implementation MapFish (http://mapfish.org/), a JavaScript based software that combines OpenLayers (http://openlayers.org/) for the mapping part and ExtJS (http://www.extjs.com) for the layout part, has been used. Using the tools available in the web application it is possible to access the published environmental observations by SOS server, select the data to be displayed, for example over a certain period of time, using simple procedures that are translated by the client web in queries for the SOS server. Thus, the user is enabled to select, with few clicks, the search parameters for the observations of interest and view them without having to deal with XML documents, whose management is delegated to the web application(Figure 3).

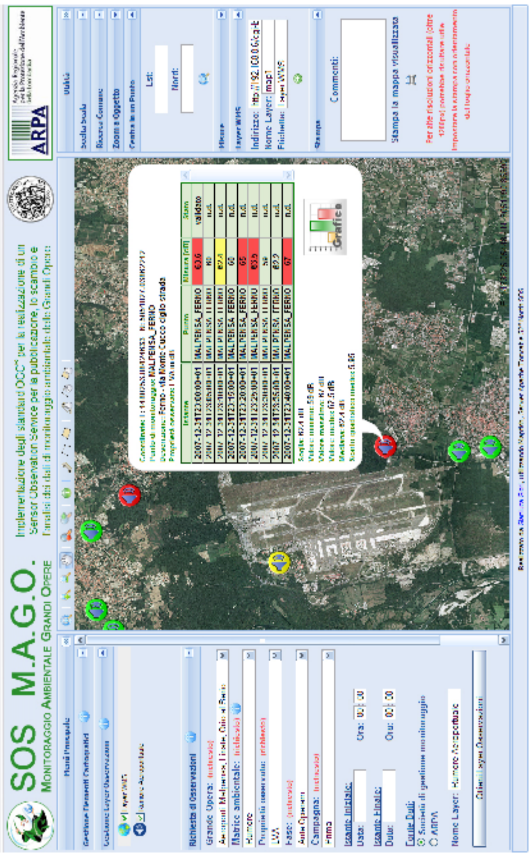

Figure 3. MAGO SOS client

MAGO SOS client is divided into: a part of main menu, a part to display maps and a part of utility.

Through the main menu the users can make requests to be submitted to the SOS server selecting required parameters, including structure, environmental matrix and physical quantity of interest. Then they refine their search, if necessary, specifying the time period. If the SOS response contains at least one observation an "observations layer" is created, manageable as a new layer from the menu, containing all the monitoring points for which data are available. These points are georeferenced and shown on the map with coloured symbols (green, yellow or red) in relation to their overcoming or not overcoming of the law's thresholds. Furthermore, it is possible to query the single monitoring point to have additional information, listed in a popup, such as: coordinates, point's identifier and description, observed property and its unit of measurement, table of values and, in case of presence of more than one observation, some statistical indexes and a key for the graph's dynamic creation.

Additional features are available in the utility section that provides tools such as: scale choice, search for municipality or coordinate pair, zoom to layer, measurement of distances and surfaces, printing. Finally, the user can add layers from other WMS. Specifying the service address and the resource name, the latter will be visualized and added to the management layers menu. This function gives the possibility to have a cartographic mash-up that promotes the study and the control of the environmental impact a large structure could have on the surrounding environment by considering, for example, protected areas, water resources, etc.

The test application and further specifics are available at: http://webgis.como.polimi.it/sosMAGO/.

6. MAGO WEB PROCESSING SERVICE

Capability of selecting and querying sensor data offered to users by the MAGO SOS suggested to evaluate the possibility of enriching the service with new functionalities related to on-the-fly data processing. The example that was considered at this stage was the interpolation of fields sampled at points irregularly distributed in a plane to obtain the corresponding thematic map. Following the same approach which has driven the whole application development (WMS for maps, SOS for sensor data), the implementation was realized ensuring the compliance with the OGC standard Web Processing Service (WPS). The newest OGC specification related to processing is the WPS 1.0.0 (OGC 2007a).

User, through the MAGO SOS client selects the specific typology of sensor and the time interval she/he is interested in and obtains back the corresponding raster map representing the average interpolated phenomenon (average is related to the time interval selected by user). The focus of the example is not to discuss and implement an optimize method for interpolating data but simply to verify the interpolation feasibility through standard web interfaces. Several products are compliant with the latest WPS OGC specification: 52N Web Processing Service (http://www.52north.org/wps), airGmap Aerospace Technology Limited OCCS (http://occs.airGmap.com/), ERDAS APOLLO Professional (http://www.erdas.com/Products/ERDASProductInformation/tabid/84/currentid/3148/objectid/3148/default.aspx), HS-RS PyWPS (http://pywps.wald.intevation.org), deegree Web Processing Service 3-alpha.01 (http://www.deegree.org), LBS Plus GNIS Server (http://www.lbsplus.com), Liquid XML Data Binder (http://www.liquid-technologies.com/XmlStudio/Xml-Data-Binder.aspx), RSI Softech Geo Data Manager (http://www.rsisoftech.com/).

Among them the choice of the authors, due mainly to their previous experiences with this package, has fallen on PyWPS.

PyWPS (Python Web Processing Service) development started in May 2006 (http://pywps.wald.intevation.org). It was initially funded by Deutsche Bundesstiftung Umwelt (DBU), a German foundations promoting innovative environmental projects, and it is currently mainly supported by the company Help Service - Remote Sensing Ltd (HS-RS), located in Benesov (Czech Republic).

PYWPS provides an environment for programming processes and it is written with native support for the Geographic Resources Analysis Support System GRASS (http://grass.osgeo.org/), even if developers of the service can use also other programs, like for instance the statistical R package (http://www.r-project.org/), or the Geographic Data Abstraction Library GDAL (http://www.gdal.org/) and the cartographic projections library PROJ (http://trac.osgeo.org/proj).

In this application GRASS, and specifically the v.surf.idw command (http://grass.itc.it/grass62/manuals/html62_user/v.surf.idw.htm), was used. The command executes the surface interpolation from vector point data by inverse distance squared weighting. As said, once implemented this first service, the extension to other processing services by means of different GRASS commands requires additional very small efforts. GRASS is a desktop GIS and therefore the internet geo-service is implemented through PyWPS. PyWPS is written in Python and the scripts which implement the geo-services by means of calls to GRASS modules must be written in this language.

At the client side the Javascript "PyWPS JavaScript client" library, made available by the same developing team of PyWPS, was used as backbone. The library, based on OpenLayers, offers functionalities for easily querying a WPS server and for managing its replies to obtain the output map but

it does not provide viewer functionality, which must be implemented
The library is at its initial stage (0.0.1 version) and therefore an important bug correction work and the extension of some parts to make the library suitable for our project were required.
The architecture of the system is shown in Figure 4 (Figure taken from the website http://pywps.wald.intevation.org/)

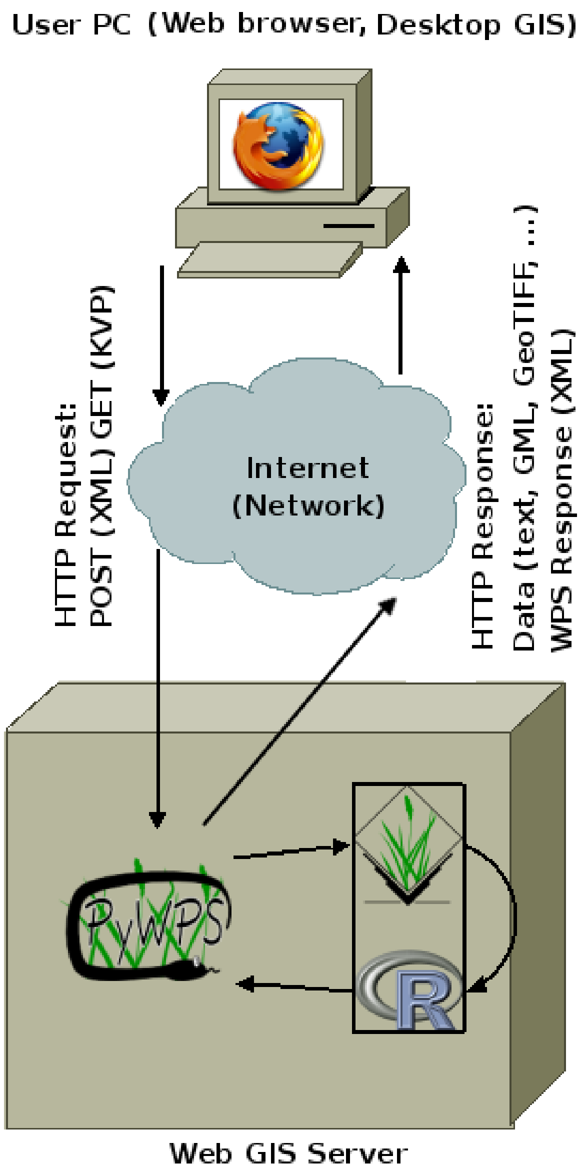

Figure 4 – System architecture

Two different implementations can be considered. The former corresponds to direct transfer of data from client to WPS: user through the web interface makes her/his request, the client sends the request to SOS, collects the results and then sends them to WPS to be processed.
This implementation is easier at server side but it has at least two drawbacks: it requires a continuous transfer of data, which can cause delay in case of large dataset, from SOS server to client and then from client to WPS; moreover in case we want to make available the same service for different clients, all these clients must have the querying and sending capabilities.
The latter implementation consists in sending to WPS only the query parameters and in leaving the server the task of directly collect data from the database underlying the SOS.
This choice requires a greater implementing work at server side but it is immediately available for every client. WPS server queries the database, interpolates data and produces both the image of the map and its georeferencing metadata needed for correctly upload the result of the interpolation in the web client. The all characteristics of the service can be obtained by means of a DescribeProcess request to WPS server (http://ows.como.polimi.it/cgi-bin/wps_grass?service=wps&version=1.0.0&request=DescribeProcess&identifier=SurfIDW_db).
In the prototype the data query is possible only through a direct query to the database. In future developments, completely transparent for users, a SOS interface at WPS side will be implemented in such a way to use that standard for querying whichever data server and to improve the current status which is limited to PostreSQL database connection.

7. CONCLUSIONS

The paper presents a first prototype (MAGO SOS) for managing environmental variables related to monitoring large structures impacts. One of the greatest advantages of the SOS technology is the possibility of merging, in the same service, data exchange and data processing. Indeed, the different actors involved in the monitoring plans can send data which are directly stored in the database exploiting the transactional function InsertObservation. After that, ARPA experts, using the MAGO SOS client, can have a geographic contextualization of the data, with the support of additional tools useful to study the structures (ortophotos, maps,…). Processing tools trough WPS can be implemented in such a way that users work in a unique, user friendly environment, the MAGO SOS client extended with WPS functionalities.
The SOS also ensures dynamic operations, providing the match in time between the data storing and their availability within the client.
Moreover, the same technology is directly applicable to all the environmental matrix, a very important factor to manage the variety of data types necessary for the environmental monitoring of large structures.
As said, the prototype is a first experiment to verify if SOS can be the answer for efficiently managing so large number and so dishomegeneos pool of sensor observations collected and analysed by various domain experts. First results obtained seem to be promising; extensions to other case studies, comparisons with other SOS and WPS packages and performance tests will be done in the next months in order to complete our study.

8. AKNOWLEDGEMENTS

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