Sensing Real-time Observatories in Marine Sites
A Proof-of-Concept

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Abstract: Managing real time data collected by a network of heterogeneous sensors from marine sites needs to face challenges such heterogeneity, quality check, harmonization, description of sensors, etc. This is the purpose of the proof-of-concept described in this paper; it tests the suitability of OGC Sensor Web Enablement services, exploiting in particular the Sensor Observation Service (SOS) and the associated SensorML and O&M standards. Two Italian marine observatories have been included in the proof, both belonging to CNR ISMAR; they are the oceanographic Platform "Acqua Alta" and a weather station in Venice (Italy). They measure multiple real time parameters and distribute them by OGC SOS.
The multilayer architecture and the service approach adopted enable decoupling of components; in particular, the proof shows that each Institution hosting a sensor station is allowed to store observations and deliver them to multiple independent clients, in a standard, interoperable way, well recognized and accepted at European and global scale. The proof has been implemented and tested in three scenarios to retrieve and display descriptions of stations, sensors and measurements available; to retrieve and display observations of one parameter selected from multiple sensors; to retrieve observations of all parameters collected from sensors of a specific station.

1 INTRODUCTION

Miniaturization of electronics components, and decrease in prices of sensors and devices led to a shift from traditional monitoring to sensor/processing networks, in particular in environmental disciplines (Papp & Hakkesteegt 2008). Environmental Sensor Networks allow increasing the number of observations and measurements, in order to facilitate studying and understanding of complex theories or fundamental ecological processes.

In a review of 50 Sensor Networks, Hart & Martinez (2006) total integration of distributed, mobile, fixed, and asynchronous sensors from different networks. Integration is the first step to allow monitoring the environment at different scales, but the real ability of diverse systems to work together has been realized only in recent years (Barnaghia, Ganza, & Abangara, 2011; Havlik et al. 2011). Concepts like interoperability are fundamental in realizing a linkup among data using spatial (e.g. depth, geographical projection or location, relative position), temporal (e.g. time zone) and thematic (e.g. quality, domain, unit of measurement) attributes.

Some research frameworks, such as the LIFE+ Project EnvEurope (http://www.enveurope.eu) and the Italian flagship Project RITMARE (http://www.ritmare.it), underlined the necessity to exploit the interoperable access to observations from marine sensors, which is more and more necessary as symptoms of climate change have to be detected and monitoring of sudden anomalies is a priority for early warning systems. Following the approach of Hart & Martinez (2006), we would analyse the challenges of real-time sensing, in particular from marine Italian observatories. Issues to be faced are:

- *Heterogeneity of sites* - The Italian marine observational network is heterogeneous and offers excellence in the type of sensor used. Managing authorities are numerous and have different skills, resources and IT expertise. Network nodes technologies are not homogeneous in the collection, frequency and distribution of the measured parameters (e.g. different temporal and spatial resolution, units, identifiers).

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- *Quality check and harmonization* - Allow for a comparison between measurements coming from sensors in the network, quality check of data is a priority. Exclusion of outliers, comparisons among nearby stations, and trend analysis at different temporal granularity are operations that must be carried out at different levels of the data processing workflow; they would allow an effective and meaningful comparison. Another important action is the harmonization of collection and storing practices in order to improve the overall quality of the observations collected from the network.
- *Description and history of sensor* - Information on sensors in the network like their description, searching keywords, identification, classification, characterization of physical properties or electrical requirements, capability, contacts of manufacturer, owner or operator, input, output and components of the system, and especially history log to track any changes or calibration must be collected and made available in order to assess their quality, capacity, features and to compare the sensors in the network.

To study how to cope with the above issues a proof-of-concept has been created whose objective is to test how distributed, heterogeneous, asynchronous sensors connected to the Web are able to interoperate and to share observations and measurements to the purpose of studying marine ecosystem.

This paper describes the proof, in particular the demonstration sites that simulate the network and the approach adopted to face the problems of real-time observatories in Mediterranean marine sites from the user prospective, exploiting Service Oriented Architecture (SOA) approach, Sensor Web Enablement (SWE) technology based on Open Geospatial Consortium (OGC) standards.

The next section briefly describes the technological solution adopted; section 3 depicts the sites included in the proof. The architecture adopted is illustrated in section 4, while conclusions and lessons learned close the contribution.

2 SENSOR WEB ENABLEMENT AND OCG WEB SERVICES

In the domain of standards for the web, the Open Geospatial Consortium (OGC) is the organization that provides the main standardization of services for geospatial data. It is a non-profit organization founded in 1994; it consists of 440 companies, governmental agencies and partner universities and develops standards to address the lack of interoperability between systems that process geo-referenced data. Several geographic Web services have been developed by OGC for exchanging different type of geographic data; among them, the most popular are: Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS) for maps, features and coverages exchanging, respectively; Catalog Service of Metadata (CSW) for metadata catalogue management.

Table 1: Requests carried out in SOS service divided by type (modify by Bermudez et al. 2009). For more information about operation descriptions see Na & Priest, 2007.

Core Operations
GetCapabilities
DescribeSensor
GetObservation
Transactional Operations
RegisterSensor
InsertObservation
Enhanced Operations
GetObservationById
GetResult
GetFeatureOfInterest
GetFeatureOfInterstTime
DescribeFeatureType
DescribeObservationType
DescribeResultModel

To the purpose of sensor management a framework of standards have been proposed and supported by OGC under the common umbrella of Sensor Web Enablement (SWE) (Botts et al. 2013), which includes: SWE Common Data Model, Sensor Model Language (SensorML), Sensor Event Service (SES), Sensor Planning Service (SPS), Sensor Observation Service (SOS) for observations collected by sensors.

In this paper we focus on the SOS service (Na & Priest 2007) that has been adopted in the proof-of-concept. The objective of SOS is to specify interoperability interfaces and metadata encodings that enable the integration of heterogeneous sensors on the Web. SOS has been developed for discovering, binding and querying individual sensors or sensors platforms in real-time (RT), near real-time (NRT) or delay mode (DM) (Bermudez et al. 2009). With SOS, two more specifications work together: SensorML for describing characteristics and capability of the sensors and Observations and Measurements (O&M) for encoding observations and measurements. SOS specifies a standard Web service interface for requesting, filtering, and

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retrieving observations and sensor system information (see available requests categorized into core, transactional and enhanced in Table 1). This is the intermediary between a client and an observation repository or near real-time sensor channel. Clients can also access SOS to obtain metadata information that describes the associated sensors, platforms, procedures and other metadata associated with observations.

3 THE DEMONSTRATION SITES

The proof-of-concept was performed by exploiting two Italian marine observatories belonging to CNR ISMAR (Figure 1). Both are nodes of the European LTER (Long Term Ecological Research) network (http://www.lter-europe.net/) and are involved in EnvEurope (Figure 4).

They are the oceanographic Platform "Acqua Alta" and a weather station in Venice (Italy). The parameters measured and included in the proof are described in Table 2.

The Platform "Acqua Alta" is a tower located 15 km offshore in the Northern Adriatic Sea, on 16 meters depth (Figure 1 left). It is the only scientific structure in Italy, and one of the very few in Europe, that allows people on board for long periods for intensive campaigns in the middle of the sea. The capability of having a structure in the open sea, large enough to withstand the worst storms, but small enough not to interfere with the surrounding environment, allows highly accurate measurements also in heavily difficult conditions. The tower has three floors plus the terrace at 12 meters above the mean sea level. It is fully energetically self-sufficient, being powered by solar panels, wind generators and power generators. "Acqua Alta" is fully equipped with a very large set of instruments, devoted to meteorological, oceanographic and chemical parameters' collection. Measurements go back to the early '70s, so that some time series provide sufficient information to detect climate changes. The site is part of the European LTER (Long Term Ecological Research) network (http://www.lter-europe.net/).

Table 2: Parameters collected at "Acqua Alta" Oceanography Tower and weather station. The table specifies also depth/altitude above/below average sea level, frequency of sampling observation, and manufacturer of the sensors used.

	"Acqua Alta" Oceanographic Platform			**Weather station**		
Parameters	*Level*	*Frequency*	*Sensor Manufacturer and Model*	*Level*	*Frequency*	*Sensor Manufacturer and Model*
Air temperature	+18 m asl average	30''	Davis Vantage Pro2	+24 m asl average	30''	Davis Vantage Pro2
Humidity						
Wind speed						
Wind direction						
Irradiance						
UV						
Precipitation						
Wave height	0 m asl average	30'	Nortek Awac	-		
Wave period						
Wave direction						
Tide						
Current speed	-1,-2,-3,-4,-5,-6,-7,-8,-9,-10,-11,-12,-13,-14,-15 (m bsl average)					
Current direction						
Water temperature	-2,-6,-12,-16 (m bsl average)		CTD Seabird SBE37			
Oxygen concentration	-2,-12 (m bsl average)					
Salinity	-2,-6,-12 (m bsl average)					
Chlorophyll *a*	-12 m bsl average					

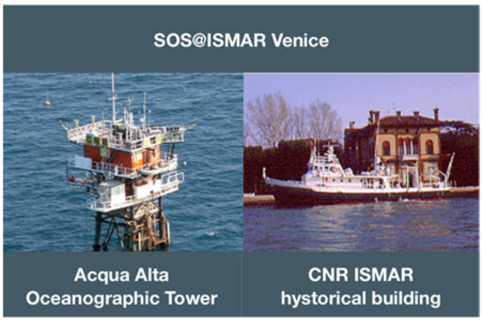

Figure 1: Images of the Platform "Acqua Alta" (left) and of the CNR ISMAR historical building hosting the weather station included in the proof (right).

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The weather station included in the proof hosts the meteorological station at +24 m and is located in the city centre of Venice nearby the historical building of the ISMAR Institute (Figure 1 right).

From the Platform, observations flow through a wireless link based on affordable radio equipment allowing the tower to be a permanent node of the Institute LAN. To this aim a wireless link on "free license" frequencies has been installed with two hops in order to overcome geographical barriers. The bandwidth is minimum 10 Mbps with QoS. In each segment two ALCOMA AL17FMP wireless devices are installed operating in "license free" 17GHz, with a power of 20dBm and reduced power requirements (25W).

4 THE PROOF-OF-CONCEPT

In the Environmental domain the need of designing Service Oriented Architectures (SOA) is a challenge to be won (Havlik et al. 2011). SOAs allow their services to be published, discovered, and finally invoked by clients in the network dynamically (Jiang et al. 2013). Many authors (Chen et al. 2009; Woolf 2008; Voigt et al. 2008; Di 2007) have demonstrated how distributed services can be coupled and interoperate, but in this moment only few examples seem to be really implemented.

In the architecture of the proof-of-concept proposed here both services and repositories are distributed, "… to ensure that spatial data are stored, made available and maintained at the most appropriate level …" (see Art. 6 - INSPIRE Directive 2007/2/EC). This aspect is very important in the marine context, where different institutions need to manage and keep the data collected from their equipment.

Table 3 describes the proposed architecture with the meaning of its five different layers and the components of the proof in each layer.

The observation flow among different components of the architecture is ruled by the standard SOS interface. Observations collected by sensors are stored in the repositories by the SOS InsertObservation() request. Also the dialogue between application layer and service/data layer occurs through different standard requests, e.g. GetObservations(), GetFeatureOf-Interest(), DescribeSensor().

The dialogue between the presentation and application layers takes advantage of the portal controller's mediation, to organize and dispatch the operations required by the proof's users. The portal controller's main purpose is to encapsulate a number of features so that they are transparent to the Presentation layer, such as unit of measurement and parameter harmonization, quality control (QC), cross-server querying or the auditing of server availabilities.

It is worth noticing that the Application layer can host different tools aimed at facing the quality check, harmonization and analysis issues cited in the Introduction. The proof allows to perform these actions on either all or selected observations delivered by their respective Web services.

Table 3: Meaning of the five layers of the architecture adopted and components of the proof.

Layers	Meaning	Content in the proof-of-concept
Sensor layer	*the layer of sensors, distributed in space and of different types, either mobile or fixed, collecting data in real-time or in delay-mode. It is different from the data layer as the sensors do not act as repositories of the observations but simply pick them up or store them temporarily*	In the proof this layer contains two distributed, fixed stations of sensors (see Table 2) connected with the Web and collecting Real Time data
Data layer	*the level contains the repositories of the observations gathered by the sensors*	In the proof-of-concept this layer consists of two separate and distributed databases, each of them storing data from the respective observatories sensors (PostgreSQL v9.2.and PostGIS v2.0 tool)
Service layer	*it consists of the Web services that enable the distribution of observations through the network; standard Web services allow to act in an interoperable way*	In the proof-of-concept the services adopted are a couple of OGC SOS (one for each station) with related SensorML and O&M specifications (52°North SOS v3.2.1 implementation)
Application layer	*this level hosts tools designed to process, transform, harmonize, analyse, etc. the observations coming from different Web services (e.g. elaboration, quality check, geographic transformation, unit of measure harmonization, etc.)*	In the proof it contains a tool to harmonize parameters' names and also a portal controller that dispatches the requests and allows to process the operations that are required by the presentation layer (JBoss Application Server v7, Tomcat v7)
Presentation layer	*this layer contains the clients to access and retrieve the observations and their elaborations; user interfaces are included here*	In the proof there is here the interface with the proof's user; it offers forms to perform selections and searching and exhibits observations in the most appropriate way to the user needs (OpenLayers v2.13.1)

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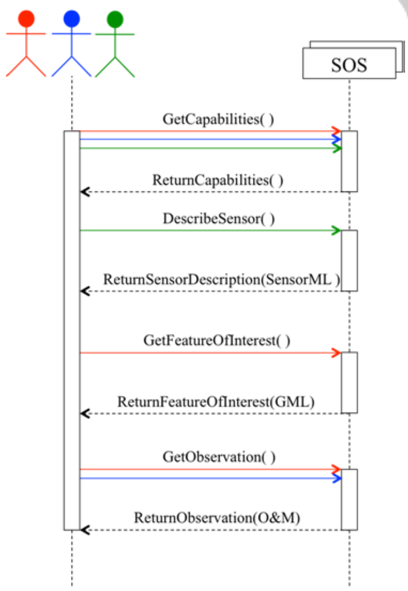

Figure 2: Unique Model Languages (UML) sequence diagram of SOS with main requests. In different colours preferential requests using by different proposed users (red, blue and green).

4.1 Use Cases

As already mentioned above, the Presentation layer of the proof contains a client in the form of a user interface.

This subsection is devoted to briefly describe the main requirements of the proof interface in terms of tasks and data, listing services coping with them and the solutions adopted in our experiment. The potential users of our application are different operators involved in marine monitoring. The main actions they would perform to assess sea-water quality through a network of heterogeneous, distributed stations of sensors can be summarized in the following three use cases:

a) to retrieve and display a description of the station, of the sensors available, and of the measurement processes (e.g. calibration, gain, accuracy, offset, etc.) which could include quality control procedure of all sensors of a station;
b) to retrieve and comparatively display observations of one selected parameter (e.g. air temperature, wind direction, wind speed, etc.) collected from multiple, distributed sensors;
c) to retrieve observations of all parameters collected from all sensors from a specific station.

The three sub-sections below describe, with real examples, how the three use cases are realised in the proof-of-concept.

4.1.1 Use Case A)

The user may want to know the features of the thermometer of the "Acqua Alta" Platform.

Actions are highlighted in green in Figure 2;

after a GetCapabilities() request in order to know if the related Web service provides data on air temperature, the proof system performs a DescribeSensor() request. This allows to display the SensorML description of the air temperature sensor with general description, keywords, identification, classification, characterization of physical properties, electrical requirements, capability, contacts of manufacturer, owner or operator, input, output and components of the system, and moreover its history log to track any changes or calibration.

4.1.2 Use Case B)

The user in this case may want to retrieve the air temperature in the whole North Adriatic Sea during August 2012, and to know also the geographic position of sensors. Actions are highlighted in red in Figure 2. The proof system performs a GetCapabilities() request, in order to know if the Web services available in the area provide data on air temperature and if observations cover the period requested by the user. In fact, the response to this request contains, among other, information about: parameters measured in each observatories, time period covered by different sensors, and geographic position. Both “Acqua Alta” tower and the weather station have thermometers for measuring air temperature (Table 2).
The second step is to get observations and display them both in a chart. The request GetObservation() with time period filtering can be used to get observations from both services.
For the user may be also important to display on a map the location of different air temperature sensors (thermometer). In this case the Enhanced Operations GetFeatureOfInterest() (Table 1) can be used to obtain the coordinates of both stations hosting the sensors collecting the observations (Figure 3).

4.1.3 Use Case C)

The user in this case may want to retrieve all data collected by all sensors in the “Acqua Alta” tower.
Actions are highlighted in blue in Figure 2. To this aim the proof system simply exploits GetCapabilities() and GetObservation() requests to list the parameters and the corresponding values, respectively. The SOS that serves observations from “Acqua Alta” tower can be queried independently and it lists all observed properties present in the response capabilities.

5 CONCLUSIONS

This paper has presented a proof-of-concept created to test the suitability of OGC SWE services as core of spatial data infrastructures for managing real time data collected by a network of heterogeneous marine sensors.

The architecture, components and implementation solutions proposed in the proof-of-concept revealed to be able to cope with all the requirements of a community of users wishing to retrieve and display observations coming from heterogeneous sensors on distributed stations, stored in distributed repositories connected to the Web and delivered via standard OGC Web services in the

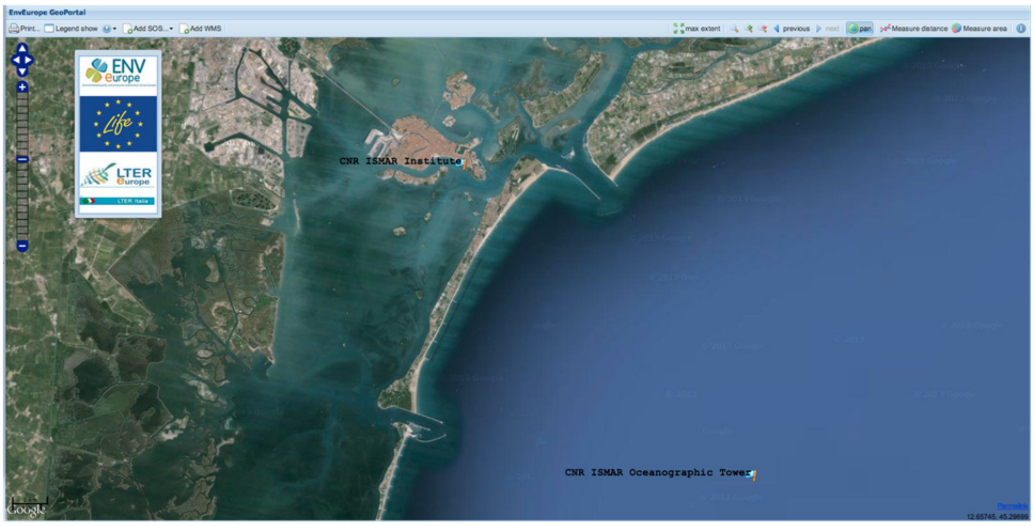

Figure 3: Presentation layer interface for displaying sensors’ positions.

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SWE framework.

The multilayer structure and the service approach enable decoupling of components; in particular, each Institution hosting and maintaining a sensor station is allowed to store observations and deliver them to multiple independent clients, in a standard, interoperable way, well recognized and accepted at European and global scale.

The success and reliability of the solution is proved by the number of SOS services, which is increased in the last few years (Tamayo et al. 2011). Using advanced search in Google engine (e.g. inurl:service=SOS inurl:request=GetCapabilities) 913 different SOS services are found, 456 of them referred to the aquatic environment. They and their observations are all potentially interoperable with the observations distributed by our proof-of-concept.

If we consider the challenges defined in the introduction, the proof-of-concept proposed is able to cope with technological heterogeneity of the sites and sensors since it is based on the use of OGC standards, able to describe sites and sensors characteristics but offering a uniform ways to communicate among the implementation components.

Quality check and harmonization are fostered by the multi-layered approach that allows to include components and tools aimed at those purposes at different level; by example a fast-track quality control can be performed before the storage of observations in the repositories, while a spatially-extended cross validation process can be included in the Application layer, where values from multiple sites are available.

Uniform metadata and a shared sensor/observation model are also a way to describe, search and compare quality.

But they are even more useful in facing the need to provide descriptions of sensors and their status, information necessary e.g. to maintain the network and to compare the sensors' performance.

Authors do not hide that the job to be done is great: in particular the technological development of the tools to implement SWE components (and in particular SOS) is still overwhelming for the community of marine researchers; the success of the approach is linked to the development and availability of easy to define, ready to use tools, enabling site managers to friendly create their own repositories and services. Cloud providers can also offer a solution to the security issues linked to service distribution in small institutions.

Another development is related to the syntactic and semantic harmonization, which requires intelligent applications that integrate the current technological solutions and standards with knowledge coming from the domain experts.

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