Sensor Observations Service for Environmentally Optimizing Irrigation: istSOS within the ENORASIS Example

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Abstract
This paper presents the experience and the lesson learned from the application of the Sensor Observation Service (SOS) standard as the main component for data fusion and distribution within the European project ENORASIS. The project aimed at developing a smart system to sustain optimal water usage in irrigation. This is mainly achieved by providing daily irrigation schedule to single farmers taking advantage of an advanced system that integrates optimization algorithms, weather forecasts, low cost sensors and soil information. The final phase of validating the ENORASIS system permitted to test the istSOS software, which implements the SOS standard, and to identify through data and service statistics the system stability, the user behavior and the service usage. istSOS has proven to be a stable solution offering useful features confirmed by usage statistics. The experiment showed also that the big data issue is one of the key challenges to be addressed by istSOS in the next future development.

1. Enorasis

ENORASIS (www.enorasis.eu) is an FP7-ENV Project which has developed an intelligent system to foster sustainable irrigation management among farmers. This objective is in agreement with the European Water Framework Directive along with the Cross Compliance Scheme of the Common Agricultural Policy that suggests the principle that the user pays. Such a kind of policy would probably lead to an increase of the water price and consequently to a reduction of the farmers' income. Therefore this policy may drive the farmer to the selection of the cultivated crop and the irrigation method and system, but may also drive the water managers to the selection of different pricing policies. The idea behind this project is to take advantage of scientific and technological advances in the diffusion of the Internet, the availability of low cost sensors and the advances in meteorological models. The combination of these components makes accessible the granular information on the status of the agricultural-field-system at the present in near-real-time and for the next days. Processing these data, the ENORASIS Integrated system (see Figure 1) provides key information such as soil and meteorological conditions together with optimal irrigation plans that minimize the water usage and maximize the yield production. On the other side, the system recording adopted irrigation methods and measuring water usage may sustain water manager authorities to define effective policies.

Users can access the ENORASIS system outputs thanks to a number of implemented user interfaces. The Web platform is the main interface that exposes all the system features and therefore can be used by all the intended users (e.g. farmers, watering authorities, consultants and administrators) to perform their daily tasks. Most of the functionalities offered by the Web platform are also provided by the mobile application developed for Android smart-phones. GSM mobile users can be notified with distilled information by means of SMS (Short Message Service).

2. Enorasis Technology

The ENORASIS system collects in-situ observations from monitoring stations and predictions from high resolution weather forecasting models. Together with land-zone specific characteristics they constitute the inputs for advanced algorithms providing optimal irrigation schedule for the next 72 hours. From a technical point of view the system implements a Service Oriented Architecture (SOA) (Rotem-Gal-Oz et al., 2012) where different types of services are meshed-up. Together with Web Mapping Services (WMS) (De la Beaujardiere, 2006) and Sensor Observation Services (SOS) a specifically developed RESTful-Web-API (Richardson and Ruby, 2007) is used to collect, store and dispatch basic information and processing results.

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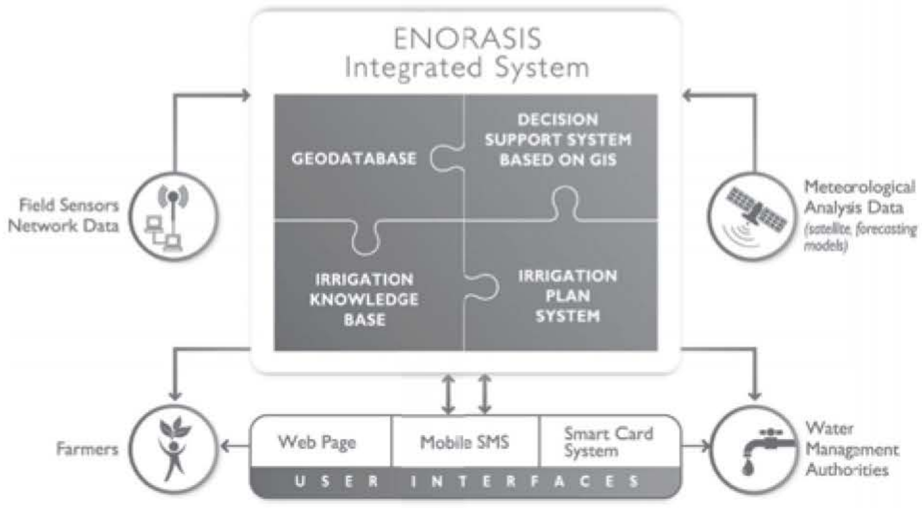

Figure 1: ENORASIS Integrated System components. Source: ENORASIS internal report

In the ENORASIS system architecture two different subsystems can be distinguished: the Land Management (LM) and the Remote Data (RD). The LM archives for each plot: the crop type, soil type and its characteristics (bulk density, saturation, capacity), the channel type and length, the irrigation method efficiency, the field size and slope, the day of year of sowing, the water price, the crop yield price, the yield without water stress, the operating costs of the irrigation system, the other costs of production minus subsidies, the minimal profitable amount of irrigation and finally the harvest day of the year. Theese data can be considered generally constant for the whole yield season. The dynamic part of the ENORASIS input data is delegated to the RD subsystem, which is responsible to manage data regarding the current status of the plots and their predicted conditions. Every day an ensemble of ad-hoc and high-resolution weather forecasts models (WRF) (Skamarock et al., 2001) provides, for each plot and for the following 72 hours, a series of distributed maps at 2 Km resolution of: precipitation probability and amount, wind speed, solar radiation, relative humidity and temperature. The weather models run with data from the Global Data Assimilation System (GDAS) (Rodell et al., 2004) at given times, which incorporates surface observations, balloon data, wind profiler data, aircraft reports, radar and satellite observations. In situ, low cost monitoring stations observe weather variables (temperature, solar radiation, absolute and relative humidity, insulation, wind speed, wind direction and precipitation), soil parameters (temperature and moisture), hydrometry (water availability, discharge, volume) and the status of irrigation valves (open - closed).

The generic Wireless Sensor Network (WSN) for in-situ monitoring of the ENORASIS system is composed by sensors and actuators. While sensors are responsible to measure and stream the data from the field to the system, actuators enable the opening or closure of the water valves of the irrigation system. The optimization algorithm maximize the net income taking into account the current soil conditions, the estimated future evapotranspiration and water availability from weather forecasts, the cost of water and the estimated yield production. Actual evapotranspiration is calculated according to FAO56 model (Allen et al., 1998) while crop yield is calculated using the multiplier crop water production function (Write and Jensen, 1978).

3. Sensor Observation Service and Enorasis

During the project execution the ENORASIS system was implemented and tested in 5 different case studies (see Figure 2) to cover several crop types, multiple geographical areas with different climate and different operational settings. The pilot implementations were deployed in Poland, Turkey, Cyprus and Serbia; installed sensors were assembled by different vendors using different hardware and different data formats. The WSNs structures deployed at the case studies were heterogeneous: they vary from a single station, to several stations connected with a single gateway in a single field to several fields managed by a single coordinator. This is the classical case where a data fusion process is mandatory in order to homogenize the data format used to ingest an analysis process. This situation is often found when there are needs of integrating monitoring networks managed by different organizations as discussed for example in Cannata et al., (2013).

Figure 2: ENORASIS pilot sites (map from © Google Maps)

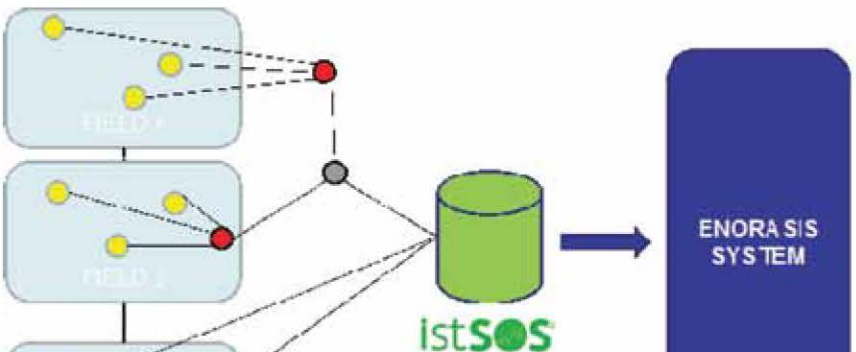

Figure 3: ENORASIS in-situ data management system architecture

In all these cases it is desired that the single sensors network (SN) adopts standardized data format and standardized services for data access. Unfortunately, today, the application of standards at the level of the single SN is rarely found, generally due to vendor market logics (proprietary software and/or data format) and/or to an already existing data management system. To achieve the standardization of the sensor data, the ENORASIS consortium decided to use the Sensor Observation Service (SOS) (Na et al., 2007) standard of the Open Geospatial Consortium (OGC). SOS defines a Web service interface and a data exchange model that mainly allows to register new sensors and data to a monitoring network management system and to access information like sensors characteristics and observations. In particular, observations can be retrieved applying spatio-temporal filters as well as observed properties definitions and sensor collections.

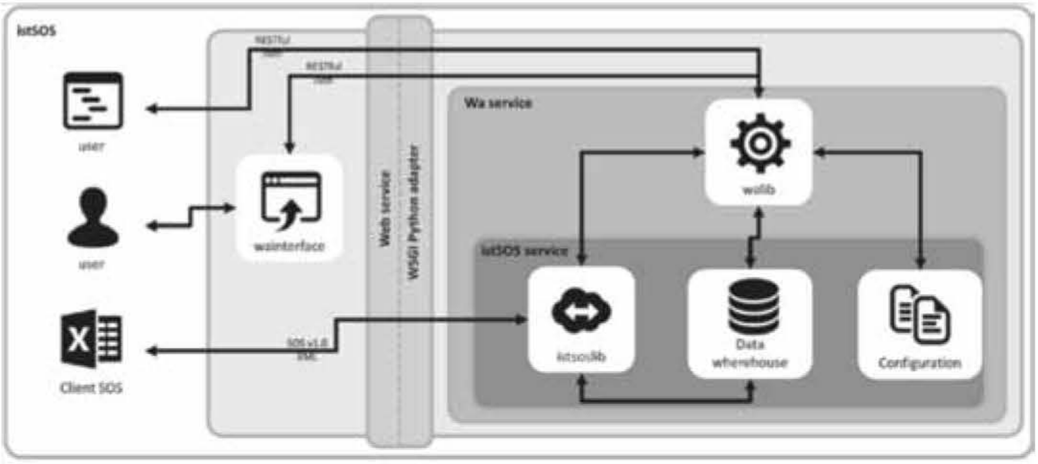

Figure 4: istSOS components

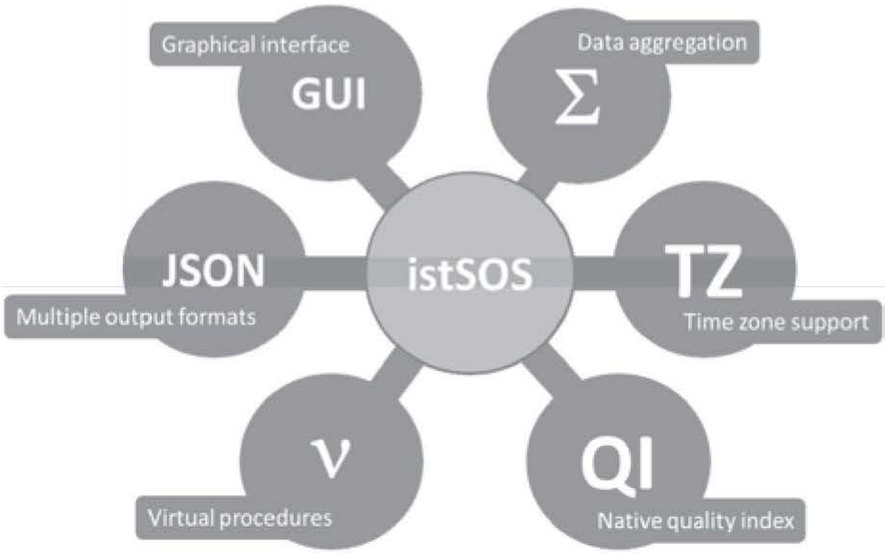

Figure 5: SOS extending features provided by istSOS

Retrieved data are in the format of Observations and Measurements (O&M) which is a general purpose standard schema (Cox, 2006) to represent along with the measured value (result) the related metadata: the feature of interest, the property that has been observed, the used sensor, the time of survey, result generation and validity period. The istSOS software (Cannata et al., 2010) has been adopted to implement the SOS in ENORASIS because of its specific features that make it, not only a "storage" for data, but a full data management system which supports the administration and processing of the data. Software details are described in the next chapter. As a result, as depicted in Figure 3, the implemented solution allows for easy integration of new plots almost independently from the used sensors and the adopted network solution.

4. istSOS

istSOS is a Python implementation of the SOS version 1.0 that encompass all the core and transactional requests as described in the standard documentation (Na et al., 2007). The software, distributed with an Open Source license (GPL v2), has been developed from the 2008 at the Institute of Earth Sciences at the University of Applied Sciences and Arts of Southern Switzerland (IST-SUPSI) to support the management of the hydro-meteorological network of the Canton Ticino. It is the result of a multidisciplinary team that includes geomatics, computer engineers, hydrologists and network managers and therefore took advantage of the multi-decennial experience of the IST-SUPSI personnel in monitoring systems and applications. For this reason istSOS was designed not only to implement the standard but also to ease the daily management tasks (according to best practices) and to fulfill the needs coming from applications. The Verbano Lake flooding early warning system (Cannata et al., 2013) is an example of istSOS usage to support the prediction of lake levels and the flood emergency response operations. Today, even though istSOS was used in several case studies (Munoz et al., 2015; Truong, 2013; Ambrosi et al. 2012; Brovelli et al., 2011) the Canton Ticino hydro-meteorological monitoring network is the most important use case where istSOS software is used in a production environment; at the time of writing, this deployment counts 151 sensors observing 16 observed properties from the 1990 and stores more then 46 millions of measures. From the software architecture point of view istSOS is composed of five components (see Figure 4): the istsos library, the database, the service configuration settings, the Web-administration library (*walib*) and the Web-administration interface (*wainterface*). The istSOS service that exposes the standard SOS requests relies on: the Apache Web server with the mod_wsgi python adapter, a PostgreSQL/PostGIS database, a configuration setting file and the istSOS library (*istsoslib*) which is implemented with a factory pattern capable to dynamically create the objects specifically required for resolving a given request type: this approach simplifies code maintenance and extension. Along with this core part of the software, istSOS distribution includes the additional *walib* library that is capable to expose, using a Representational State Transfer Application Programming Interface (RESTful-API) (Richardson and Ruby, 2007), also key features that are not offered by the SOS requests. The *wainterface*, which is also included in the software, is a Web based interface (HTML5, CSS3 and Javascript) that makes extensive use of the *walib* features and allows the service management through a friendly Graphical User Interface (GUI). Thanks to these components different user types can interact with istSOS: SOS clients using XML format, machine processes using the *walib* and the JSON format, and human users using the graphical interface. istSOS is easy to install and the service set-up is simple. In fact, thanks to the *wainterface* it is possible to interactively prepare the database and configure the service (service identification, service provider, proxy parameters, coordinate systems, etc.). Since a single istSOS installation can host several SOS services, the *wainterface* is also used to monitor the status of the services: a dedicated page lists the summary statistics of each service (number of registered sensors, number of observed properties, number of feature of interests) together with the status of the service, of the database and of the supported SOS requests. istSOS implements a series of specific features that extend the SOS standard. The most interesting are represented in Figure 5 and briefly described in the next paragraphs. One important feature is the support of multiple result formats. In fact, istSOS offers along with the standard O&M also the JSON and text formats. While the JSON format reflects exactly the XML elements found in the O&M without loss of information, the text format is a mere Comma Separated Value (CSV) listing for the time of observation, the sensor name and the observed measured values. Other interesting features of istSOS are the capability to provide aggregated observations, to natively manage the data quality, to support time-zones and to create virtual procedures: features extending the SOS standard capabilities. istSOS allows to retrieve on-the-fly aggregated observations if two extra-parameters are provided: the aggregation interval (*aggregateInterval*, expressed as ISO 8601 time duration, (ISO-8601, 2004)) and the aggregation function (*aggregateFunction*, currently one of average, sum, maximum, minimum). The quality of data is natively supported in istSOS by an automatic assignment of a quality index (QI) to each measured value recorded in the system. This quality index is used to assign for each value the successful testing of one or more data quality-check algorithms or rules. For example the user can discriminate among data that are numerically correct (QI=100), that are acceptable (not gross errors) for a given observed property (QI=110), that are statistically resonable for a given station observing a given property (QI=200), that are temporally coherent with the observed phenomenon (QI=300) and that are in agreement with nearby stations observing the same property (QI=400). istSOS supports the first three levels of checks above described by performing tests in real-time during the insertion of observations (provided that specific values are configured). The combination of these two features, in the frame of the ENORASIS project, permitted to extract regular time series, from raw data that were acquired at irregular instants, with the indication of the quality of the data: this has been extensively used to extract historical average, max, min, sum daily time series for the validation of meteorological models. Time zone support was also a key feature in the project execution. In fact, the case studies and the partners were located in different areas with different time zones. Each of them wanted to work in their own time-zone for an easier understanding and analysis of the data, but at the same time compare and fuse data from other stations (e.g.: the modelers access all the data in the same time zone).

Table 1: ENORASIS SOS service requests statistics during the validation phase

library	request	average daily requests	average daily requests [%]
istsoslib	GetCapabilities	0.04	0.0003
istsoslib	RegisterSensor	0.00	0.0000
istsoslib	InsertObservation	0.00	0.0000
istsoslib	DescribeSensor	0.04	0.0003
istsoslib	GetObservation	8,423	55.6200
walib	RegisterSensor	0.15	0.0010
walib	InsertObservation	2,238	15.7800
walib	*others*	*4,271*	*28.6000*

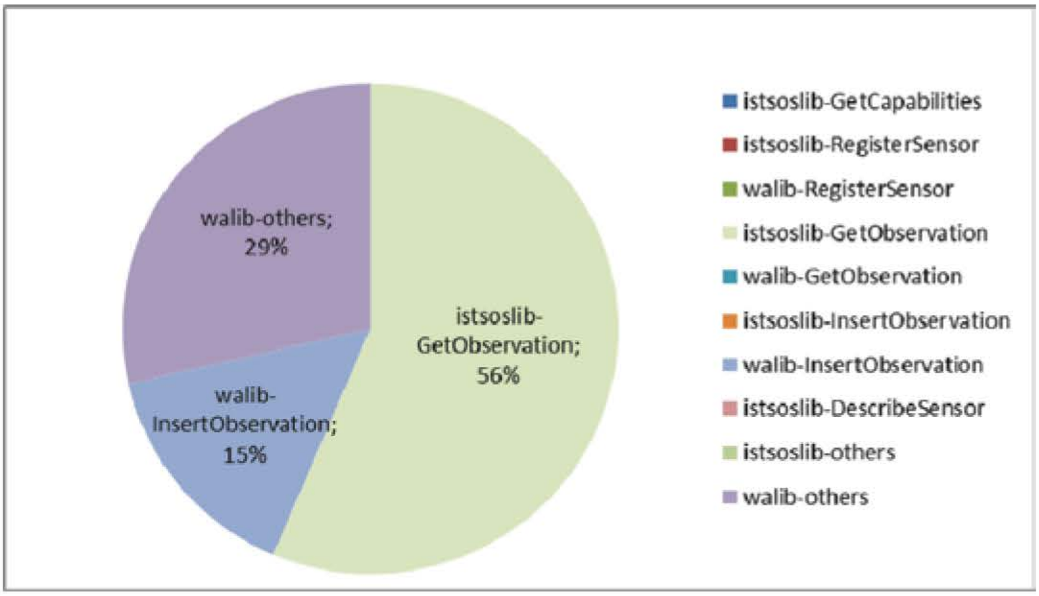

Figure 6: ENORASIS: istSOS average daily requests distribution

The providing of virtual procedures, even though less used in the project, is a very interesting specific feature of istSOS. This capability allows the instantiation of a procedure which is based on the real-time elaboration of other data registered in the current SOS instance. During the project execution a virtual sensor which "observes" the potential evapotranspiration (ETP) using the data from a weather station has been implemented. This virtual procedure elaborates the observations of hourly air temperature, relative air humidity, wind speed and incoming solar radiation by applying the well-known Penman-Monteith (Allen et al., 1998) equations and directly provides the ETP to the user. The advantage of this approach is that no derived measures are stored and no user elaboration is needed.

5. SOS Service: Data and Statistics

As described in the previous sections the istSOS software has been selected to deploy a SOS service for the ENORASIS system as a single access point to the sensor data coming from the WSNs deployed in the ENORASIS's fields. For this reason one istSOS instance (ENORASIS SOS service) was created during the "ENORASIS platform development" working package, which ran for 29 months (almost the entire project duration) and was focused on the design and development of the ENORSIS system based on an open-architecture, interoperable and expandable environment as described in the ENORASIS technology section. The choice of having a single istSOS instance satisfies the need of simple data gathering with filters on all the observations. In fact, to fulfill this need having multiple istSOS instances would require either an a priori knowledge of the data stored in each instance or the execution of redundant requests to all the instances. Having a single instance allows for example to extract all the observations of soil humidity within the polish boundaries for the last week with a single request.

The ENORASIS SOS service was hosted in Switzerland at one of the project's partner institutions (IST-SUPSI) so that istSOS developers could promptly operate and manage the service. Access privileges were provided to all the project's partners that were responsible for registering the sensors, setting the observed properties and ingesting the system with the data measured in the field by low cost stations located at the pilot plots. They had access to the entire istSOS components and, after one day training and with the support of the istSOS documentation, they autonomously selected the preferred methods of interacting with the system: the istSOS graphical user interface (*wainterface*), the SOS service (*istsoslib*) or the RESTful-API (*walib*). During the entire period of the project, 53 procedures were registered and 1,372,046 measurements were observed from February 2012 to June 2015. Twelve observed properties were registered: soil moisture, battery charge level, irrigation water availability, irrigation water discharge, relative air humidity, insulation, precipitation, air temperature, wind direction, wind speed, direct solar radiation, and irrigation valves status. The time resolution of the data was one hour. The "pilot implementation and further improvements" working package (WP6) lasted 16 months and encompassed the set-up (4 months), the running (10 months) and the assessment (2 months) of the ENORASIS system in real life conditions. For this purpose different WNS was deployed at the different pilots so as to cover several crops types, multiple geographical areas of different climate characteristics, and different operational settings. During the running phase of the pilots in WP6, according to the istSOS and Apache logs, the service accumulated 5.6 GB of bandwidth consumption, registered 1,596 unique visitors, executed 4,954,540 requests with 0.03% of errors associated with about 2.15 hours of registered downtime and only 0.0002% of service response failure. Requests were equally distributed during the hours and the days. The service registered 50.71% of hits from France, 33.74% from Serbia, 4.40% from Poland, 9.90% from Turkey, 0.03% from Cyprus, 0.03% from Romania and the 1.19% from other countries, including unknown locations. In the same period the service registered an average of 15,143 requests per day, subdivided as shown in Table 1 and Figure 6.

6. Discussion and Conclusions

The istSOS service used during the execution of the ENORASIS project was certainly successful and mainly contributed to accomplish the data fusion needs of such kind of heterogeneous data source with sampling locations spatially distributed. From the geo-location of service hits, it is clearly visible that the weather forecasts located in France absorbed half of the usage. The sensor providers, which administered the network gateways and coordinators, used most of the other half (Serbia, Turkey, Poland). The remaining usage can be associated to farmers and stakeholders data access. The software stability was proven by the low rate of service errors and downtime. The service usage-statistics underlines that users mostly rely on the data gathering request as indicated with the SOS standard. The usage of the other requests as defined by the standard is negligible. walib, which is the RESTFul interface, registered a quite important volume of transactions and it was mostly used for inserting new observations into the system. This is due to the fact that data providers took advantage of the istSOS utility which allows to schedule the insertion of data from ASCII files to istSOS through the *walib*. Nevertheless, the important volume of other walib requests registered is a clear indication that the *wainterface* has been extensively used and preferred to the XML interface offered by SOS standard. Looking at the possible development of a platform like ENORASIS, aiming at supporting single farmer at optimizing irrigation, we could easily expect millions of users if successfully marketed. As a consequence, istSOS shall be able to manage millions of sensors and billions of data: this raises the need of supporting service scalability and big data distribution. This case study has clearly indicated the road for future developments that shall be focused on optimizing data retrieval and data insertion.

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