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SESAMO: An Integrated Framework for Gathering, Managing and Sharing Environmental Data

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Abstract: *ICT systems are widely adopted for environmental management, but existing solutions address limited tasks and compose a plethora of heterogeneous tools, which impose a great additional effort on the operators. This work presents SESAMO, a novel framework to provide the operators with a unique tool for gathering, managing and merging environmental and territorial data. SESAMO uses WSNs for providing pervasive monitoring of environmental phenomena and exploits a multi-tier infrastructure in order to integrate data coming from heterogeneous information sources.*

Key words: *Computer Systems and Technologies, Environmental Management, Pervasive Sensing.*

INTRODUCTION

Nowadays, ICT systems are widely adopted in the field of environmental management, where they are used for supporting many activities, such as environmental data gathering, information management and decision-making. Nevertheless, such systems are devoted to specific and limited tasks and constitute a non-integrated set of heterogeneous tools, which requires operators to take on a relevant additional effort. Moreover, the effectiveness of management procedures relies on the specific knowledge of territorial phenomena held by the operators, and, as a consequence, a uniform quality of services cannot be guaranteed. Thus, the necessity of semi-automatic tools for supporting environment management tasks, with predictable performances, arises.

One of the most relevant obstacles to reach such goal is the lack of a Spatial Data Infrastructure (SDI) for managing geospatial data coming from heterogeneous sources in order to enable their understanding by different stakeholders [18] and the execution of semi-automatic procedure for extracting high-level knowledge [21]. However, the implementation of a SDI does not automatically simplify environment management procedures, even if it represents a fundamental step toward their full automation.

A further issue is to produce the flows of environment data by monitoring the phenomena of interest. Often, such phenomena cover a wide portion of territory and monitoring them requires the development of a pervasive sensory infrastructure that enables a simple access to data. One of the technological paradigms that allows to address such issue is the Internet of Things (IoT) [4] which aims to develop a pervasive communication network composed by many physical objects, even used by people in their daily life. Devices composing the IoT are generally capable of communicating each other and of perceiving some physical quantities through a set of sensors. Wireless sensor networks (WSNs) [5] are one of the enabling technologies of the IoT. The devices constituting such networks take on an active role, by exploiting their capability of performing few computations on board. Moreover, thanks to their reduced dimension, limited cost, and energetic autonomy, WSNs allow to provide a widespread monitoring of the phenomena of interest.

This work presents SESAMO, a novel framework for gathering, managing and merging environmental and territorial data. SESAMO sensory infrastructure is based on

WSNs for pervasive monitoring environmental phenomena, as in [1] and [2], and aims to integrate data coming from heterogeneous information sources through a multi-tier architecture. SESAMO is based on a Service-Oriented Architecture (SOA) [24] for providing high-level services for data management in order to support the decisions of specialized operators.

One of the main issues addressed by SESAMO is to provide a solution for the heterogeneity that characterizes the environment management domain, regarding both gathered information and sensory devices. In order to deal with such heterogeneity, SESAMO adopts opportune formalisms for the high-level representation of data, based on the standards defined by the Open Geospatial Consortium (OGC), and in particular promotes the definition of a common interface for different devices, on the basis of the Sensor Web Enablement (SWE) approach [6].

SESAMO allows to enrich the knowledge about the territorial and environmental phenomena, through the use of pervasive sensors, also providing high-level functionalities such as sharing data among different actors, merging data coming from heterogenous sources, and supporting decision-making processes.

RELATED WORK

Many works in the ICT literature aim to provide solutions for decoupling sensors and applications, in order to deal with heterogeneity and support interoperability, as detailed described in [27].

MapServer [26] is a popular Open Source project whose purpose is to display dynamic spatial maps over the Internet. It is supported by the Open Source Geospatial Foundation (OSGeo) and it supports many standards defined by OGC, included Web Map Service (WMS), for requesting georeferenced map as images, Web Feature Service (WFS), for describing data manipulation operations of geographic features and requesting vector data, and Web Coverage Service (WCS), for requesting geospatial information representing space/time-varying phenomena and requesting raster data, Geography Markup Language (GML) and Observations and Measurements (O&M) as XML-based conceptual models. Thanks to the abstraction interface, MapServer provides users with a common web interface for accessing many geographic data source types, e.g., ESRI Shapfiles, PostGIS, Oracle Spatial, and MySQL data. The adoption of a web-based approach allows to use MapServer through a simple web browser. MapServer supports the GIS-based visualization of stored data, and provides operators with a configuration tool for defining cartography's properties, such as layer definition, colors and symbols, thus enabling a simple customization of the web interface.

GeoServer [15] [23] is a java-based open source server for sharing geospatial data, supported by OSGeo. In order to support interoperability, it publishes data according to several open standards for spatial data, such as PostGIS, Oracle Spatial, DB2, MySQL, Shapefiles and many others. GeoServer is the reference implementation of the OGC WFS standard and implements several other OGC standards, such as WCS, WMS and Web Processing Service (WPS), standardizing inputs and outputs of geospatial processing services. It allows users to interact with generated maps, through the OpenLayers library, and to publish geospatial data to Google Earth. Thanks to the Spring-based implementation, GeoServer is characterized by a modular, extensible and configurable architecture.

Also Deegree [16] is an open source software for managing geo-spatial data, complying with OGC standards. The Deegree project has been designed in 2002 at the University of Bonn in Germany, and with respect to other projects already presented in the literature, it also provides metadata services for the creation, storage, query, retrieval and display of metadata. Deegree supports the construction of georeferenced maps, through map tiles, several small image files individually requested, by means of the Web Map Tile Service (WMTS). It exploits Catalogue Service for the Web (CSW) to make geospatial records available through HTTP requests.

The 52°North Web Processing Service [22] enables the development of standardized processes on georeferenced data. It is a java-based framework for composing spatial processes as plugins, through an OGC WPS interface [25]. 52°North focuses on implementation of functionalities compliant with standards for enabling the research of sensory information through the web, such as Sensor Observation Service (SOS), defining a Web service interface for querying observations, sensor metadata, and representations of observed features, Sensor Alert Service (SAS) and Sensor Event Service (SES), for providing a publish/subscribe-based access to sensory data and measurements, Sensor Planning Service (SPS), for requiring information about sensor capabilities and integrating new sensors into the system, and Web Notification Service (WNS), for managing asynchronous notifications for sensory events.

Several European Projects aim at designing software architectures for simplifying the access to sensory data and supporting data management services, such as Orchestra [3] and SANY [19]. Orchestra (Open Architecture and Spatial Data Infrastructure for Risk Management) proposes a Service-Oriented Architecture for managing environmental data in the context of risk management. The SOA approach aims to improve interoperability between procedures managed by different authorities. Orchestra supports many OGC standards; moreover the reference model for the ORCHESTRA architecture is an extension of the OGC Reference Model and represents an OGC Best Practice. With respect to other existing solutions, Orchestra introduces the use of ontologies for supporting semantic interoperability both for data and services. While Orchestra focuses on services and applications, SANY (Sensors ANYwhere) focuses mainly on sensors, by aiming at the interoperability of in-situ sensors and sensor networks. SANY exploits several open standards defined by W3C (World Wide Web Consortium), OASIS (Advancing open standards for the information society), ISO (International Organization for Standardization) and OGC. In particular SANY uses the OCG SWE initiative that enables the access to sensors, instruments, and imaging devices via the Web.

Such brief literature review shows the paramount importance of adopting standards for modeling data, providing services and enabling the access to sensory information even in complex systems still guaranteeing interoperability. Such lesson has been learned also in other applications characterized by the exploitation of pervasive sensory infrastructures, such as the work proposed in [11], [12], where an Ambient Intelligence system exploits a sensory layer based on WSN represented according the specifications provided by the OpenGIS sensor model language [7], the work described in [20] proposing the adoption of OGC Sensor Web Enablement for risk monitoring and disaster management, and the work in [8] proposing the adoption of the Sensor Web Enablement Architecture for developing a Video Surveillance System.

SESAMO ARCHITECTURE

SESAMO is an integrated ICT solution for gathering, managing and sharing environmental data, in order to support the development of Decision Support Systems (DSSs). SESAMO has been designed according to the following guidelines, defined by the OGC and adopted by the SANY and ORCHESTRA projects:

- *Standard Compliance*: to make SESAMO an open system and avoid dependencies from proprietary solutions;
- *Decoupling of information sources and applications*: to guarantee the independence of applications from information sources, and to promote the autonomous development of components by different stakeholders;

- *Modularity*: to enable the development of new applications through the simple composition of available components;
- *Generality and Flexibility*: The core of SESAMO has been designed to manage data and information independently from the specific application scenario; the customization for new scenarios requires only the definition of new application services or new sensory components.

The SESAMO architecture is designed according to a three-tier model, as shown in Fig. 1.

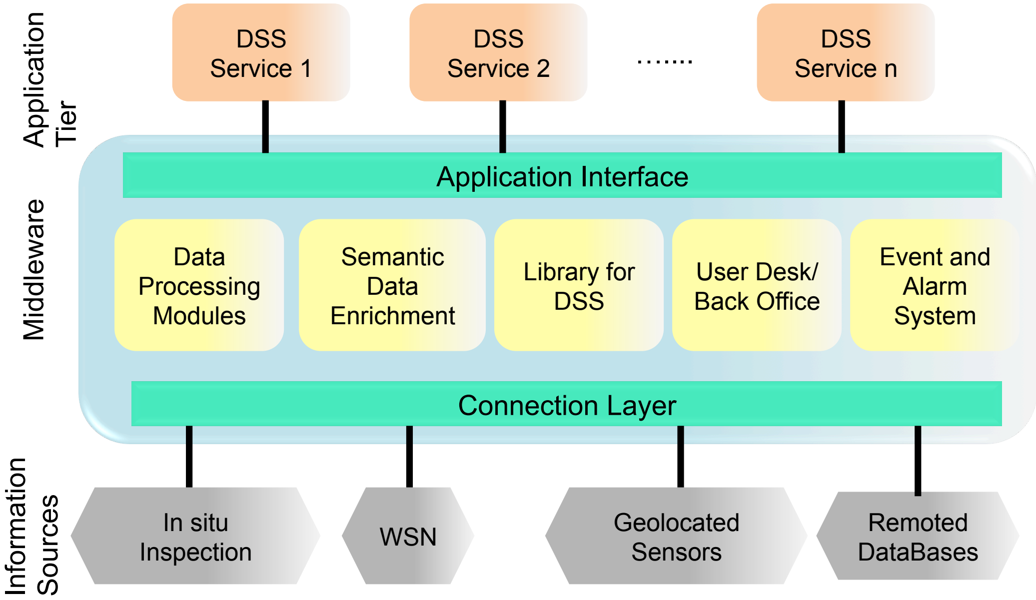

Fig. 1: The three-tier architecture of SESAMO

The lowest tier is composed by the heterogeneous set of information sources, and includes wireless sensor networks, geolocated sensors, mobile terminals used by operators during *in-situ* inspections, and remote databases. Such information sources may be managed by different stakeholders, support different communication protocols and provide data in different formats. A *Connection Layer* is responsible for managing such heterogeneity, by coping with communication issues and parsing gathered information in a SESAMO-compliant format. It enables the *Middleware*, built on top of it, to uniformly manage information coming from different types of sources, disregarding low-level details. The Middleware has a modular structure and provides both management functionalities independent from a specific application scenario, and application-dependent ones. It provides to the *Application Tier* a library of components useful for developing DSS services, which strictly depend on the specific applications. The Middleware represents the core of SESAMO, it gathers raw information from the heterogeneous set of information sources and provides of high-level functionalities for developing DSS applications. In the following, its constituting modules are described.

Connection Layer

The Connection Layer is responsible for providing a uniform point of access to heterogeneous information sources. Its functionalities enable the easy integration of gathered data with the Spatial Data Infrastructure (SDI) implemented by SESAMO; among them the most relevant are the following:

- *Search sensors and data*: to obtain a detailed view of information sources and data that meet filter criteria, such as the geographic area and the observed physical phenomenon; the search functionalities may be *sensor-centric* or *observation-centric*;

- *Request sensor features*: to obtain metadata associated to a specific device, such as observed physical phenomena, units of measurement, battery level, and geographic coordinates;
- *Evaluate measurement reliability*: to evaluate the reliability of a set of measurements, with respect to the expected sampling rate, or by evaluating the coherence with data gathered by near sensors;
- *Manage devices and simulators*: to monitor and modify functioning parameters of available information sources, e.g. the sampling rate of WSN's sensor nodes. Such functionalities strictly depend from the sensor devices connected to SESAMO.

The Connection Layer adopts the SOS standard for providing its services, according to a publish/find/bind paradigm. According to such paradigm, a generic *data consumer* accesses data by following the steps described in Fig. 2.

The service discovery step allows to explore the available services for accessing data, listed by cataloguing the information sources. The observation discovery step allows to identify the set of observations produced by a specific services. The third optional step allows to obtain the metadata associated with sensors, according to the SensorML standard. Such metadata may be enriched by human operators through the *Semantic Data Enrichment* module which modifies the service catalogue maintained by the Connection Layer. Finally, the *Get Observations* step allows to obtain the pre-filtered set of data selected by the data consumer.

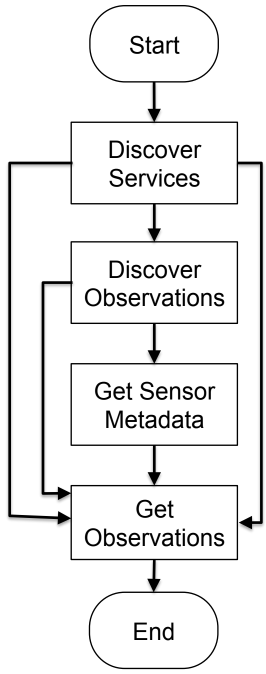

Fig. 2: Flow chart of steps for accessing observations.

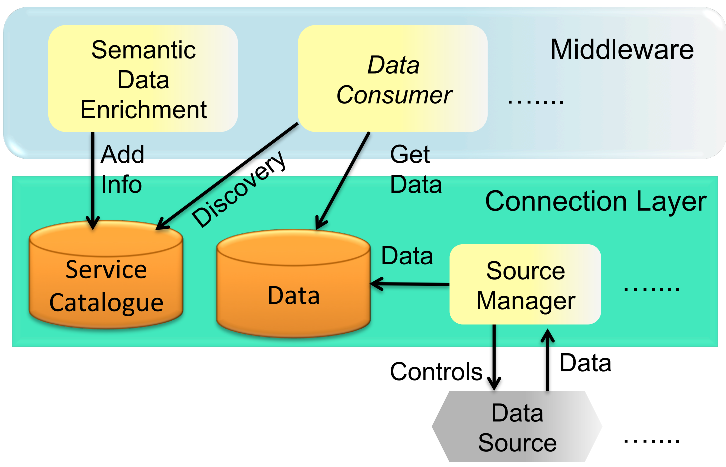

Fig. 3: Connection layer components according the publish/find/bind paradigm.

The interactions among Connection Layer modules and other SESAMO components are shown in **Fig. 3**.

Event and Alarm System

The Event and Alarm System allows users and other modules to be notified when a given event occurs, through different communication methods, i.e., SMS, MMS and e-mail. It adopts a subscription/publishing model, and it is consequently composed by three types of components, i.e., a *broker*, a *notification system* and a set of *producers*, whose interactions are shown in **Fig. 4**. The broker is an intermediary between *consumers* and producers of events. It allows consumers to subscribe to a notification service and is responsible for managing the mapping from producers to consumers, when a new event occurs. A producer is a software component, activated by the broker according to consumer's requests, which is responsible for monitoring the event occurrence and to inform the broker. The notification system sends the notifications following the method selected by consumers.

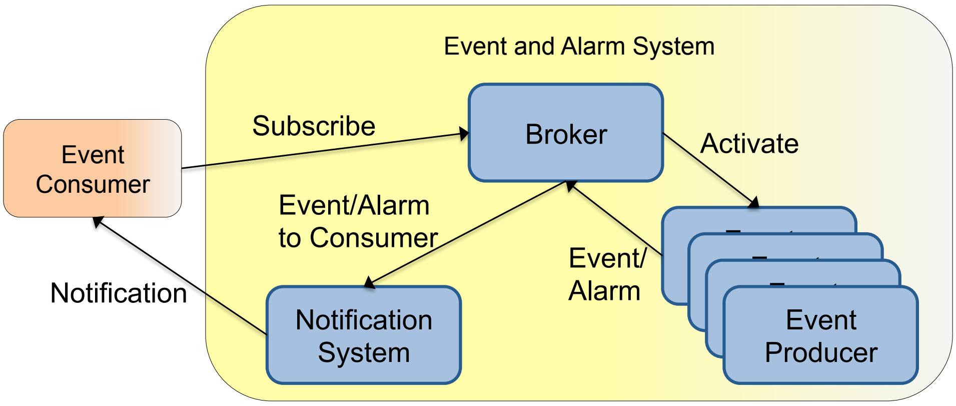

Fig. 4: Block diagram of the Event and Alarm System

User Desk and Back Office

This module provides functionalities for users' registration, services' purchasing, billing (*User desk*), and for managing users account and service configuration (*Back Office*). It has been designed to be compliant with security requirements such as, authentication, privacy, and authorized resource access.

Data Processing Module

This module provides functionalities for processing data and information, in order to extract high-level information, which can be provided to DSS services. SESAMO provides several basic functionalities that can be combined in order to obtain complex functionalities, such as merging sensory data flows with different temporal and spatial resolution, averaging sensory measurements obtained by devices in a given geographic area, and feature extraction from images.

DSS Services

In order to evaluate the performances and potentialities of SESAMO, three different DSS were developed, for three critical scenarios in the environmental management domain: early warning for hydrological risk, assisted agriculture, and detection of leaks in urban water distribution networks.

The early-warning domain allowed to evaluate the SESAMO's capability to handle programmable sensors; in particular, such feature has been exploited to change the sampling rate, via opportune control messages, in order to tune sensors' behavior with respect to different levels of geological risk, thus obtaining a higher sampling rate during dangerous periods and adopting an energy-saving mode in safe periods.

The DSS developed for the detection of water leaks allowed to verify the possible integration with non traditional sensors characterized by the necessity of a complex communication infrastructure, due to the presence of underground sensors.

The assisted irrigation domain allowed to evaluate the ease of performing multi-sensor information fusion by exploiting images obtained by drones with georeferenced information gathered by sensors installed in the field.

CONCLUSIONS AND FUTURE WORK

This paper describes SESAMO, a novel integrated framework for gathering, managing and merging environmental and territorial data. Based on open standard for managing sensory data and for providing services, SESAMO is capable of integrating data coming from heterogeneous information sources, in order to provide high-level information to decision support systems. This feature has been proved thanks to the adoption of SESAMO in three critical environmental management domains. As future work, we plan to adopt SESAMO in other application scenarios, such as in Ambient Intelligence systems [13], [14], [9], [17] and in systems for monitoring user mobility in an urban domain [10].

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