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A cloud-based system to protect against industrial multi-risk events

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Abstract

Industrial areas frequently present a high concentration of production operations which are source of anthropic risks. For this reason Smart Public Safety is receiving an increasing attention from industry, research and authorities. Moreover, due the consequences of global warming, these areas could be subject to risk events with increased probability with respect to the past. Information technologies enable an innovative approach towards safety management, which relies on the evolution of tools for environmental monitoring and citizens' interaction. This work presents the preliminary results of the Italian research project SIGMA - sensor Integrated System in cloud environment for the Advanced Multi-risk Management. The proposed system includes a continuous monitoring of the different information sources, thus reducing human control as much as possible. At the same time, the communication system manages multiple data flows in a flexible way, adapting itself to different working scenarios, enabling smarter applications. SIGMA intends to acquire, integrate and compute heterogeneous data, coming from various sensor networks in order to provide useful insights for the monitoring, forecasting and management of risk situations through services provided to citizens and businesses, both public and private. Based on the integration of different interoperating components, the system is able to provide a complete emergency management framework through simulations/optimizations and heterogeneous data manipulation tools. The prototype solution is detailed by a use case application in an industrial area located in the region of Sicily, Italy. In particular, web based modular applications connected through SIGMA allow the monitoring of the industrial environment through data gathering from different sensor networks, such as outdoor sensors mounted in the surroundings of large industrial areas, and support of the design of the logistics network aimed at covering the industrial risks.

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1. Introduction

Economic losses of natural disaster continuously hit new records. In 2011 they has been estimated in 380 USD billions [1]. Natural and anthropic disasters are often strictly connected in a multi-risk environment. During the last decade, several catastrophic events forced to bring the attention to a new approach for the mitigation and management of risks. A new approach should be holistic and supported by new models and methods from one side and from new hardware and software infrastructures from the other. The 2012 OECD [1] report on natural hazard risks underlined the strong demand for data mining, data harmonization and data standards, the importance to improve or create access to existing data and the consideration that effective multi-risk/multi-hazard assessment models are still in their infancy with their ability to consider cascading/domino effects. For this reason Smart Public Safety is receiving an increasing attention from industry, research and authorities which started several public/private actions in order to propose innovative approaches to the multi-risk mitigation and management panorama. This work presents in particular the actions of an Italian research project aimed at effective use of cloud based platforms for the provisioning of high ended services for multi-risk management and mitigation. Information technologies enable an innovative approach towards safety management, which relies on the evolution of tools for environmental monitoring and citizens' interaction. The article presents the preliminary results of the Italian

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research project SIGMA - sensor Integrated System in cloud environment for the Advanced Multi-risk Management. The proposed system includes a continuous monitoring of the different information sources, thus reducing human control as much as possible and providing a framework which can be used to facilitate the assembly of applications for risk management and mitigation to be used by public authorities, companies, and private citizens. The rest of the paper is organized as follows. Section 2 overviews scientific literature on risk management platforms. Section 3 describes the SIGMA framework. Section 4 details the aspects of the cloud based infrastructure. Section 5 shows an application of the SIGMA framework to planning problems, while section 6 reports concluding remarks.

2. Literature review

One of the most important tasks in risk mitigation is the building of early warning and hazard monitoring systems. There is a long tradition in early warning systems [2,3] demonstrating from one side their effectiveness and from the other side their high implementation costs. Existing hazard warning systems are in fact expensive, site-specific and require elaborate administration procedures [4]. Moreover a lack in connecting these systems to decision support systems for risk management can be noticed. In recent years several approaches has been proposed to build a new generation of hazard mitigation systems by using the latest internet based technologies with the aim to build more general, modular and cost effective solutions. Following this direction Ghosh et. al [4] propose a generalized geo-hazard warning system based on standard communication technologies. In particular they make use of an open-source development environment in order to integrate a hazard evaluation system with a warning communication framework by means of standard messaging systems. Xuan et al. [5] propose a logical architecture for early warning management of disaster based on logic modules. The authors individuate 7 modules ranging from the model bank and the monitoring, to the disaster management & evaluation and the decision making & commanding. These modules are supported by geo-localized social, economic and financial data. Details on the implementation of early warning systems are given in [6]. Warning and hazard management systems require architectures able to guarantee rapid access to global and heterogeneous data, and systems to automatically detect alerts. The authors underline the importance that early warning systems should link several and different hazard-based systems. Several international initiative and projects are trying to systematize the support methods to risk evaluation, management and mitigation. One of the most important initiative for risk evaluation modelling is proposed in the CAPRA project [7]. CAPRA is focalized on earthquake related risks and the novelty of its approach is related to its modular composition: different modules are dedicated to hazard, exposure, and vulnerability estimation, while other modules are used as decision support to land use planning, emergency response, cost-benefit analysis for prevention/mitigation. A totally different approach is represented by initiatives based on internet collaboration aimed at gathering mining and broadcasting of disaster related information. Among these initiatives we cite GDACS (www.gdacs.org) which is a cooperation framework between the United Nations, the European Commission and disaster managers worldwide to improve alerts, information exchange and coordination in the first phase after major sudden-onset disasters. It is also notable the google initiative named Crisis Response (https://www.google.org/crisisresponse/) and aimed at supporting the rescue activities by providing a easy to use platform for gathering and broadcasting of alerts. From the modeling side, multi hazard systematic study and management is not an easy task because, as pointed out in [8], multi-hazard risk analyses are not just the sum of single hazard risk examinations. The characterization of each risk is different; hazards are related and influence each other; methods to describe vulnerability vary between hazards; comparison among risks can be done only after adapting different quantification measures. Moreover a multitude of well-established approaches to integrate the analysis is available and this situation is reflected on the several not-communicating risk management frameworks. The SIGMA framework, introduced in the following of this article, has its main innovative features in the ability to integrate different risk management subsystems and in the infrastructure built over a cloud based information system.

3. The SIGMA framework

SIGMA is a multilevel architecture whose main functionality is the gathering, integration and mining of heterogeneous data coming from sensor networks with the aim to enhance control and monitoring of systems both of natural and industrial origin. The aim is the provision of useful data for the forecasting of early warning and management of hazards through the provision of services for the citizens and the public and private companies.

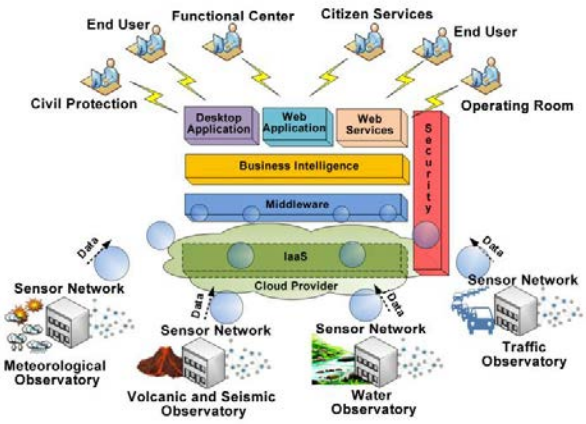

Fig. 1. SIGMA architecture.

One example of SIGMA's provided services are the applications and the processes built over the SIGMA framework for the development of intervention plans, by the elaboration and integration of data coming from the affected zones with the data coming from road traffic in order to have more effective operative rescue plans. Moreover the planning applications can benefit from simulation functionalities used for training of emergency personnel. The architecture is composed of five different layers listed in the following and showed in Fig. 1, starting from the lowest layer:

- the physical heterogeneous sensors networks;
- a distributed, virtualized infrastructure deployed in cloud environment composed in Infrastructure as a Service (IaaS);
- the middleware, an intermediate software layer having the scope of integrate heterogeneous data coming from different networks, by the unification of them and by making them available to the business intelligence layer;
- the Business Intelligence, having the scope of elaborate data. By using ad hoc algorithms complex forecasting, monitoring, and management problems are solved; its results are used as support to monitoring and management activities;
- the application layer which realizes the interfaces needed for the interaction between the framework and the system.
- A cross layered module is dedicated to the realization of the security requirements.

4. SIGMA and cloud based sensor networks

SIGMA is a cloud-oriented solution to integrate heterogeneous Monitoring Infrastructures (MIs) into the cloud according to agreements between the SIGMA provider and MI administrations (e.g. real-time access, time scheduled access, limited access to the physical infrastructure or to the available data, etc.). There are several possible models that lead MI owners to share their data over the cloud:

- The MI provides data as open sensory data through the web. In this case, the SIGMA provider is interested in integrating such type of data in its system and will develop a specific adapter for such type of data provisioning.
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- The MI owner is at the same time both resource provider and consumer. In such a scenario, the MI owner exploits SIGMA to extend his physical infrastructure by means of the cloud virtual infrastructure.
- The SIGMA provider and the MI company can make commercial agreements, but the definition of such commercial agreements is out of the scope of this article.

SIGMA offers all the aggregated heterogeneous sensing/actuation and software systems to its clients according to two *as a Service* models. In SIGMA a client could be an end user, a programmer, or a software system. According to the NIST (National Institute of Standards and Technology), which provides the de facto standard in the definition of cloud computing, cloud computing services are structured into Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) [9].

SIGMA provides two types of services, at the IaaS and PaaS layers, according to the *data-centric* and *device-centric* models in offering sensing/actuation resources.

The data-centric model gathers physical measurements and environmental information from heterogeneous MI, and organizes them according to a uniform format. To support a data-centric resource provisioning model, SIGMA implements a PaaS, that is a seamless provisioning platform able to abstract and store heterogeneous sensing/actuation data, to provide such data to clients. Thus, clients do not need to have knowledge of the monitoring system's features or technologies, and they access data through high level interfaces regardless of the monitoring system. The device-centric model offers a sensing/actuation infrastructure to the clients. Such infrastructure aggregates sensing and actuation resources that the applications exploit to deliver services to the end users. SIGMA implements the device-centric model as an IaaS. Cloud principles enable the virtualization of such infrastructure, hiding specific deployment issues from the end user. Sensing and actuation resources are managed to offer a customizable virtual node for environmental monitoring. A virtual device can be equipped with several capabilities, such as sensing, storage, and computation power.

As shown in Fig. 1, SIGMA clients may exploit both the PaaS and the IaaS offered by the SIGMA itself. Clients can be end-users interested in sensing/actuation data and/or virtual sensors. Possible SIGMA clients can be SaaS providers that exploit SIGMA services (or a mashup of services) to offer new applications.

Moreover, PaaS providers can offer to their end users new functionalities at the platform level by using the SIGMA virtual infrastructure. To better understand the benefits of the proposed cloud solution and their feasibility, we provide a comparison between the services developed according to the data-centric and device-centric models in Table 1, thus to highlight their similarities and differences.

As already mentioned, the data-centric model focuses on data, whereas the device-centric model focuses on the infrastructure (Feature 1) in Table 1. It means that, following the data-centric model, SIGMA provides a PaaS for gathering data from MIs, storing and providing them to clients (Feature 2). Otherwise, SIGMA offers an IaaS to export the device oriented model, where the sensing/actuation physical resources are virtualized in sensing/actuation components, accessible from clients. A client requests a data-centric service (that is PaaS) if it needs environmental information and physical measurements, but has no expertise in virtual/physical infrastructure configuration and exploitation. Observations can be the result of multiple or aggregated measurements over several MIs, in order to fulfill client needs. In contrast, the client requests a device-centric service (that is IaaS) if it needs full control of the sensing/actuation resources.

Table 1. Comparison between data- and device-centric models to provide sensing resource management services.

#	Feature	Data-centric	Device-centric
1	Type of resources	Data	Infrastructure
2	Type of offered cloud service	PaaS	IaaS
3	Client needs	Environmental information, contextual measurements, and compound observations	Full control of sensing/actuation resources, and the ability to customize the behavior of devices.
4	Support for heterogeneous distributed infrastructures	Yes	Yes
5	Need of abstraction technologies	Yes	Yes
6	Need of virtualization technologies	No	Yes
7	Decoupling between cloud and MI activities	High	Low

In this case, the client can also tune the device parameters and customize the on-board software (Feature 3). To achieve the above goals, both the SIGMA services based on the data-centric and device-centric models aggregate heterogeneous and distributed MIs (Feature 4), which can be different both in terms of hardware equipment and software systems. Moreover, the SIGMA services abstract MI information and monitored data, in order to provide a uniform description of available resources, device components, and physical observations (Feature 5). To provide the device-centric service, specific virtualization techniques decouple physical devices from the virtual devices. Indeed, the virtual sensors on a cloud platform are dynamic in nature, and hence facilitate automatic service provisioning. Clients can supervise virtual sensors using some standard functions and interfaces (Feature 6). The data-centric model guarantees a good isolation between cloud and MI systems; data gathered from sensors into MIs flow toward the cloud, and actuation directives flow from the cloud toward the MIs. Thus, the service provisioning of the cloud provider does not affect activities inside the MIs. In contrast, the device-centric service extends the cloud functionalities inside the physical monitoring infrastructure, and hence the MIs' behavior can be influenced by the specific requirements of the clients (Feature 7).

5. Web application for emergency logistics optimization

This section details a selection of applications built over the SIGMA framework dedicated to the planning of the rescue activities and to the monitoring of hazardous events.

5.1. Planning applications

The first developed application we describe is a discrete simulation model for analyze the effectiveness of the rescue procedures implemented by rescue teams [10]. The application works over geo-localized data and can be used for what if analysis and training purpose. Fig 2 shows a display of the simulation model front end. The second application is used to optimize the location and allocation of rescue personnel and resources. The problem has been modelled as a modified Capacitated Facility Location Problem (CFLP) and a Mixed Integer Linear Programming Model has been developed by use of the CPLEX Optimization Studio [11]. The network has been built by using a geographic information system. Sensitivity analysis has been carried out to study the effect of resources relocation among facilities. The model is wrapped by java routines (with J2EE standards) while a persistence model interact with MYSQL database in order to load the information of the geo-localized zones actually at risk (see Fig. 3) The presentation layer is built with JSF (Java Server Faces). The data of the destinations of affected areas to serve is denoted with the flag "at risk" displayed on the tabular data shown in figure. This field is the connection point with the alerting subsystems deployed over SIGMA.

5.2. Monitoring applications

The modularity of the SIMGA framework allows to develop and deploy different applications built with a variety of technologies and consumed by users with different modality. Data collection, analysis and presentation applications have been deployed and tested on the platform. The application is able to integrate heterogeneous sources (including open data) in order to present in a unified way real time data coming from different sensor networks and representing different risk sources. Now is already available a data visualization (with the OpenLayer framework) and an integration with a Global Forecast System (GFS) Model for particular layers (wind speed and water activity).

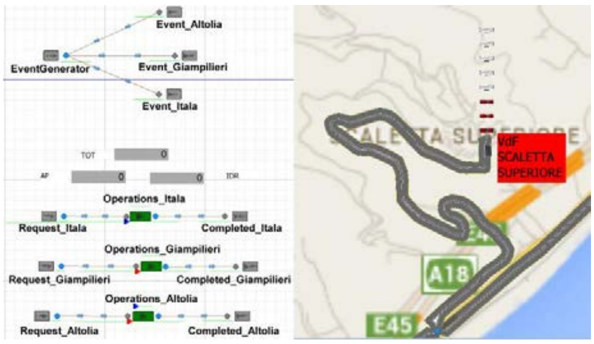

Fig. 2. Simulation model for rescue operations analysis

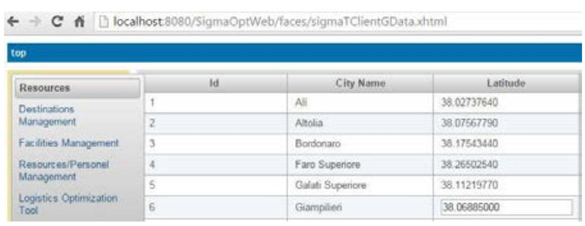

Fig. 3. Front-end for the emergency logistics planning

Moreover, using ad hoc APIs, it will be possible to integrate in real time the simulator described in section 5.1 and the vehicles used for first aid, to obtain geotagged positions.

The application logic is built over a rule engine able to detect correlations among events. The application is able to record alerts which are visualized through the ad hoc web interface and which are made available to other applications, such as the emergency logistics planner described in previous sections or applications tailored for smartphones and social networks or other end-user app for real- time alerting and interaction. The SIGMA web application for monitoring is organized in layers in order to load different risk monitoring connected networks providing also geo-located messages with rich multimedia contents (images, video, audio).

Among the available layers the application make available data on earthquakes, air quality, precipitations, landslide prediction, contaminated water, wind speed, temperature, air pressure at sea level, clouds coverage, snow, rain.

6. Conclusions

This work presents the preliminary results of the Italian research project SIGMA - sensor Integrated System in cloud environment for the Advanced Multi-risk Management. The proposed system includes a continuous monitoring of the different information sources, thus reducing human control as much as possible. At the same time, the communication system manages multiple data flows in a flexible way, adapting itself to different working scenarios, enabling smarter applications. It is crucial to have a new generation frameworks supporting the integration of multi-risk analysis, mitigation and management. SIGMA allows to integrate different approaches and can be used as a building block to provide services to public authorities, companies, and citizens. The applications built as demo over the SIGMA framework demonstrated its usability both for civil protection and for industrial usage. In fact as exploited results the same application has been populated with data coming from an industrial district in Sicily – Il Priolo – in order to provide risk estimation and emergency logistics planning supporting tool to industrial territories affected by natural and anthropic disasters.

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