# Proactive Marine Information System for Environmental Monitoring

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***Abstract*—Detecting and monitoring oil spills at sea has become an important issue due to both the increased demand and use of oil based products, and the more careful attention given to environmental protection. Safety in maritime transportation has improved, but contextually the number of vessels along shipping routes has increased, thus raising the risk of accidents occurring. Along with this, also monitoring sources and capabilities have individually grown; what still needs to be improved is an integrated approach to monitoring, in particular in case of sensitive areas, such as protected marine parks.**

**The Marine Information System proposed here is an integrated and interoperable system able to monitor maritime traffic, using sensing capabilities from various electronic sources, along with geo-positioning tools, and based on a specific communication infrastructure. This system, integrating seamlessly heterogeneous data, supplies a collection of decision support services providing proactive functionalities, which demonstrates its potential in facilitating dynamic links among different data, models and actors. Accomplishment of several field tests demonstrates these potentialities.**

***Keywords—Marine Information Systems; Oil spill monitoring; Environmental Decision Support Systems; Proactive environmental monitoring; risk maps***

## I. INTRODUCTION

Oil pollutions affect the environment, the economy and the quality of life for coastal inhabitants. The increasing importance of petroleum products raised the concern on maritime safety and environmental protection, leading to a greater interest in frameworks for remotely detecting oil spills at sea. Several technological advances were made, especially under the propulsion of catastrophic events. Nevertheless, most of the approaches have been focused on large oil spills while smaller ones and operational discharges have received less consideration, despite their importance in the routine work of local authorities, especially in protected areas of great environmental value. In addition, classical remote sensing frameworks can be enriched by adding information collected in situ thanks to static and mobile sensors and leveraging on innovative methods for data correlation and fusion.

In this work, we aim at addressing these issues by proposing an integrated and interoperable Marine Information System (MIS) based on advanced sensing capabilities from a variety of electronic sensors along with geo-positioning tools, yet suitable for local authorities and stakeholders. The designed system has to be very effective in managing and organizing quick solutions to severe and complex environmental problems. In order to solve these problems, which have a multidisciplinary and heterogeneous nature, it is needed to put into cooperation many different subsystems, which must be integrated for a wide and more complete view and understanding of the specific situations.

In particular, the proposed MIS integrates multispectral aerial data, SAR satellite processed data, environmental data from in situ monitoring stations (e.g. buoys) and dynamic data acquired from in situ mobile sources, such as Autonomous Underwater Vehicles (AUVs). The MIS architecture will be described in Section II.

The integration and aggregation of the available heterogeneous data is based on a model designed for the computation of a dynamic real-time risk map. This kind of visualization provides a quick but very efficient way to the global monitoring of sensitive areas, details on the dynamic risk map will be given in Section III.

An Environmental Decision Support System (EDSS) in charge of monitoring and detecting pollution events is included and represents an important asset of the MIS. The EDSS is in charge of monitoring and detecting pollution events, and thus providing a collection of environmental decision support services, for:

- automatically screening the overall situation;
- quantitatively representing risk factors;
- proactively notifying events that deserve the consideration of end users.

Details on the proactive services and the EDSS designed for the MIS will be given in Section IV.

The proposed system has been demonstrated during extensive test exercises held at the National Marine Park of Zakynthos and at National Park of Tuscany Archipelago in the frame of EU-FP7 Project ARGOMARINE. A summarization of these tests and obtained results is given in Section V.

## II. Architecture of the Marine Information System

The first goal in the designing of the MIS architecture has been to obtain independent and re-configurable units, thus guaranteeing interoperability and portability of the system. This way, in case of different domains of application (or case study), single units could be re-designed, or simply their internal components modified to target that specific domain, without the need to re-design the whole architecture [1].

Such a system, needing to provide an effective and feasible detection and management of marine pollution events, has to deal with many kinds of knowledge within the *environmental management process* [2], typically consisting of four different ordered activities: (1) hazard identification, (2) risk assessment, (3) risk evaluation and (4) intervention.

The MIS development followed INSPIRE and GMES recommendations [3], thus the modalities to communicate and interact among systems, and, in general, to and from the MIS have been reviewed, especially for what regards the efficient management of the information flow within the system, which is needed for guaranteeing interoperability among the different components. Hence, the design of the MIS includes a set of specialized subsystems cooperating among each other.

The MIS is designed as an integrated group of subsystems for performing various activities connected to the environmental management process: data acquisition and storage, decision-support, data analysis and mining, as well as a web-GIS portal for the access and usage of products and services released to end-users. Products are intended as the marine and environmental data acquired by the system or resulting from their processing; while the services represent the processing facilities supplied by the system [4].

The MIS architecture can be seen at different levels of detail, the main level with all the composing units and the communication infrastructure are represented is shown in Fig.

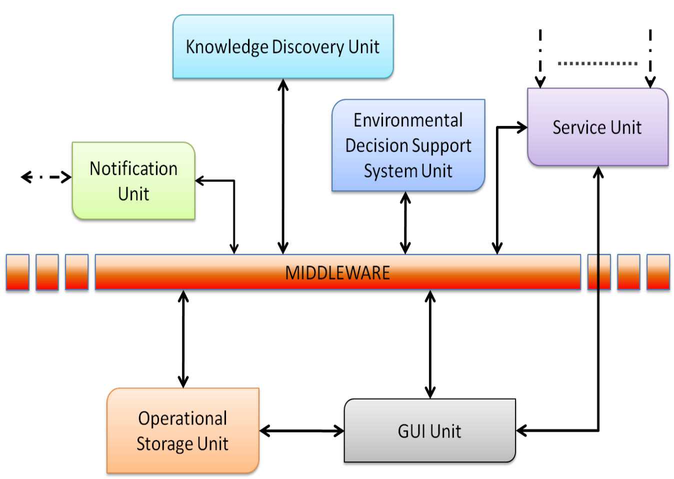


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Fig. 1. The MIS architecture with all units and modular structure

The Environmental Decision Support System is designed to be the real intelligence of the system and represents the core unit of the MIS. The EDSS analyses and combines heterogeneous multisource data acquired from different sources and subsystems of the MIS. The three different levels of functionalities among which the EDSS operates are:

- Data gathering;
- Diagnosis and/or Prediction;
- Decision Support.

### A. Data Gathering

The combination of heterogeneous multisource data arises because information is acquired and gathered into the MIS from a variety of sensors and from various monitoring resources. Moreover, this information is sent to the MIS at different timings and time rates, as well as based on very different standards. These sources have been identified for our case study in the following:

- SAR images and interpretative reports;
- Hyperspectral images from airborne sensors and interpretative reports;
- Data collected by buoys;
- Data collected by underwater autonomous vehicles;
- E-nose data;
- Forecast data obtained by applying simulation models;
- Data about the maritime traffic through AIS systems;
- Data reported by sailing volunteers.

Each of the other subsystems of the MIS is in charge of interpreting and storing these data, which can then be accessed and used by the EDSS in the other following two levels of functionality.

### B. Diagnosis and/or Prediction

Models for both risk analysis and diagnosis are applied based on the integration of the above-acquired information. In particular, the main goal is to characterize the monitored area for the detection of possible oil-spills. A parametric diagnosis is needed for this functionality to work, firstly because a time-space correlation among the available data has to be performed, secondly because among all the possible data sources only some can be available for the time and space being analyzed, and each of them needs to be synchronized to a common (i.e. the MIS one) timing.

### C. Decision Support

In order to support the decisions to be taken by end-users (e.g. authorities in charge of monitoring), the EDSS is designed so to optimize the exploitation of available resources for both monitoring and processing of data. The final goal remains to confirm or dismiss a preliminary detection of an oil-spill event, and in case of confirmation to issue an alert and supply the end-users with suitable documentation of the event.

The conceptual model followed what has been suggested in [5], thus two different components have been designed: the Risk Analysis Model and the Resource Management Service.

These two components have been designed based on a series of needed features:

- representing and structuring the available knowledge;
- separating data from models;
- dealing with geo-referenced data;
- providing expert knowledge;
- planning, managing and alerting;
- assisting and interfacing the end-users with the system and selecting of resolution methods.

## III. Real-time Risk Estimation

A main component of the MIS is the model for the provision of real-time and dynamic risk maps. This designed model relies on the available heterogeneous data integrated into the MIS, by aggregating these sources ranging from maritime traffic density to water quality parameters sensed by electronic noses. The aggregation goal is to bring a visual information through a single quantitative parameter for each point in the area of interest. The so-called risk map provides a quick yet effective way to have an outlook of the situation in the monitored area [6].

Risk estimation is an addition two factors: hazard potential and vulnerability (see Fig. 2). The first one is evaluated by multiplying the likelihood of occurrence of adverse consequences by the magnitude of each consequence (e.g. maritime traffic density); while the latter is the lack or deficiency in monitoring resources that reduces the resilience of the area in case of a possible hazard (e.g. proximity to natural resources).

Each detection gathered by the MIS contributes to the hazard potential as a summand weighted by the confidence of the detection and having the shape of the detected region smeared by an isotropic Gaussian kernel. The weight decreases as time passes, because the oil spill report becomes obsolete and eventually becomes zero after a prefixed time. Other kinds of reports, including notification of oil spill sighting by volunteers, are dealt in analogous way.

The computation of the vulnerability relies on the local monitoring coverage quality, meaning that an area with a higher level of monitoring resources available in situ will be easier to control with respect to an area with less coverage. For example, in less vulnerable areas, accidents and pollutions can be promptly detected and countermeasures can be immediately implemented in order to mitigate the environmental damage. Consequently, monitoring coverage reduces vulnerability of the area; therefore, we assume that vulnerability is proportional to the negative of coverage quality. Numerically it is assumed that each monitoring resource (coast guard vessels, moored buoys and AUVs) has a positive effect, reducing the vulnerability with a strength that decreases with distance.

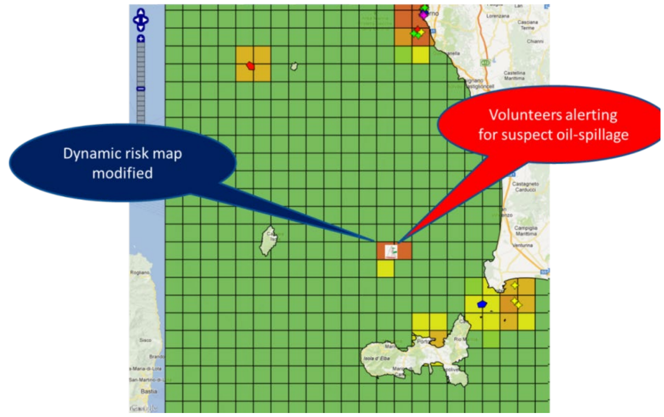


Fig. 2. MIS showing the dynamic risk map modification in real-time.

## IV. The Proactive MIS

Within the MIS framework, several services have been developed in order to provide continuous monitoring of the monitored area. In particular, the goal of the proactive services has been to optimize the dynamic management of the available monitoring resources, and to actively notify end-users in charge of managing and monitoring the marine areas in case of confirmed events [7].

Intelligent software agents have been implemented for each of the developed services. These agents work in autonomy and are independently reconfigurable. Each of them has a number of probes for fetching data from the MIS and a set of preconfigured actions to command. Each step in their workflow is represented as a condition-action rule. The workflow might include the acquisition of further data or the triggering of external computational methods (e.g. for running simulation or assessing risk again). Agents activate their probes at regular interval of times (e.g. they poll data from a repository) or they are triggered on demand (e.g. by other agents or upon reception of special requests).

The MIS services for notification are in charge of analyzing the current situation and of issuing alerts in case a confirmed event is detected [8]. These alert notification can be sent either via mail or via text-message automatically to the person(s) in charge of the actual event which has been detected and confirmed.

In particular, oil spill reports coming from image processing facilities, volunteers' alerts and the risk map estimation are continuously monitored by the services. In the situation of receiving a report from the image processing facilities with a high confidence, an alert is immediately generated. Moreover, if there are a number of volunteer's alerts which might refer to the same pollution event, an alert is generated with different levels of severity. Finally, on the basis of the risk maps, alerts are generated considering both the absolute value of the risk and its trend. With the generation of an alert, the service takes care of contacting the most suitable authority selected automatically based on a proximity criterion.

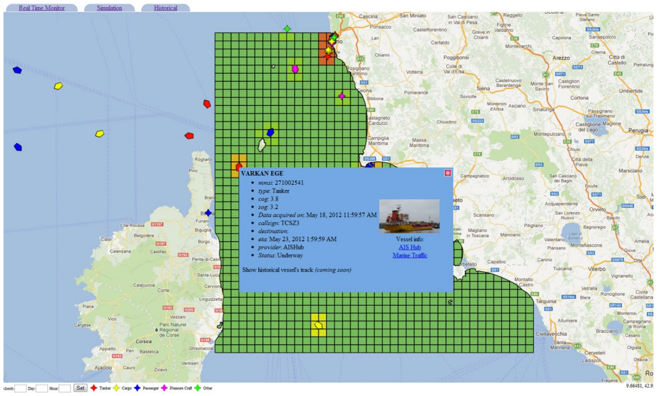

Fig. 3. MIS interface with the risk map overlay and a possible interaction.

## V. Results and Field Tests

The features and functionalities of the developed MIS have been demonstrated during extensive test exercises held in the frame of EU-FP7 Project ARGOMARINE. These case studies took place both at the National Marine Park of Zakynthos and at National Park of Tuscany Archipelago.

In Fig. 3 the appearance of the interface implemented is shown with the overlay of the risk map, and a possible interaction to check information about visualized vessels acquired in real-time through AIS data.

The tests have involved the acquisition of data from the different sources, identified in Section II.A, and their integration. The MIS proactive functionalities have been tested simulating the presence of an oil spill through in loco volunteer alerts and through the acquisition values reported from the electronic nose (eNose) mounted on a moored buoy. During those test phases, the system has been also stress tested in order to verify its robustness and reliability, as well as the important near-real time functionalities and capabilities.

The MIS has been demonstrated as a useful and reliable tool for the monitoring of sea areas and for the early detection of oil spills and quick response in case of emergencies. Indeed, the system has been able to receive, store and integrate all the several types of data involved in the experimentations. Data correlation has been proved by relating the vessels recognized from the processing of SAR images with the acquired AIS signals. The system robustness and reliability over the time have been ensured by the positive result of the stress test where the MIS have been able to acquire all the produced data without suffering data loss or delay problems.

Finally, the proactive services have been able to recognize the presence of an oil spill, on the basis of both, the data polled from the MIS databases, and the logic used for suggesting resource management alerting; thus finally, alert notifications were issued to the most suitable authority for the emergency management. As a confirmation of this, the computed risk map changed consistently after receiving the volunteer reports, thus triggering a consistent list of actions to be performed.

The designed interface, which could be accessed by the suitable and responsible authorities, contains all different kind of data which can be viewed as informative layers on a map (see Fig. 4). Moreover, it also allows to perform various cross-correlations among various reports and available data (e.g. the above mentioned maritime traffic versus related SAR processed image).

Moreover, the modularity and flexibility of MIS framework makes it a suitable candidate not only for oil spills monitoring systems, but also for more general geospatial data management for marine applications.


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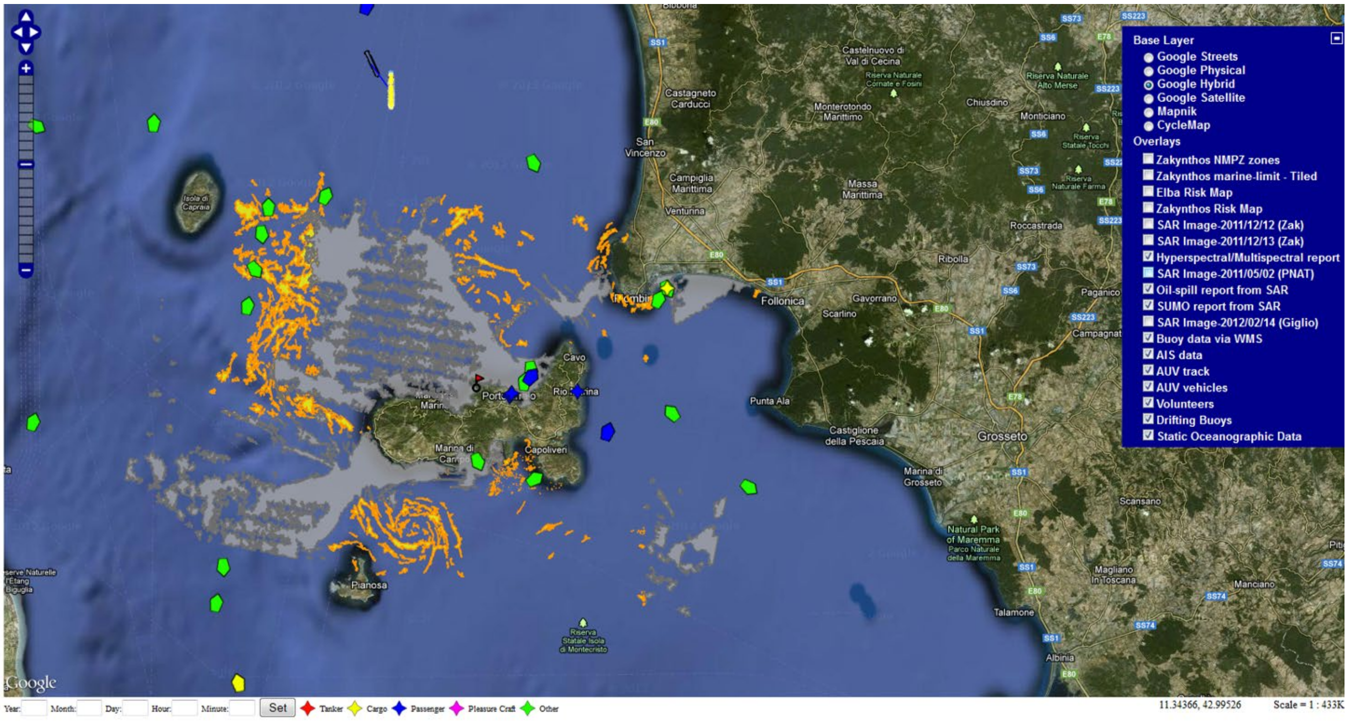


Fig. 4. Example of the MIS interface with all possible interaction layers available