Marine Pollution Bulletin 102 (2016) 316–322

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

A proactive system for maritime environment monitoring

Davide Moroni, Gabriele Pieri *, Marco Tampucci, Ovidio Salvetti

Institute of Information Science and Technologies, ISTI-CNR, 56124 Pisa, Italy

ARTICLE INFO

Article history:
Received 13 June 2014
Received in revised form 13 July 2015
Accepted 20 July 2015
Available online 29 July 2015

Keywords:
Oil spill monitoring
Environmental Decision Support Systems
Real-time monitoring
Marine Information Systems
Proactive environmental services

ABSTRACT

The ability to remotely detect and monitor oil spills is becoming increasingly important due to the high demand of oil-based products. Indeed, shipping routes are becoming very crowded and the likelihood of oil slick occurrence is increasing. In this frame, a fully integrated remote sensing system can be a valuable monitoring tool. We propose an integrated and interoperable system able to monitor ship traffic and marine operators, using sensing capabilities from a variety of electronic sensors, along with geo-positioning tools, and through a communication infrastructure. Our system is capable of transferring heterogeneous data, freely and seamlessly, between different elements of the information system (and their users) in a consistent and usable form. The system also integrates a collection of decision support services providing proactive functionalities. Such services demonstrate the potentiality of the system in facilitating dynamic links among different data, models and actors, as indicated by the performed field tests.

1. Introduction

Oil pollutions impact 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 spill at sea (Abascal et al., 2010). Several technological advances were made, especially under the propulsion of catastrophic events (Balseiro et al., 2003; Janeiro et al., 2014). Nevertheless, most of the approaches have been focused on large oil spills while smaller ones and operational discharges in regional area have received somewhat less consideration, despite their importance in the routine work of local authorities, especially in protected areas of great environmental value (Ferraro et al., 2009). 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 (Guo and Wang, 2009; Jordi et al., 2006).

In this work, we aim at addressing these issues by proposing an integrated and interoperable system based on advanced sensing capabilities from a variety of electronic sensors along with geo-positioning tools, yet suitable for local authorities and stakeholders. In particular, the proposed Marine Information System (MIS) integrates multispectral aerial data, SAR satellite processed data, environmental data from in situ monitoring stations (e.g. buoys), dynamic data acquired from in situ mobile sources, such as volunteers and Autonomous Underwater Vehicles (AUVs) along with information about vessels, their status and route gathered exploiting Automatic Identification System (AIS).

The MIS is enriched with a collection of environmental decision support services, for (i) automatically screening the overall situation, (ii) quantitatively representing risk factors and (iii) proactively notifying events that deserve the consideration of end users.

A model for the computation of dynamic risk maps has been included, by aggregating the available heterogeneous data source ranging from maritime traffic density to water quality parameters sensed by electronic noses (E-noses). Visualization of the risk map provides a quick yet effective way to have an outlook of the situation in the monitored area, while its automatic analysis – performed by intelligent agents – allows the delivery of proactive alerts to local authorities in charge of monitoring.

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 framework of FP7 Project Argomarine.

The paper is organized as follows. In the next section, we recall the architecture of the designed MIS, describing its components and features. Then, methods for the real-time assessment of risk based on the heterogeneous data collected into the MIS are introduced. We next describe the proactive services capable of exploiting

---

* Corresponding author.
E-mail addresses: Davide.Moroni@isti.cnr.it (D. Moroni), Gabriele.Pieri@isti.cnr.it (G. Pieri), Marco.Tampucci@isti.cnr.it (M. Tampucci), Ovidio.Salvetti@isti.cnr.it (O. Salvetti).

http://dx.doi.org/10.1016/j.marpolbul.2015.07.045
0025-326X/

the computed risk maps for issuing alerts to local authorities. Finally we discuss the test fields performed for the validation of the proposed model and we conclude the paper with ideas for further improvement.

2. Architecture of the Marine Information System

The MIS has been designed to provide an effective and feasible detection and management of marine pollution events, by integrating and analyzing data acquired by a number of monitoring resources, exploited to get useful and relevant information about the controlled sites. The main task of the MIS is to serve as a catalyst for integrating data, information and knowledge from various sources pertained to the marine areas of interest, by means of adequate Information Technology tools. More precisely, the MIS has been conceived as a connected group of subsystems for performing data storage, decision-support, data mining and analysis over data warehouses, as well as a web-GIS portal for access and usage of products and services released to end-users. Products are herein considered as the marine environmental data acquired by the system or result of their processing; while the services are the processing facilities supplied by the system.

The system has to deal with all these kinds of knowledge for being effective and useful in *the environmental management process* (Cortes et al., 2000), which typically consists of four activities in the following: order hazard identification, risk assessment, risk evaluation and intervention (Fedra and Winkelbauer, 2002).

The MIS has to be very effective in managing and organizing quick solutions to severe and complex environmental problems. Due to their multidisciplinary and heterogeneous nature, in order to be solved, such problems need the cooperation of many different subsystems that must be integrated, for a wide and more complete view and understanding of the specific situations.

The specific MIS requirements, first of all, take into account all the acquisition sources that are available and used within the monitoring activities, and belonging to specific technological devices, as well as the archiving and storage systems. In order to develop the MIS following INSPIRE and GMES recommendations (INSPIRE, 2007), the modalities to communicate and interact among systems and, in general, to and from the system have been reviewed. In particular, aiming at an efficient management of the information flow within the system, needed for guaranteeing interoperability among the different components, the MIS is designed as a set of specialized subsystems cooperating among each other.

More in detail, MIS architecture was designed with independent and re-configurable units in order to guarantee interoperability and portability to the MIS, meaning that single units could be re-designed, or its internal components could be modified to fit to specific different domains of application (or case study), without the need to re-design the whole architecture (Pieri et al., 2012).

The MIS architectural design is shown in the following Fig. 1, where the composing units are represented, along with the communication paths that exist and are needed for the MIS to operate.

The MIS intelligence is represented by the Environmental Decision Support System component (EDSS) which is responsible for detecting and monitoring pollution accidents by analyzing and combining the multisource data coming from the different data acquisition and processing subsystems of the MIS.

The design of the EDSS required understanding of the environmental problem domain and identifying the domain experts and authorities to cooperate with. Particularly important has been the identification of the problems to be solved by exploiting the EDSS aid, and how the system can intervene and improve the current oil spill detection and management procedures. According to these results, the EDSS has been conceived according to a three levels structure, i.e. by endowing it with three main functionalities:

1. Data gathering
2. Diagnosis and/or prediction
3. Decision support.

2.1. Data gathering

As typically happens, the EDSS has to cope with very different types of data, which can arrive even in real time from a variety of sensors. Indeed, data are gathered from various monitoring resources and consist of:

- 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.

The heterogeneity of these data has suggested distributing the interpretation task among different modules that nominally correspond to different subsystems of the MIS. Results of the interpretation are stored within the MIS, in dedicated databases, and are used by the EDSS for the other two functional levels.

2.2. Diagnosis and/or prediction

Risk analysis models are applied for diagnosis and prediction. In particular, the environmental data acquired by the various monitoring resources are fused for site characterization and observation, in order to detect possible marine pollution events.

2.3. Decision support

Support to decisions is, finally, supplied by drawing an optimized plan of exploitation of the resources available for monitoring and of the processes for data analysis, so as to confirm the detection of the event and issue an alarm. Suitable presentation and documentation of alarms are supplied along with feasible EDSS suggestions aimed at supporting the feasible event management and recovery interventions.

According to this conceptual model, the EDSS has been designed as composed by two main components: the Risk Analysis Model and the Resource Management Service.

These have been modeled in order to assure a number of desirable features, such as:

- ability to acquire, represent and structure the knowledge in the specific domain under investigation,
- ability to separate data from models, in order to be re-usable,
- ability to deal with geo-referenced data,
- ability to provide expert knowledge related to the specific domain,
- ability to be used for planning, management and alerting, and
- ability to give the end-users (both on the manager/experts side, and the external users) assistance for interfacing with the system and selection of resolution methods.

3. Methods for real-time risk estimation

The goal of this section is to introduce methods for the provision of real-time risk assessment, in order to produce a snapshot of risk in the region of interest which can then either (i) automatically exploited by proactive services (as explained in the next Section)