Supporting Environmental Analysis and Requalification of Taranto Sea: an Integrated ICT Platform

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Abstract—**Pollution in Taranto Sea must be monitored constantly to detect potential issues to public health, marine biology and economic activities in the basin. A recent environmental analysis and intervention initiative is performing a systematic and multidisciplinary research on the area. This paper describes the support software platform, which is being devised for the project. It is based on the crowdsourcing paradigm and on open source software and open data formats. The platform collects heterogeneous data from different research units and presents them as multiple georeferenced and timestamped information layers, which can be combined for advanced analysis. The overall architecture, developed tools and prospected integration of Radio Frequency Identification (RFID) technologies for survey sample tracking are discussed in detail.**

Keywords - ***Environmental monitoring; OpenSeaMap; Crowdsourcing; Geographic Information System.***

I. INTRODUCTION

Human settlements and activities have an impact on the coastal and marine environment. Marine litter and industrial waste impair the sea ecosystem and economic activities based on it. The Taranto Sea is one of the most critical situations in Italy and an internationally relevant case study [1], due to the Taranto basin having low water circulation [2]. Pollution can affect the health of the local population, as well as the wildlife and the traditionally relevant seafood breeding activity in the area. Authorities have set up a program [3] for the requalification of Taranto Sea. In order to accurately plan the best and safest intervention strategies, systematic analysis of seawater and seabed is needed with an interdisciplinary approach, including geological, geotechnical, physical, chemical and biological investigations. Borehole sampling of the seafloor is one of the most important and sensitive activities: stocking samples and moving them to the various analysis laboratories requires accurate and timely tracking. Furthermore, collected data need to be stored systematically and shared among the different research units in order to allow the discovery of relevant patterns and correlations providing the needed insight to operate effectively and efficiently.

This paper presents an integrated Information and Communication Technology (ICT) platform supporting the ongoing environmental analysis and intervention activities in Taranto Sea. The proposal is based on the principle of information *crowdsourcing*. In the last years, this paradigm has established itself thanks to the ICT progress increasing large-scale information sharing possibilities. Experience with crowdsourcing has shown that a large, loosely coupled and heterogeneous community of users is able to produce and maintain a data or knowledge base, which is superior in size and quality w.r.t. a narrow team of dedicated professionals. The key for crowdsourcing success lies in three factors: (i) a motivated community, which globally possesses the required skills; (ii) an ICT support platform; (iii) a decentralized organization model respecting individual autonomy but promoting shared policies and mechanisms to maintain high quality of information as size grows. This work proposes an integrated ICT support platform based on open source software and open data formats. The core of the platform consists of tools and technologies derived from *OpenSeaMap*, a worldwide collaborative project for marine cartography creation. It allows to collect heterogeneous data about points of the Taranto Sea basin into a unified, general data model, where results from the different investigations appear as multiple layers of information, wildwhich are individually georeferenced and timestamped, in order to support space-oriented, time-oriented and attribute-oriented queries. A further capability is to allow cross-checking data from different domains in order to perform interdisciplinary analysis and find hidden correlations. The whole platform is accessible through a uniform and user-friendly interface.

Functional requirements of large-scale research projects go beyond those of typical cartographers or Geographic Information System (GIS) users. First of all, security was of paramount importance, therefore a Virtual Private Network (VPN) link protects all communications from/to the server hosting the proposed platform. Access is granted only to the staff of involved research units. Furthermore, the need to work on massive data required specialized tools for (i) automating repetitive entry and import operations, and (ii) performing advanced search and data mining. Finally, integrating sample tracking management with the platform was studied through the use of Radio Frequency IDentification (RFID) technologies. The developed and proposed solutions constitute an integrated ICT platform to support the whole workflow of environmental analysis and monitoring, from field to laboratory. The platform is under use in the Taranto Sea marine environment requalification initiative, but it provides a general solution which can be exported to a number of analogous scenarios with minimal or no modification.

The rest of the paper is as follows: the next section discusses related work. Section III describes the core components of the integrated crowdsourcing platform, while Section IV provides details on data management tools. RFID-based traceability solutions are outlined in Section V, then conclusion is in Section VI.

II. Related work

GIS systems allow georeferencing data, performing various kinds of analysis and producing chart-based reports. GIS technology is constantly improving and its adoption has been rising for several years. They have been used successfully in a wide range of scenarios, from urban planning [4] and transportation [5] to epidemiology [6] and environmental monitoring [7]. Nevertheless, available solutions are usually based on closed software, which is expensive to purchase and even more to customize to the peculiar needs of a particular project. Even though open standards exist for georeferenced data, not all tools support them, so requiring format conversions with the risk of losing valuable information.

Crowdsourcing approaches and platforms propose a radically different approach, based on the contribution of large numbers of –often volunteer– participants to solve a complex problem or collect large bodies of information [8]. Since the concept is quite recent, defining characteristics of the crowdsourcing paradigm is still openly debated [9]. Anyway, the need to facilitate global-scale collaboration directs crowdsourcing ICT platforms toward open data formats and often open source software. This creates opportunities for customizations and extensions in order to satisfy specific requirements.

Environmental collaborative monitoring networks were proposed in [10], combining traditional environmental monitoring with the principles of crowdsourcing. They were based on three key elements: (i) motivated citizens, (ii) sensing devices and (iii) a back-end information infrastructure. Although that work is more limited in scope w.r.t. the one proposed here, it shares the same basic perspective.

Among map-based crowdsourcing projects, *OpenSeaMap* [11] and OpenStreetMap [12] (OSM henceforth) are likely the largest and most successful. They are worldwide collaborative initiatives for shared creation of cartographic corpuses, respectively dedicated to sea and land mapping. They are based on World Wide Web technologies and follow *open data* license models, granting anyone the right to use, expand and modify the data. The core software components were originally designed and developed for OpenStreetMap since 2004 and then adopted –with some adjustments– by OpenSeaMap in 2009. They are freely available through open source software licenses.

The complete OpenSeaMap solution comprises several components, including:

- PostgreSQL [13], an efficient and scalable database management system with support for georeferenced data;
- Overpass [14], a geospatial query engine with a very flexible language and Application Programming Interface (API);
- a Web-based interface, mainly for information visualization and exploration;
- various editors for classical computers and mobile devices to modify and add cartography data.

Among the editors, the Java OpenStreetMap editor (JOSM) [15] is particularly relevant: it was developed in Java technology, making it compatible with Windows, Mac OS, Linux and other UNIX-like operating systems. It has a user-friendly interface, depicted in Fig. 1. Finally, it adopts a modular extensible architecture: *plug-ins* add new functionality without altering the whole software tool.

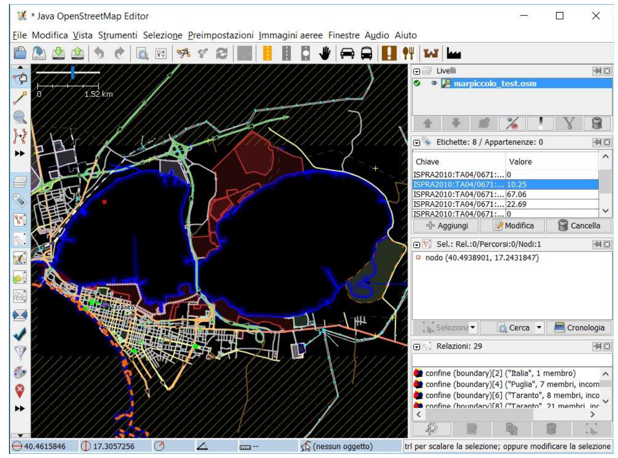

Figure 1. JOSM cartography editor

An important evolution of software platforms for environmental data management is the integration with automated information gathering devices and infrastructures. Wireless sensor networks [16], Internet of Things technologies [17] and robotics [18] have been adopted for this purpose in various projects, exploiting their respective peculiarities. RFID can be similarly integrated and is the most suitable technology whenever there is the need to track physical objects such as collected samples.

III. Requirements, strategy, architecture

Supporting the characterization of Taranto Sea for monitoring and requalification requires the development of a distributed information system capable of storing and retrieving gathered data efficiently. All the relevant information for the different research units should be stored along with geospatial and temporal references for each point as a stack of superimposed informative layers, in order to ensure full data traceability.

The support platform should also facilitate the systematic upload of information. This functional requirement posed the first significant challenge for the project, due to the sheer size and heterogeneity of the raw data at stake. Information characterizing the probed seabed points actually pertains to several disciplines, including geotechnics, hydraulics, hydrogeology, hydrology, chemistry, marine biology and biodiversity. Data must be properly stored, through an annotation process capable of making their nature and information content as explicit as possible. A second challenge involves querying the information system for systematic and interdisciplinary investigation. Complex environmental analysis needs searching techniques able to discover correlations and links between different attributes, acquired by separate teams with diverse tools and in variable time spans. The information system must allow users to express complex queries in order to retrieve the point(s) matching more closely a specific set of characteristics within the area of interest. This requires data mining capabilities and cross-checking all information produced in the investigations carried out by the various research units.

A preliminary analysis of necessities and desiderata of the marine environmental monitoring tasks has elicited further important non-functional requirements:

- security and privacy of data and communications between users and the system, allowing to share information only among teams involved in the project;
- support for open and interoperable data formats, due to the diversity of tools and platforms to be used;
- general and flexible data storage models and schemes, to support heterogeneous sources and allow integrated analysis;
- high performance scalability;
- easily usable and accessible interface, as the main users of the platform will be scientists but not necessarily trained in computer science.

The above constraints have led to consider *crowdsourcing* as the most appropriate information sharing model. Global distributed collaborative projects have already shown it to be scalable, reliable and effective. After an extensive survey of the state of the art, the overall proposal was based on the OpenSeaMap, with appropriate custom extensions to meet the specific requirements of the project. A careful audit has shown OSM technologies and tools fully meet the identified requirements of generality, openness, reliability, scalability, usability and security.

The OSM data model adheres to a simple and extensible Extensible Markup Language (XML) Schema, comprising three basic element types: (i) *nodes*, *i.e.*, single geospatial points; (ii) *ways*, representing ordered sequences of nodes; (iii) *relations*, grouping logically multiple nodes and/or ways. Each element includes latitude and longitude coordinates, a unique identity code and versioning fields. The basic model can be extended through optional informative *tags*, *i.e.*, key-value pairs of Unicode strings of up to 255 characters. The OSM community has defined a large number of tags to describe a wide range of entities and attributes, but new ones can be introduced freely to meet new and unforeseen use cases. The base model was therefore extended exploiting tags to create a general-purpose schema for environmental data and their geographical and temporal metadata. It is structured as follows:

- **Key:** unique prefix currently unused in OSM (according to the community-managed Wiki [19]), concatenated with a timestamp of the data entry.
- **Value:** concatenation of sub-fields, each with the same key-value structure, including:
  - `sur`: survey identifier (ID);
  - `sid`: sample ID;
  - `sts`: survey extraction time;
  - `dmi`: minimum depth;
  - `dma`: maximum depth;
  - `a`: attribute name;
  - `v`: attribute value.

Including a timestamp in the key makes each data insertion unique, so creating a traceable record of all editing operations. Furthermore, as data concern samples extracted at different values of marine or seabed depth, a depth range attribute was added in order to evolve the basic two-dimensional coordinate system of OSM into a three-dimensional one. Finally, general-purpose attributes obtained through laboratory analysis are stored individually for each point on the map and each depth range, in every survey campaign (both historical and ongoing ones). The above data model allows spatial, temporal and attribute-oriented queries to support a wide range of use cases.

In order to further optimize the analysis of data from different sources distributed at large scale, ongoing developments are assessing the possibility of using artificial intelligence techniques. The adoption of automated techniques to extract high-level knowledge from raw georeferenced data through mining algorithms allows building knowledge-based tools for environmental monitoring, decision support and control. A promising direction is grounded on the combination of machine learning and knowledge representation techniques [20], exploiting non-standard inference services for the analysis of information streams [21].

IV. Data editing tools

JOSM was selected as the main data editing tool in the proposed integrated platform. Two extensions to the basic editor developed for the project are discussed in this section. They are devoted to massive data import and advanced search, respectively.

A. Survey data importer

Population of the proposed environmental information system involves high volumes of data. Therefore it is necessary to provide tools to automate the process of information migration and integration from existing sources. In order to facilitate data entry, the proposed platform includes a JOSM plug-in allowing users to import georeferenced data from common formats, such as Comma Separated Values (CSV) and Microsoft Excel. This enables importing in the proposed system not only data gathered in past surveys, but also the output of analysis processes currently used by the involved research units. Such an approach removes time-consuming and error-prone computerized data entry procedures, and enhances automation in laboratory workflows.

After opening a data source file, the tool lets the user choose the set of records to import and select the fields of interest, through an assisted procedure, after which loading is performed automatically in batch mode. The main steps are as follows:

1) determination of fields and records to be imported from the data source, as shown in Fig. 2;
2) selection of coordinates and reference system, which are mandatory features, as depicted in Fig. 3,;
3) selection of further optional features, concerning the survey the imported records refer to (see Fig. 4).

At the end of the assisted procedure, individual nodes are imported. When import is complete, nodes can be viewed directly on the map as shown in Fig. 5. When a point is selected on the map, its records are shown in the boxes on the right hand side of the user interface.

Initially loading procedures will involve historical data, collected by surveys carried out on Taranto Sea sites in the past. Subsequently, in the same way new data will be uploaded progressively during the environmental observation period.

B. Advanced query interface

A second JOSM plug-in was developed to support retrieval and analysis in the environmental data management platform.

 ISBN: 978-1-61208-505-0

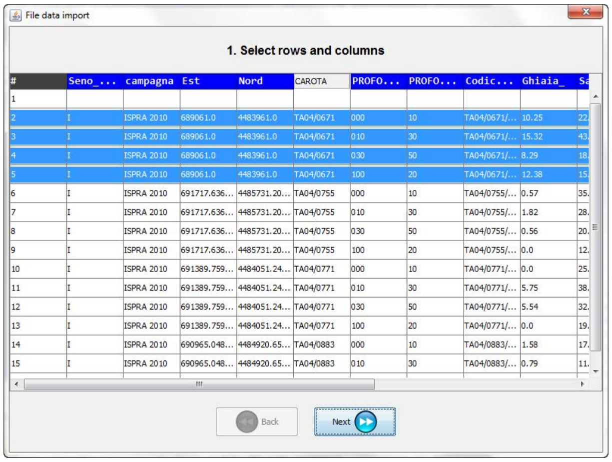

Figure 2. Import plug-in: record selection

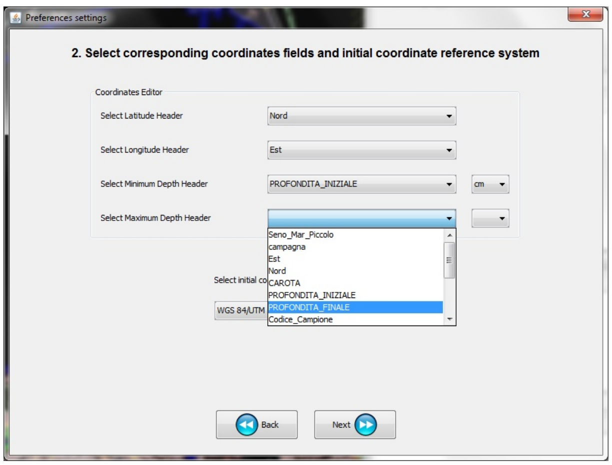

Figure 3. Import plug-in: geographical attributes selection

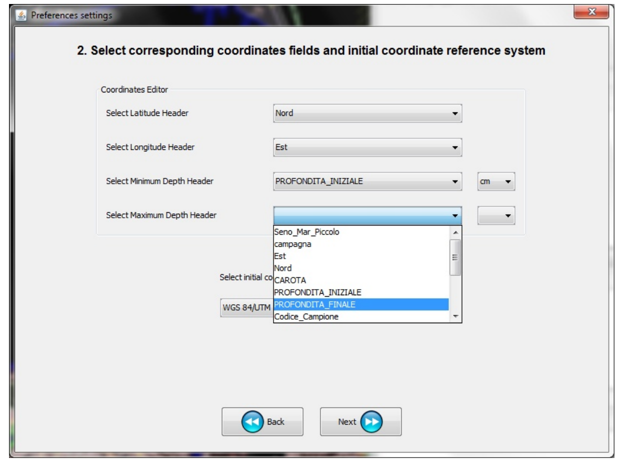

Figure 4. Import plug-in: optional attributes selection

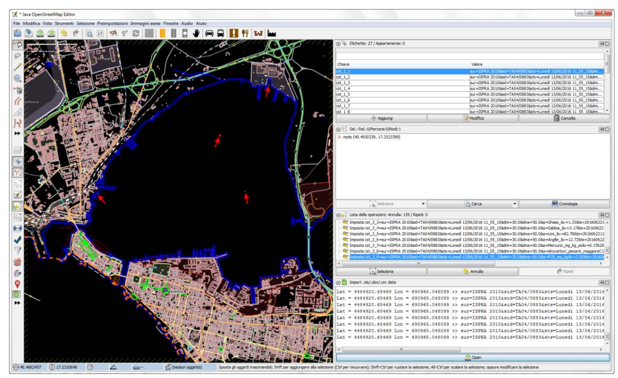

Figure 5. Import plug-in: result panel

It was designed to enable the advanced search of points of interest through the combination of multiple criteria. The built-in search functionality in JOSM provides a very basic interface, accepting just a query string as input. This poses a high usability barrier, since the user is required to have a working knowledge of the OSM data model, regular expressions and logical operators. This cannot be taken for granted for typical users, even for scientists and engineers working on environmental data. Furthermore, the limited syntax does not allow several kinds of complex queries. A different kind of search interface is needed, to enhance both user-friendliness and query flexibility.

As depicted in Fig. 6, the devised tool allows to express complex queries with:

- a filter on depth range;
- a filter on survey metadata, particularly useful for historical analysis;
- user-specified filters on any attribute stored in the system, both for number and string types.

Individual filters can be joined through logical connectors in a simplified, fully visual fashion. The tool hides the complexity of query composition behind a straightforward user interface. Users are not required to master the Overpass language in order to be able to compose articulated queries. After confirmation, search starts. The tool displays in red on the map the points of interest matching the query criteria.

V. Environmental Sample Tracking via RFID

As tracking of seabed samples is a challenging logistic task, the proposed ICT platform is open to the integration of RFID technologies. RFID allows the identification and tracking of

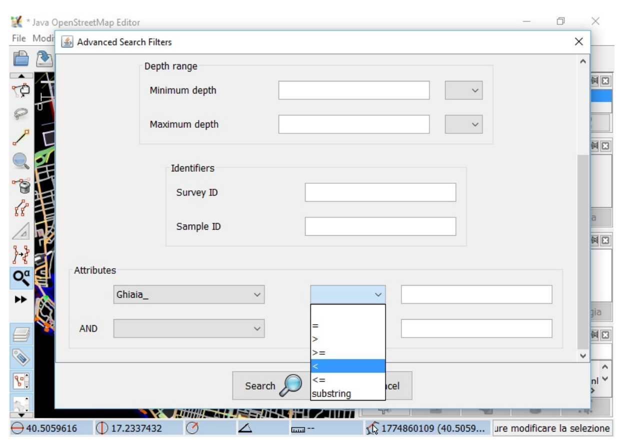

Figure 6. Advanced query user interface

objects equipped with transponders (*tags*), by means of fixed or mobile interrogators (*readers*) able to read and write data. Each tag stores a unique code which identifies the object throughout its life cycle. Compared to traditional technologies such as bar codes, RFID has a fundamental advantages, because reading occurs at a distance, with a range depending on the device technical specifications, and it does not require the optical alignment of the reader with the tag. Each RFID tag can be equipped with an enclosure capable of tolerating the operating environment conditions, making this technology suitable for processes with risk of exposure to liquids or acids and saline vapors, wide temperature changes, mechanical vibrations and shocks.

The RFID products market is very large and diversified: specialized offerings exist for a wide range of industrial sectors. A complete RFID solution typically includes: (i) a set of tags suitable for the objects to identify and the environment in which they will be used; (ii) a set of fixed readers to be placed appropriately, to detect objects crossing passages or presence in confined environments such as trucks or shelves; (iii) a set of portable readers, for operators in the field who have to read and write tags; (iv) a back-end software receiving real-time alerts of reading events from connected readers. A typical reading event consists of at least three elements: the identification code read from the tag (which uniquely identifies an object); a reader identification code (used to determine the location of the reading); a timestamp. In this way, the back-end software is able to build and manage a history of all handling operations on objects equipped with RFID tags. On this data, rules and queries of varying complexity can be specified to meet business needs. Furthermore, semantic annotations could be written into RFIDs attached to objects so that a meaningful articulated description accompanies the item the tag adheres to [22]. In such semantic-enhanced contexts, tagged objects act as actual resources, revealing –in addition to their identification code– a semantic annotation to nearby RFID readers; this allows them to describe themselves on the fly even when a central support infrastructure is not available. Semantic-based sensory data dissemination and query processing technologies could enable advanced solutions for environmental monitoring.

For marine environment analysis, RFID tags must be applicable to the containers of samples extracted from the seabed. The writing of the identification code will be performed on the pontoon hosting the extraction tools, as soon as a sample is placed in its container equipped with an initially empty RFID tag. From then on, each sample will be identifiable and traceable along the following planned steps:

- from the extraction workers to the logistics supervisor, on the pontoon;
- from the supervisor to a staff member of an analysis laboratory which takes charge of the samples directly on the pontoon;
- from the logistics supervisor on the pontoon to the warehouse;
- from the warehouse to analysis laboratories, where staff takes charge of the samples in their premises, and back again to the warehouse;
- from a laboratory to another laboratory directly, with possible partitioning of a sample into smaller ones (which have to be tracked individually thereafter).

In detail, a process analysis step revealed the following requirements for the proposed RFID solution:

- a set of tags attached to the body and the cap of each container. The container and cap identification codes will be strongly correlated to allow verifying the simultaneous presence of both elements. Tags must be resistant to sea water also in the presence of any pollutants;
- portable readers for writing tags on the pontoon;
- fixed readers on each warehouse gates as well as on shelves, to monitor the arrival and the departure of samples and to check how many samples are currently present;
- fixed readers at the gates of each laboratory to monitor sample movements;
- fixed or portable readers for writing operations, dedicated to laboratories which must be able to divide a sample into smaller ones, each with its own container.

Among the different available RFID tag families, the EPCglobal Generation II Ultra High Frequency (Gen2 UHF) standard from GS1 Consortium [23] emerges as the most advisable, since it guarantees secure read/write operations and the compatibility with the majority of readers and software tools. Examples of different types of tags available on the market are reported in Table I. They are all enclosed in a waterproof plastic material resistant to dust and water immersion, and equipped with user memory for the storage of additional data beyond the Electronic Product Code (EPC) identification code.

TABLE I. RFID TAG EXAMPLES (PRODUCT NAMES OMITTED)

Storage	Packaging	Reading range	Operating temperature	Cost
EPC 128 bit, 512 bit of user memory	Plastic (IP 68 certification)	up to 9 meters	From -40 to 80 °C	€450 for 100 tags
EPC 96 bit, 512 bit of user memory	Thermoplastic (IP 68 certification)	up to 6 meters	From -40 to 85 °C	€60 for 10 tags
EPC 96 bit, 512 bit of user memory	Polypropylene (IP 68 certification)	up to 7 meters	From -40 to 85 °C	€32 for 10 tags

Back-end software solutions are currently divided in two main categories: full packages to be installed and run on one's own computing infrastructure; Platform-as-a-Service (PaaS) cloud offerings, with elastic computing resources and pay-as-you-go fees. Anyway, the general architecture of RFID software compliant with GS1 standards is shown in Fig. 7. The main elements are:

- Low-Level Reader Protocol (LLRP), ensuring compatibility with interrogator hardware from multiple manufacturers;
- Application Level Events (ALE) compliant middleware to catch and manage RFID reading events; it embeds a rule engine for declarative specification of customized business rules;
- Electronic Product Code Information Services (EPCIS) for describing, gathering and sharing data associated with tracked objects, also across computer networks.

As back-end software tools support custom extensions, real-time RFID event tracking can be integrated with the OSM-based software solution described in Section III, in order

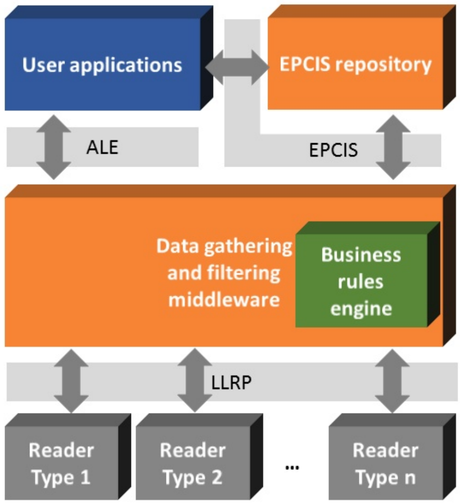

Figure 7. RFID management software architecture

to provide a unified platform for the whole environmental analysis workflow, from field to laboratory.

VI. Conclusion

The paper presented an integrated ICT platform supporting analysis of the marine environment in Taranto Sea, Italy. The proposal is based on principles of crowdsourcing and comprises an information system –based on OpenSeaMap– for managing georeferenced and timestamped data, as well as specialized tools –as plug-ins for the JOSM editor– for massive data import and advanced queries. Furthermore, the feasibility of integrating RFID technologies to track survey samples in all steps of their life cycle was evaluated.

Future work includes a full validation of the proposed platform in all activities of the environmental analysis and requalification program. As the devised platform provides a general solution for many analogous scenarios of environmental monitoring and decision support, it is possible to export it to other contexts beyond the Taranto Sea, with minimal effort.

Acknowledgment

Authors acknowledge the project “Accordo con il Commissario Straordinario per gli interventi urgenti di bonifica, ambientalizzazione e riqualificazione della città di Taranto”.

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 ISBN: 978-1-61208-505-0