Innovative strategy and process for underwater data gathering and results elaboration.

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***Abstract* — The development of new marine environment monitoring technologies is a field of research involving an heterogeneous public. The documentation and cataloging of underwater sites as well as the supervision and sampling of biological parameters have always involved researchers like archaeologists and biologists. Moreover, sport activities regarding the sea have been showing a keen interest in more efficient devices that are specifically developed for storing data during the immersion. Within the introduced framework, it is important to let the user operate in an efficient and easy way, without creating damages to the environment.**

This paper describes the design and realization of a device, called DiRAMa, and the relative architecture for data gathering in underwater environments. The device is planned to make the image and data acquisition easy, and let the user upload all the information on an appropriate Web Server as soon as an Internet connection is available. Users can launch 3D reconstruction processes, which use photos and other materials just uploaded, while the Web Server sends notification on the mobile device informing about elaboration status. Innovation and potentiality brought by DiRAMa are introduced, and the general architecture of the system described. The validation of the structure out of water and its use in real field mission involving biologists and other scientist is discussed, together with possible future improvements.

I. Introduction

THE underwater world has always fascinated researchers from different areas, as well as all lovers of the sea, because it hides treasures difficult to reach, and at the same time, many aspects of biological processes are still unknown. For these reasons, the study of submarine environments is affecting a growing audience in the fields of science, technology and entertainment. The main problem shared by several applications is the ability of obtaining detailed maps and documentations in an efficient, low cost and safe way; obviously, reaching such kind of objective is probably the most difficult in such a hostile environment [1], [2], [3].

Several application fields have proved the necessity of new easy instruments and strategies for:

- detecting potential sources of contamination related to industrial, agricultural, animal husbandry [4], [5]; monitoring and sampling data, physic, chemical and morphological features of the biological environment [6], [7];
- reconstructing archaeological sites with 2D or 3D maps, both for study purposes and presentation to the community [8], [9].

Even the recreational sphere requires an increasing assistance of technology for:

- taking pictures, storing data and distributing through 3G/4G networks explored areas directly from visited sites (with diving or snorkeling activities) [10];
- exchanging information through social networks, blogs or sharing applications.

Within the different application fields described above, a lot of work has been done in order to investigate methodologies and theories and to obtain measurement instruments and robotic systems optimized for final users. The technology available on the market requires development costs and huge work, foreseeing the employment of large vessels and qualified staffs, as well as efficient tools for data processing [11]. The conjunction of all these features, however, has becoming uncommon: experts search for economic solutions, the community prefers usability. Roman et al. in [12] and other publications explained their research on robotic systems capable of operating in complex dynamic environments. They work on 3D reconstructions, segmentation, data mining, and visualization for massive datasets gathered with robotic systems, developing even an iOS application to visualize 3d models of the seafloor. In [13], authors present a service, called ARC3D, that creates complete and realistic 3D models out of a set of photographs taken with a consumer camera. Results are made available for web browser viewing using WebGL. The system is very functional, but it lacks of a device which can guide users during images acquisition and through which they can directly upload photos and launch the processing.

Starting from this framework, the present work describes DiRAMa, a device designed for image acquisition and three-

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dimensional reconstruction of submarines heterogeneous environments. The project won the Working Capital 2012, Telecom Italy S.p.A. initiative aimed at rewarding the most promising ideas in the field of research. The project tries to answer the need for new tools to detect potential sources of contamination related to industrial, agricultural, animal husbandry and treatment of municipal wastewater, contributing to environment monitoring in an autonomous or semi-autonomous way. DiRAMa can also provide useful application in protection and preservation of marine cultural heritage, represented by marine species, connotative basic parameters or archaeological sites and wrecks. Regarding the protection of cultural heritage, it is interesting to underline that studies on the archaeological sites have always aimed at obtaining very accurate graphical representations of reality. In the field of recreational diving, divers can use the device to photograph and reconstruct the explored areas; the documentation produced in this way can subsequently be analyzed by other divers before reaching the point of immersion.

The paper is organized as follow: Section II describes features and innovation aspects of DiRAMa; Section III explains the general architecture of the system, while Section IV illustrates solutions designed for each component implementation; validation and test results are presented and described in Section V, conclusions and future developments are illustrated in Section VI.

II. Features and Innovations

DiRAMa is an acronym meaning embedded device for the reconstruction of the physical, chemical and morphological status of marine environments; Fig.1 represents its logo.

DiRAMa

Figure 1 DiRAMa logo

As introduced in the previous paragraph, it is conceived as an innovative device containing and managing instruments necessary for the 3D reconstruction of a given area; it includes different kind of sensors, though being low-cost and small. The project aims at providing the device with tools for image capturing, synchronized with inputs from sensors allowing specific knowledge of the position and inclination of the machine at the acquisition time; the microcomputer constituting its intelligence is able to process this different set of sensor information. No other device currently on the market is able to collect, process and synchronize data of a kind at low cost. The principal innovation brought by DiRAMa is the integration of multiple heterogeneous knowledge concerning the marine and underwater environment, using COTS component already tested and reliable. Images acquired during an immersion hide additional levels of information from the same area, concerning mainly location coordinates, pressure, and temperature, saved within the EXIF part at the time of shooting. This is achievable using sensors and low-cost intelligence, and developing a suitable software for managing collected data. A list of useful elements is the following, graphical represented in Fig. 2:

- a 2D or 3D camera;
- a microcontroller for data processing and synchronization;
- a series of sensors for geolocation and detection of other specific quantities, i.e. example temperature, pressure, brightness, PH, GPS sensors (usable on the surface), position sensors.

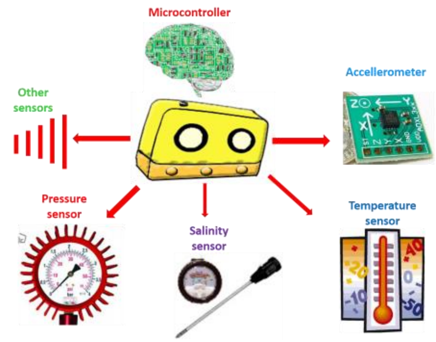

Figure 2 DiRAMa principal components

Data gathered by the device has to be stored in a database managed by a well-organized server technology, able to process them and return results to external users. This project is aimed at providing greater data processing, implementing 3D reconstruction algorithms on the external server; this expands the list of possible results with a three-dimensional model of the area explored, and answers to the necessity shown by several kind of researches [7], [8]. It is also important to let reconstruction being modifiable with software suites of common use or open source, even directly from the mobile device employed for taking mission data. Section III will describe the specific architecture and realization choices done to reach the project final aim.

III. Global Architecture

Developing DiRAMa has implied the implementation of a complete architecture. This section describes the general structure and its components, focusing on the choice done regarding the technologies used. Fig. 3 shows a schematic representation of DiRAMa system:

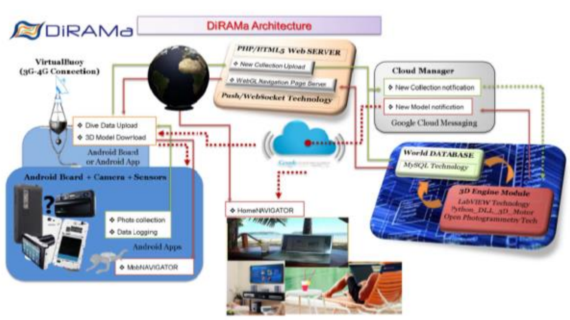

Figure 3 DiRAMa system: general architecture

The figure shows the single actors playing their role within the global framework. Lines represents the information exchange. In the following, each block is introduced.

A. *Mobile acquisition device (Android Board)*

This block characterizes each aspect related to DiRAMa, the device used by the final user to collect data. An image acquisition sensor, a microprocessor and other measuring device constitute it. When the device is brought out of the water and an Internet connection becomes accessible, it plays the role of a virtual buoy, sending the saved information to an opportune server. Scouting for a suitable technology, we identified smartphones, tablets and smart cameras equipped with open source Android OS, including the fundamental part needed for the project, which has been developed in a small slot of time (less than one year). Other external sensor data can be acquired using external hardware specifically designed (i.e., IOIO for Android). The realization of an interface has consisted in developing an appropriate application able to gather images together with other data, and send them to a server. The possibility of registering and login to services implemented in the Web application has been added to guarantee the user privacy. The same device allows displaying the post-processing results. In order to use DiRAMa underwater, commercial or custom underwater housings are available.

B. *PHP/HTML5 Web server*

The data acquisition and cataloging has been implemented on a web server. It takes care of managing customer data registration and photos sent with DiRAMa, storing them into the database, showing results to the user, and displaying the Web app developed in order to reach and edit the immersion information. Another fundamental role of this part consists in the connection with the 3D Engine Module, to which it requests to elaborate reconstructions and from which it receives back results. The Web application introduced above is based on PHP server-side scripting and HTML5 markup language.

C. *3D Engine Module and Database*

The 3D Engine module implements complex reconstruction algorithms and shares information with the Web Server. The module make use of the database where info and elaboration results are stored. Users can request a 3D elaboration using both the Android application and Web interface; these commands are managed by the PHP Web server.

D. *Cloud Manager*

Users are able to monitor the elaboration progress thanks to the notification system, an additional functionality considered important by several beta tester. For this reason, the system implements notification using Google Cloud Messaging (GCM), a free service that helps developers to send data from servers to their Android applications. It could be a small acknowledgement or a message of up to 4 kb of data payload. In this framework, GCM is useful to send short text messages informing about elaboration success or eventual errors. The 3D Engine Module is also able to send email notification containing the same kind of information, useful for Web application users.

E. *Home navigator*

Results can be handled using free software available online, such as MeshLab [19], an open source software is able to display and modify models of three-dimensional geometries and the relative texture. Results are presented in PDF format too, so they can be visualized with Adobe Acrobat Reader®.

IV. IMPLEMENTATION

This section describes the global architecture just introduced, detailing implementation procedures and choices. The system is basically a client-server application. In the following, client applications and the server side development are detailed.

A. *Android Application*

First of all the attention has been focused on the client, and then on the end user: the principal aim is to provide a user-friendly interface, through which managing data and information. For these reasons, the use of devices such as Android smartphones and tablets required the development of an appropriate application able to guide the customer to an efficient data-gathering mission. The Android application integrates the management of registration and user login, shooting, ability of displaying data from missions already loaded on the server, and reconstruction lunch. It was written using Eclipse as an IDE, integrating the appropriate Android SDK released by Google. The application has been divided into 4 modules:

• **camera management**: contains everything related to camera management: shooting, integration of location data from GPS and accelerometer, the choice of camera settings, image upload on the server, and reconstructions launch;

• **libraries:** this module implements libraries needed to communicate with the web server via JSON , the management of Android device internal database, the wake locker management useful for notifications delivery;

• **user data:** contains the code for user registration and log in, creation of a new mission, missions list and mission details display;

• **notification:** contains the classes essential to use the GCM.

Fig.4 shows the Application Activities and their relation:

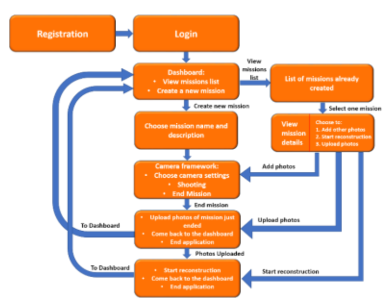

Figure 4 Android Application: Activities and their relations

First, the user as to register or, if he has an account, can directly choose to login: if the operation is successful, the device is automatically register to the GCM notification system. Once logged in, it is possible to create a new task, or to visualize other missions already generated. Mission details contain the principal information useful to recognize it; other details are accessible from the Web interface. At the end, it is possible to upload immediately images just gathered; vice versa, the user can decide to make this operation successively, through the mission details menu. Communication with the Web Server has been implemented using get or post methods, encoding data with the open format JavaScript Object Notation (JSON). A post method has been used also to inform the server that the user wants to start a reconstruction. From the application, indeed, it is possible to choose between 9 combination of quality-type of result as described in the following figure:

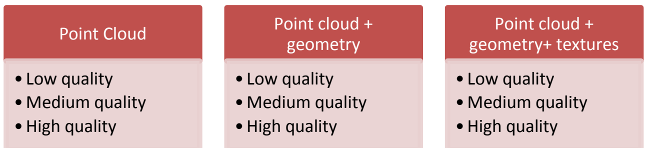

Figure 5 Android Application: possible quality – type of reconstruction

This corresponds to predefined process parameters, which will be distributed to the 3D Engine Module by the Web Sever. The Web server sends periodical notifications to the device informing about the reconstruction status, using the GCM; notifications appear as status bar on the mobile display.

B. *Web Application*

The development of a Web Application was considered important in order to allow the user to access data using the personal computer, and to manage them easily when at home. Moreover, the Web Interface can be used independently from the mobile application, giving to the customer the same functionalities (except the camera capturing) and the possibility of uploading images taken with device. This step make the system completely cross-platform. Pages related to the graphical interface are hosted on the PHP/HTML5 Web server.

The development of the Web interface has been carried out using modern capabilities of HTML, generating pages dynamically thanks to insertion of the markup code in PHP scripts executed by the Web server. The access is always allowed with the same credentials used in the Android application, and vice versa. Functionalities implemented on the Web App are represented in Fig. 5:

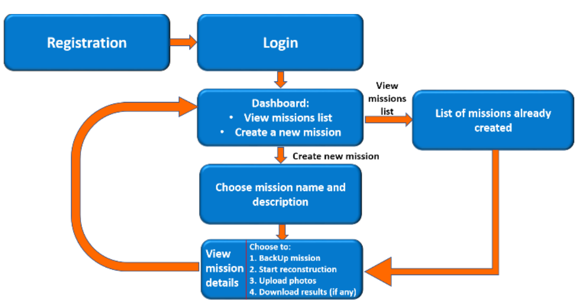

Figure 6 Web Applications: pages and their relation

From the figure it results clear that a lot of tasks are the mirror of Android Activities. The main differences are the following:

- the camera capturing has been substituted by the possibility of upload images taken with other cameras;
- the notification service implemented on de mobile device thanks to GCM is substituted by an email report service;
- from the Web it is possible to download 3D elaboration results.

C. *Web Server*

The global architecture depicted in Fig. 3 requires a server able to manage users, store their data, keep track of all information regarding gathered data and show a simple and intuitive interface as the one describe in point B, through which users access and manipulate materials. The work presented in this paper involved the development of a Web Server with the feature just introduced, and the ability of talking to the 3D Engine Module, launching reconstructions and recovering results to make available.

The following figure presents the script structure and the main functions of the Web Server:

Figure 7 Web Server software structure

• **authentication**: is responsible of let the user register and login to the system services, storing opportunely his data on the database. As introduced previously, this is possible both from the mobile device and the Web App, using the same credential;

• **mission:** concerns all the script managing the missions; in this part all commands and data recovery to the 3D Engine are implemented;

• **gcm:** contains the code which allows the dialog with Google servers and the mobile device through which the user have logged in.

D. *3D Engine server*

The 3D Engine Module depicted in Fig. 3 is responsible of processing images gathered by the user to obtain three-dimensional reconstructions of the explored environment. The algorithms able to carry out this task are implemented in a server physically separate from the one described in point C and make use of the LabVIEW Web Server technology. LabVIEW is a system-design platform and development environment for a visual programming language from National Instruments. Here the LabView Web Server is responsible for starting scripts implementing the 3D reconstruction algorithms, after having received POST requests from the PHP/HTML5 Web Server. At the end, the same Web Server sends back results, stored in the most common modeling formats as PLY (Polygon File Format), OBJ + MTL, DAE (Collada), and PDF. PLY, OBJ and DAE. It should be emphasized that these are easily usable through common GIS (Geographic Information System) and processing software including MeshLab, open source and available for multiple platforms. In the future, the Web Server controlling the 3D Engine will be implemented using python on a Linux machine.

V. Results

This section shows the system validation, presenting firstly the reconstruction of an out-of-water object; then, results obtained from coralligenous environments using the system on the site of Gallinara Island (Ligurian Sea, Italy) will be described and discussed. The Android application was employed to take few images of an external bench. Fig. 8 shows the visualization of the obtained 3D geometry model directly on the mobile device, using MeshLab [14] for Android, freely available on Google Playstore.

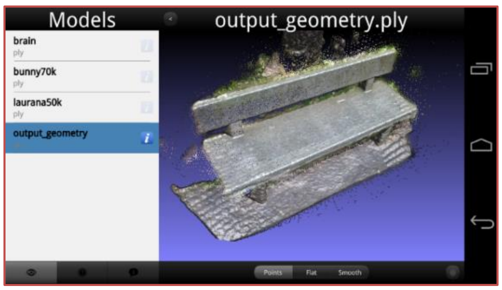

Figure 8 Bench model on MeshLab for Android

The same figure demonstrate the possibility of access elaboration results directly from the smartphone or smart camera. Fig. 9 depicts the detail page of the Web Application relative to the same test. User has an immediate feedback on mission position, images uploaded, and results available. Among the possible formats for the 3D elaboration, fig. 10 shows the PDF one using Acrobat® Reader®.

Once fixed the system in a terrestrial context, the proposed method has been validated on real marine data; the first underwater test has regarded the acquisition of images depicting coralligenous habitats located at Gallinara Island (Ligurian sea; Italy) [15], using external cameras and the Web Application. The final biologists ‘aim was to provide baseline maps for future monitoring of coralligenous environments changes and evolution in the Mediterranean basin. Another key aspect is represented by the opportunity of involving trained volunteers not necessarily confident with technologies, sponsoring the collaboration of heterogeneous teams and exploiting with higher frequency innovative web technology [16].

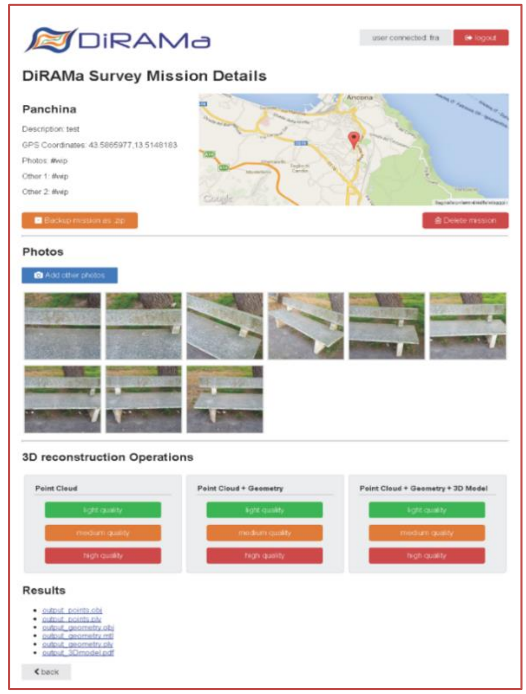

Figure 9 Mission detail page of DiRAMa Web Application

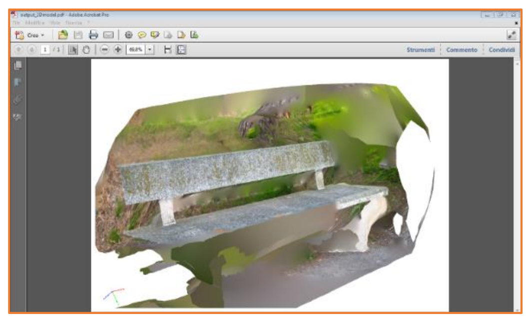

Figure 10 Bench 3D Model: PDF format

Two calibrated Go-pro Hero (3D system) were used to collect video, while one Go-pro Hero 2 had the role of acquiring only images. The SCUBA diver moved the cameras trying to maintain always the same distance over the substratum (around 40 cm) and progressed around the locations (Fig. 11).

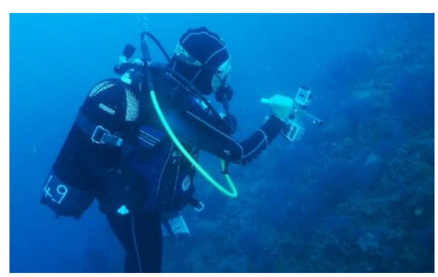

Figura 11 Field trip data collection: diver holding 3D system camera

Cameras were moved over transects measuring about 10 meter in flat position or inclined 45°: five or six transects were collected at each location. Morevover, specific targets where deeply investigated, such as sponges, and used as reference points. The accessory data to be used during the reconstruction and documented by divers are depth and direction information. In this case, the same information have been constituted a starting point for autolocalization algorithms swallowed in the 3D Engine module. Results have shown and interesting overview on coralligenous structure and the spatial heterogeneity of marine organisms composing the habitat. Biologists have underlined the high-resolution of the results: the selected areas can be exactly reexamined in post processing and used for future immersions (Fig. 12); this is strengthened by the fine scale features of the terrain visible within the 3D documentations: the reader can analyze the surface roughness and slope that provide notion of the habitat structure.

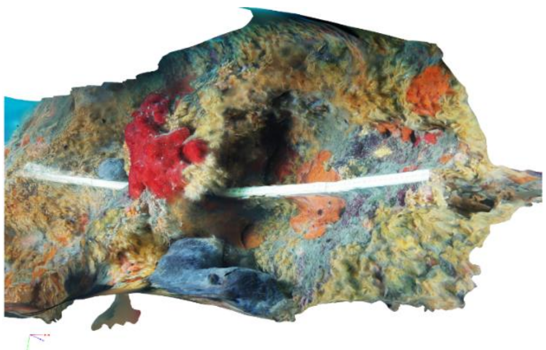

Figura 12 Gallinara Island survey: 3D reconstruction using DiRAMa

In addition, spatial relationships within the data are preserved, and users can move from a high-level view of the environment down to very detailed investigation of interesting features within it (see for instance the high resolution of *Parazoanthus axinellae* in the scene, represented in Fig. 13). The collected data allowed the valuation of the substrate types and the characterization of the epibenthic assemblages associated with coralligenous environments. The relative 3D representation make biologists able to monitor any kind of transformation in these environments. Next target is represented by identification of patterns that can be used for automatic classification of images.

Figura 3 Gallinara Island model: detail of *Parazoanthus axinellae*

VI. Conclusion

This paper discussed the design and realization of DiRAMa, a device aimed at acquiring photos and other information from the underwater environment, and the infrastructure through which users can upload images on a Web Server, store their data and launch 3D reconstruction with gathered images. System validation and results obtained underwater have proved the robustness of DiRAMa architecture, able to present professional documentation in an easy framework to common users. Results can be used to analyze the environment with scientific methodologies, or can be shared in the recreational scuba community.

Future works will concern the extension of both mobile and Web applications with new functionalities, the implementation of the 3D Engine and the PHP/HTML5 Web Serve in a common framework, tests and validations of the whole structure in other field missions.

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