IMEKO International Conference on
Metrology for The Sea
Naples, Italy, October 11-13, 2017

Procedures and Technologies for 3D Reconstruction with Divers of Underwater Archaeological Sites and Marine Protected Areas

Luca Panebianco[1], Silvia Zingaretti[1], Nicolò Ciuccoli[1], Corentin Altepe[1,3], S. Murat Egi[4,5], Fiorenza Micheli[5], David Scaradozzi[1,2]

[1]*Dipartimento di Ingegneria dell'Informazione, Università Politecnica delle Marche, Ancona, Italy*
[2]*LSIS, CNRS, UMR 7296, Marseille, France*
[3]*Bogazici Underwater Research Center, Istanbul, Turkey*
[4]*Galatasaray University, Computer Engineering Department, Istanbul, Turkey*
[5]*DAN EURope Reseach Department, Roseto, Italy*
[6]*Hopkins Marine Station, Stanford University, Pacific Grove (CA), USA*

***Abstract* – Underwater monitoring and exploration actions are fundamental to preserve natural habitats and submerged cultural heritage, but researchers have to face high costs related to technology and staff to carry out researches in this troublesome environment. As a partial solution to these problems, Citizen Science has been incrementally employed by the scientific community but, to effectively make the most of it, it is mandatory to design two components: a generic-scenario procedure that describes the steps to perform before, during and after the survey and tailored technologies to acquire, gather, process and visualize the environmental data. In this work, a procedure tested in different underwater missions, that is the enhancement of a precedent one, and technologies that, arranged in a pipeline, carry out all the process from data acquisition to output visualization are presented. The procedure and technology were tested in tailored tests aimed to guarantee the validity of the technologies.**

I. INTRODUCTION

The marine environment is well known to be very important from different point of views. For example, it is fundamental to sustain a high number of life species and human activities but, at the same time, its sea bottom is rich of artifacts of ancient and more contemporary human history, so its preservation provides benefits to the whole society and it constitutes a basic need for the mankind. Archaeologists conduct surveys looking for historical areas, to catalogue the distribution of material culture over regions, to extract information or test hypotheses about past cultures, and to analyze the impact of human activities on archaeological heritage. For biologists, it is therefore essential to monitor factors and indicators to evaluate the effectiveness of Marine Protected Area (MPA) establishment and management, and to put in place adaptive measures to address emerging challenges such as climate change. Therefore, for these researcher groups it is fundamental gathering and accessing a wide amount of robust and georeferenced data from the underwater environment, performing widespread surveys among different years. However, these measures are often too expensive in terms of personnel, time and instrumentation to be carried out by a single research group.

In the recent years, to reduce the time and costs for those types of marine research, many scientists started to exploit Citizen Science in their activities (see [1], [2], [3], [13] and [4]). Citizen Science studies and projects enlist members of the general public in the collection, categorization and analysis of data with or under the direction of professional scientists or institutions.

The engagement of such non-specialist volunteers brings to many positive consequences: the access to manpower sufficient to conduct extensive and long-term surveys, large financial savings and an increase in the level of public awareness of ecological problems through active participation in ecological survey work. Citizen Science projects regarding the marine environment are particularly successful thanks to the fact that diving is nowadays a mass leisure activity, that involves millions of people from all over the world.

This kind of research, requires tailored procedures to conduct the survey and technologies employed by divers to efficiently manage the data acquired.

In this paper, a refactoring of a successful previous methodology, with an insight for the exploitation of Citizen Science, and low cost and easy-to-use technologies, that aim to integrate all the different steps of processing of data will be introduced.

The rest of the article is structured as following: in Section II the survey procedure adopted previously is presented and some critical aspects are discussed. Section III presents the refactoring of the previous methodology that is now employed. Section IV presents the data pipeline that has been considered to allow to obtain visual-enriched results from the data acquired from the marine environment and which technologies are involved in this process. Section V presents some tests performed during different sea trials by volunteer divers that exploited the presented survey procedure and technologies. Finally, in section VI some results and considerations are marked in account for future developments of the procedure and the technology involved.

II. PREVIOUS SURVEY PROCEDURE CONSIDERED

In the Green Bubbles project, one task of the engineering partnership is to investigate and suggest new technologies to gather data in the most automatic and efficient way, with the possibility of enrolling recreational divers. To use, in efficient way, autonomous devices for untrained divers rigorous protocols with strict procedures, easily to teach, are needed. This problem can be related to what happened at the end of nineties, when the underwater geomatics techniques started to benefit of robotics technologies but found not trained field operators. During last decades, authors, within many European Projects partners, tailored the following winning methodology for measuring and documenting archeological sites [5]. After some years of application, nowadays this process has been proven robust and viable to be extended and employed in different scenarios and research areas.

The original archeological protocol was usually composed of nine different steps (with some of them repeated more times), briefly described as *Area Choice*, *Site Localization*, *Site Cleaning*, *Site Positioning*, *Artifact Cataloging (Point Of Interest Cataloging)*, *Sea-Bottom Reference System Adding*, *Site Surveying*, *Site Restitution* and *Site Exploration*.

These are some considerations and issues that were brought in consideration during the years:

- *Too tailored for archeological purposes*: the kind of scenario where the methodology was applied was related exclusively to underwater archeology. It is possible to notice, in fact, that some phases (such as Site Cleaning and Artifact Cataloging) are not mandatory in other scenarios and additional phases could be required in different cases. The new proposed methodology must be viable for researches conducted by any kind of marine scientists that need to acquire large amount of underwater data, providing different procedures for different scenario that follows, overall, the same methodology;
- *The surveys were performed exclusively by researchers and professionals*: to fully exploit the potential of Citizen Science, volunteer divers must be introduced in the process. This consideration implies tailored briefing sessions and tutorials, that should be viable to the wider number of people possible;
- *The instrumentation was too specialized*: the type of instrumentation was limited to professional underwater cameras, ROVs and USBL tracking devices. These technologies are usually costly to buy and maintain (for example, a supply vessel could be necessary to deploy and recover a ROV). A partial solution can be found for example in [6], [7], [8] and [9], where autonomous vehicles are exploited to lower the overall costs of an underwater mission.
- *No training was involved in the process*: the people involved in the research were already able to use the instrumentation, so no training phase was designed and implemented. In new scenarios, divers are not scientists or initially aware of the technology that they must be able to master in a short time. This aspect conditions mainly the requirements of the technology involved in the process, that should be easy to use and user friendly.

Because of these considerations, a reworking of the procedure used until now and of the technologies employed is suggested to improve the overall spread and ease of application of it in a generic underwater scenario.

III. PROPOSED GENERAL METHODOLOGY FOR GEOSPATIAL MEASURING AND DOCUMENTING UNDERWATER AREAS

The above-mentioned consideration made necessary a refactoring of the previous procedure, with these main objectives:

- To define a set of procedures applicable in general underwater inspection and research scenarios carried out by scientists and volunteer divers;
- Exploitation of Citizen Science as a tool to decrease costs and leverage the awareness of the cultural/biological heritage of the marine environment;
- Insert in the methodology a specific phase for training and feedback evaluation to allow a continued improvement of the methodology;

The proposed methodology is composed by three main phases:

- *Pre-Survey*: this phase is conducted by marine scientists. This phase is usually made one time for each site. These are the actions that are taken:
  - *Investigation Area Choice:* in this phase an interesting area is chosen and proper documentation is collected;
  - *Site Preparation:* this phase is different for each type of mission scenario and different procedures are designed. In a scenario of archeological survey for 3D documentation, for

example, some steps of the previous procedure are applied such as cleaning of the site and artifact cataloging;
  - *Site Localization:* in this phase the survey area is organized in different zones called "sites". Each site area is localized by means of GPS coordinates.
  - *Mission Profile Creation:* for each site or for groups of sites, different mission profiles are created. A mission profile is defined by a unique name, a list of tasks to process and a site or a list of sites where the mission will be performed. Each task is defined by a time limit and a list of actions to perform. An action is an atomic procedure that the diver must perform (such as "go-to", "shoot a photo"). This allows to scientists to limit and formally define the number of action that must be trained to the divers.
- *Survey* (repeated more times): in this step the volunteer divers are introduced in the process. It is divided in these phases:
  - *Training:* the volunteer divers are introduced to the technology that they will use during the survey. It is mainly divided in two phases: firstly, an explanation is given by means of slides or oral presentation that introduces the features and operation of the devices, then there is a dry hands-on with a simulation of different procedures;
  - *Mission Profile Briefing:* the volunteer divers are introduced to the mission profile that they will follow. After the overall scenario is introduced, the list of different actions that can be requested together with some suggestions are described. These tips are usually a mix of previous knowledge and feedback received from previous surveys;
  - *Survey:* the actual survey is performed. During this phase, the data are acquired by the devices carried-on by the divers;
  - *Data Gathering:* just after the dive, it is mandatory to store ultimately the acquired data, attached with all the information related to the performed mission;
  - *Survey Feedback:* feedback is received from divers to exploit weaknesses related to the technologies and to the process. This is performed in the form of interviews after the dive or surveys.
- *Post-Survey*: in this step the data is processed and validated.
  - *Data processing*: in this phase the data is processed by automatic tools to transform raw data in images in higher-value outputs such as 3D reconstructions and enriched maps;
  - *Survey and Data Validation:* finally, the scientists will be able to review the data to validate it, to perform further researches or to take specific actions. To increase awareness and sense of participation of the divers, collected and processed data is usually available to them.

IV. EMPLOYED TECHNOLOGIES

The proposed procedure must be integrated with technologies that aid the phases where volunteer divers are involved. In fact, in the *Survey* and *Post-Survey* phases the data must be processed through a pipeline that can be synthetized by four important steps:

- *Acquisition*: in this phase, the environmental data is acquired by a device and temporary stored. Each data must correspond to a specific class of data. A fundamental information that must be attached to each entry is the timestamp, that allows in the following step to synchronize data;
- *Gathering*: in this phase, all the data acquired from a single device, that performed a single mission, is uploaded and stored ultimately. In this phase, the representation of the information is standardized: for example, a GPS position is defined by a couple of floating-point expressed data, where the first is the latitude and the second is the longitude;
- *Elaboration*: in this phase, through tailored algorithms, the input data is transformed to the required output;
- *Output Visualization*: in this phase, a device can download the enriched and elaborated data in order to show it to the end-user by means of proper applications.

Using this formalization will be useful to introduce requirements and validation indexes easy to implement on expert management tools with the aim of design site study and preservation actions. Some of the requirements that can be highlighted to evaluate hardware technologies could be for example:

- *Easy-to-use* and *easy-to-master*: the designed equipment should be employed efficiently by an unaware user in the less time possible. This can be achieved also by means of well-known technologies such as smartphone, tablet and user friendly GUI;
- *Modular*: a modular design helps to decrease the amount of knowledge necessary to use a different version of the same technology and the amount of time to design it;
- *Low-Cost*: lower the costs, while increasing the overall performance and robustness of data acquired, can help many researchers to improve their studies by using better technologies.

Before develop a systematic tool for design intervention actions, authors concentrate their work on providing the scientific community of an easy-to-use, low cost tools for automatic data survey and site documentation.

In this paper two are the main technologies designed to fulfill the steps of the previous pipeline: DocuScooter ([10]) and DiRAMa ([11]). The first can take care of the acquisition and output visualization phases, while the latter can gather the underwater data and elaborate it, performing for example a 3D reconstruction from the acquired images.

A. DocuScooter

DocuScooter is an innovative tool able to equip different types of commercial underwater scooters to acquire heterogeneous data from the marine environment. This instrument has been developed in the context of the H2020 Green Bubbles European project. The structure of DocuScooter is shown in figure 1:

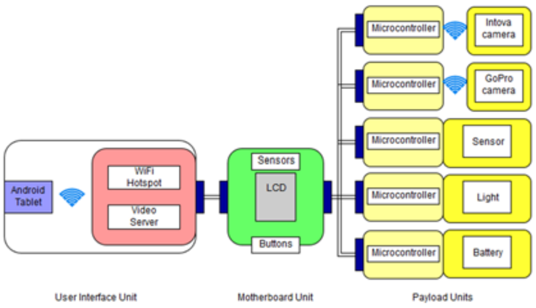

Figure 1: DocuScooter architecture

It is defined as a three-layer structure composed by:

- *User Interface Unit*: composed by an Android tabled with a tailored application that can manage the DocuScooter and a subsystem that acts as a bridge between the underwater tablet and the rest of the device by means of a Wi-FI connection. To decrease the overall cost, this unit is optional;
- *Motherboard Unit*: composed by a custom electronic board that manages the data exchange in the DocuScooter. It is equipped with an LCD screen to show some information about the ongoing mission, buttons to provide interaction with the system and some exclusive sensors such as a depth and temperature sensor;
- *Payload Units*: this layer is composed of an array of compatible COTS (Component-Off-The-Shelf) that the diver wants to attach to the DocuScooter and control from the underwater tablet or with buttons and LCD of the Motherboard Unit. At the moment, these are some of the available devices: underwater Wi-Fi sport cameras (from Intova, GoPro and Kodak), underwater lights, external batteries and other sensors for environmental monitoring. The COTS are connected to the system by means of a microcontroller that uses a common protocol shared between the different Payload Units;

One of the newly designed Payload Unit is a surface buoy able to estimate, through tailored algorithms, the underwater position of the diver during the survey ([12]).

The requirements for its design were:

- *High modularity*: different scenarios need different Payload Units. Because of this, these devices are engineered to be connected, disconnected or swapped in the system without compromising its functioning;
- *Low-cost*: to be easily employed by researchers and by the diving industry, it is necessary to decrease costs by exploiting COTS component. This allows the end users to use their own equipment as much as possible and to exploit the overall lower price of commercial equipment;
- *High extensibility*: in order to provide a facilitated way to add new compatible devices in the system an effort has been channeled to define a well-documented and easy-to-use interface to provide access for a wide range of different COTS. In fact, it is mandatory to respect only the power supply voltage, the protocol used to communicate through the system and the connector;
- *50m depth rated*: the developed hardware is designed to be used for extended periods of time at a maximum depth of 50mt, that is the maximum depth achievable by commercially-available underwater cases of sport cameras.

B. DiRAMa

DiRAMa is a platform designed for image acquisition and three-dimensional reconstruction of submarine environments.

The principal innovation brought by DiRAMa is the integration of multiple heterogeneous knowledge concerning the marine and underwater habitats using tested and reliable COTS component. This project aimed at providing greater data processing, implementing 3D reconstruction algorithms on an external server; this expands the list of possible results with a three-dimensional model of the area explored.

The outcomes can be stored in the most common three-dimensional formats like PLY (Polygon File Format), OBJ + MTL, DA (Collada), and PDF. A schematic representation of DiRAMa is shown in figure 2.

It is possible to recognize five different components:

- *Mobile acquisition device:* any suitable device (Pc, tablet, smartphone, smart-camera) able to send photos and other environmental data to the web server;
- *PHP/HTML5 Web server:* this component can receive the data from different devices of different users, communicates with the 3D Engine Module and can show the results to end users;
- *3D Engine Module and Database:* this component implements complex reconstruction algorithms to perform the 3D reconstructions. Moreover, it

manages the internal database where information and results are stored;

- *Cloud Manager*: this component implements a notification server in order to inform the end users about the status of the ongoing elaboration;
- *Home navigator*: any suitable device that can download and visualize the output data from the 3D reconstruction and other processes. The DocuScooter is an example of Home Navigator device, but a series of API are designed to provide easiness to access to a wide range of devices.

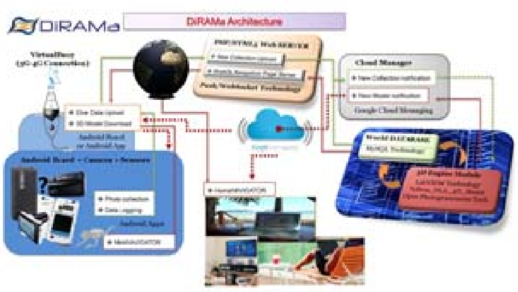

Figure 2: DiRAMa architecture

V. TESTS AND RESULTS

The proposed procedure and technologies have been tested in a validation environment at Hopkins Marine Station, Monterey, California, USA.

The technology was already tested by expert staff to perform 3D reconstructions in previous sea tests ([10]). The tests during these trials were focused on two topics:

- Receive feedback from divers about the maneuverability of the hardware and about the effectiveness of the GUI of the User Interface Unit. During the mission briefing, the divers were instructed to perform different actions during the survey. These tests will be evaluated by comparing the list of required commands and the list of actions done through a log file and direct feedback from the divers;
- Receive high value 3D reconstructions and other data from the marine environment (depth, temperature) from scientists trained quickly. These tests will be evaluated by considering the output 3D reconstruction.

During each mission, also other important parameters will be acquired through DocuScooter such as depth, water temperature, orientation data from the onboard IMU and the GPS position.

The team working on the DocuScooter development defined two types of mission profile: the first aimed to perform different type of actions with the DocuScooter such as "start/stop mission", "shoot photo", "start/stop video" and "turn on/off lights". This mission profile aims to evaluate the ability of volunteer divers to master quickly the hardware and the effectiveness of the training. The second mission profile was about the acquisition of images to perform a 3D reconstruction of relevant sediments. This latter mission requires slow, controlled and repetitive movements around the object, to acquire enough images to perform the 3D reconstruction,

Other scientists, untrained on the technology that they had to use, were introduced to the DocuScooter and to its usage and to the mission that they had to perform. The divers, with just a 15-minute training (divided in oral presentation and simulated hands-on), could fully use the platform and perform all the requested actions to begin the survey. After the dive, the images acquired were uploaded to the DiRAMa web server to perform the final 3D reconstruction and feedback was received from divers by means of an interview.

For the first type of mission, good results were received: from the logs, all the requested actions were performed correctly by the divers and feedback was received from the divers as suggestions to improve the handling of the DocuScooter. For the second type of mission, however, we found out issues about the 3D reconstructions caused by the low quality of images captured. In fact, the procedure of obtain good quality images for 3D reconstruction has shown to be very a complex task for an amateur.

This occurrence highlighted problems and difficulties related to:

- Training that was not enough exhaustive about the reconstruction procedure;
- No feedback from the DocuScooter about the quality of image acquisition during the survey.

In each mission, other data has been acquired to better document the survey such as the GPS position before starting the dive (figure 3) and the orientation data during the whole survey (figure 4).

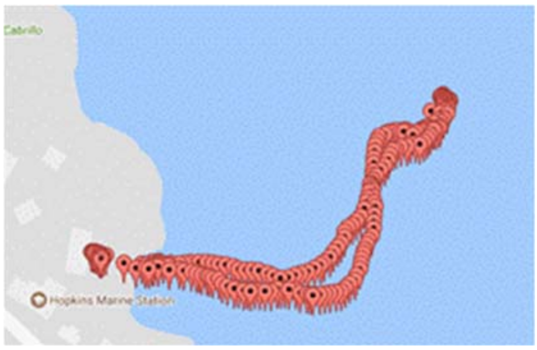

Figure 3: GPS track of one dive

VI. CONCLUSION

In conclusion, the proposed procedure and developed technology has been successfully employed to perform different underwater surveys.

Thanks to the feedback received from divers about the procedure and the technology, we started a process of improvement of different phases of the procedure and about the technologies employed.

Some planned updates related to the procedure consist of having a richer set of slides with media for better tutorials and tailored surveys to assess the performance of the proposed solution in different areas (tutorial, the procedure itself and the GUI of the tablet). The usage of the survey will be useful also to gather statistical data about the divers and the dives.

In relation to the technologies, it could be useful to add some assistance algorithm to aid the acquisition of images for 3D reconstruction such as detect if the diver is moving too quickly or which movement he is performing by means of internal sensors in the tablet.

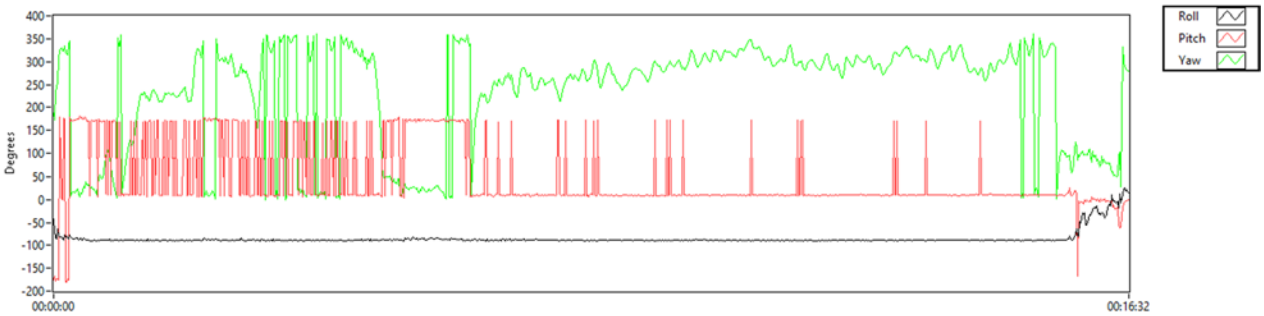

Figure 4: Orientation data of a dive

ACKNOWLEDGMENTS

This project has received funding from the European Unions's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 643712.

REFERENCES

[1] R. Follett and Strezov, "An Analysis of Citizen Science Based Research: Usage and Publication Patterns," *PLOS ONE 10,* 2015.

[2] R. Bonney, J. Shirk, T. Phillips, A. Wiggins, H. Ballard, A. Miller-Rushing and J. Parrish, "Next Steps for Citizen Science," *Science,* vol. 343, no. 6178, pp. 1436-1437, 2014.

[3] D. Brightsmith, A. Stronza and K. Holle, "Ecotourism, conservation biology, and volunteer tourism: A mutually beneficial triumvirate," *Biological Conservation,* vol. 141, no. 11, pp. 2832-2842, 2008.

[4] Scaradozzi, D., Conte, G., De Capua, G.P., Sorbi, L., Luciani, C., De Cecco, P.G., Sorci, A., "Innovative technology for studying growth areas of Posidonia oceanica", *Proceedings of 2009 IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems, EESMS 2009,* Crema; Italy*;* pp. 71-75, 2009

[5] L. Sorbi, D. Scaradozzi and G. G. P. Conte, "Geoposition data aided 3D documentation of archaeological and biological sites" *Proceedings of Meetings on Acoustics,* pp. 1-9, 2012.

[6] Drap, P., Seinturier, J., Conte, G., Caiti, A., Scaradozzi, D., Zanoli, S.M., Gambogi, P., "Underwater cartography for archaeology in the VENUS project", *Geomatica*, 62 (4), pp. 419-427, 2008.

[7] Drap, P., Scaradozzi, D., Gambogi, P., Gauch, F., "Underwater photogrammetry for archaeology -The VENUS project framework", *GRAPP 2008 - Proceedings of the 3rd International Conference on Computer Graphics Theory and Applications*, pp. 485-491, 2008.

[8] Conte, G., De Capua, G.P., Scaradozzi, D., "Designing the NGC system of a small ASV for tracking underwater targets", *Robotics and Autonomous Systems*, 76, pp. 46-57, 2016.

[9] D. Scaradozzi, G. Conte and L. Sorbi, "Assisted guidance system for Micro ROV in underwater data gathering missions," *MED 2012 - Conference Proceedings,* pp. 1373-1378, 2012.

[10] D. Scaradozzi, S. P. L. Zingaretti, C. Altepe, S. Egi, M. Palma, U. Pantaleo, D. Ferraris and F. Micheli, "DocuScooter: a novel robotics platform for marine citizen science," in *ISOPE 2017*, San Francisco, 2017.

[11] Scaradozzi, D., Sorbi, L., Zoppini, F., Gambogi, P., "Tools and techniques for underwater archaeological sites documentation", *OCEANS 2013 MTS/IEEE - San Diego: An Ocean in Common*, art. no. 6741298, 2013.

[12] D. Scaradozzi, L. Panebianco, N. Ciuccoli, S. Zingaretti, S. M. Egi and C. Altepe, "Underwater position estimation for an underwater vehicle using unscented Kalman filter," in *25th Signal Processing and Communications Applications Conference*, Antalya, 2017.

[13] Conte, G., Scaradozzi, D., Sorbi, L., Panebianco, L., Mannocchi, D., "ROS multi-agent structure for autonomous surface vehicles", MTS/IEEE OCEANS 2015 - Genova: Discovering Sustainable Ocean Energy for a New World, art. no. 7271543, 2015.