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The Lab4Dive Project: a Mobile Smart Lab for Augmented Archaeological Dives - Overview and First Results

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Abstract **– Marine archaeologists study a large number of submerged sites of interest around the world, which require continue diving explorations and monitoring. Although technology has improved a lot the research in the underwater environment, human intervention is preferred whenever depth makes the sites accessible by divers. This paper presents the concept, the first steps and the preliminary results of the Lab4Dive project, which is co-funded by the EMFF programme of EU, that aims to design, develop, and validate an innovative, marketable and competitive product for surveying, documenting and preserving Underwater Cultural Heritage. The archaeologist will be provided with an underwater tablet equipped with environmental sensors, where a properly designed data gathering system will be accessible through a dedicated application. Lab4Dive aims also to train young researchers and to encourage multi-disciplinary cooperation through the concept of a "Blue Lab".**

I. INTRODUCTION

Underwater archaeological and biological sites are generally more difficult and more hazardous to access when compared with dry land working. The study of the large number of submerged archaeological sites around the world requires long and repeated diving explorations in the interested areas ([1] and [3]). Until recently, the only sites accessible to underwater archaeologists were those that could be reached by divers. In the last years, this activity has been benefiting from the development of unmanned underwater vehicles, mostly by the use of Remotely Operated Vehicles (ROVs), which help scientists to survey the sites at major depths and to cover bigger areas ([4] and [9]). Furthermore, ROVs are quite simply to use and even inexpert pilots are able to operate them easily ([2] and [5]). Although this technology has improved a lot the research in the marine environment, there are a series of tasks and situations where the work of the underwater archaeologists cannot be substituted by a robot. Indeed, human intervention is often preferred when water depth makes the site of interest accessible by divers. Particularly regarding archaeological applications, great efforts have been focused on the documentation, preservation and conservation of our Underwater Cultural Heritage (UCH), which is an important part of the archaeologists' work. Therefore, the introduction of new technological devices and tools could considerably help divers to collect data from the marine environment, thus playing a significant role to the archaeological science.

This paper introduces the idea and presents the first steps of the Lab4Dive project, co-funded by the EMFF programme of EU through the EASME and DG MARE call on "Blue Labs". The project aims to design, develop, and validate an innovative, marketable and competitive product for surveying, documenting and preserving UCH. Lab4Dive will provide a solution by equipping divers with portable, low cost and relatively small sized data-gathering systems, in order to hugely improve both the amount of data collected in a single mission and the management of time and human resources at disposal. The professional diver could use an underwater tablet

equipped with environmental sensors, like high-resolution cameras and an acoustic localization system, where a dedicated data gathering system is accessible through its own application.

The rest of the article is composed as following: in Section II the project is described in more detail; Section III presents the designed system architecture of the Lab4Dive device; Section IV illustrates the characteristics of the Blue Lab concept; lastly, Section V presents the first results obtained.

II. PROJECT OVERVIEW

The general objective of Lab4Dive is to design, develop and validate an innovative, marketable and competitive product for surveying, documenting and preserving underwater cultural heritage with the active cooperation of business experts, young researchers, tutors, end users and local stakeholders coming from different scientific disciplines and industries. A non-comprehensive list of the main objectives of Lab4Dive is the following:

a) To train young researchers in the design and development of new and innovative technologies for underwater survey and documentation;
b) To encourage multi-disciplinary cooperation with the set up and operation of a Blue Lab;
c) To guarantee end-user satisfaction, product sustainability, and market-readiness with market oriented product design and development;
d) To boost innovation capacities of underwater archaeologists by making available a cost effective, innovative and user friendly solution that they can pilot test in the context of their own work;
e) To develop a solution for the protection and preservation in-situ of underwater archaeologies and cultural heritage;
f) To contribute with special events at the raising of public awareness of local societies with respect to the protection and preservation of UCH and to the importance of a sustainable valorization of UCH for the benefit of local economies.
g) To ensure an effective transnational networking with UCH stakeholders, and foster the exchange of good practices and the cross-fertilization of knowledge and know-how.

More specifically, this project aims at helping archaeological divers with the development of a so called "portable smart lab" usable as a support for the surveying and documentation phases. The smart lab will be based on a tablet coupled with an intelligent underwater case embedded with environmental sensors, a high-resolution camera and compatible with a number of commercial acoustic positioning systems, which will be integrated with a cloud data gathering system. The entire system will assist archaeologists before, during and after the dives on their daily on-site work to:

- Plan a survey;
- Show the area map based on acoustic bathymetry where points of interest are marked;
- Show the path followed by the diver during the immersion thus evidencing the areas already explored and the ones that needed to be investigated;
- Acquire geo-localized photos for marking interesting evidences or for the subsequent creation of orthophoto and 3D models of the explored areas;
- Acquire geo-localized environmental data from the available sensors;
- Acquire geo-localized notes for marking acquired samples and other interesting points.

Moreover, it offers the possibility of improving the safety of the diver: his position and movements can be shared with the component of the diving team and with the support personnel that supervise the operation from the boat.

The Lab4Dive system is based on three physical devices:

- an underwater tablet (UT) that supports the diver during the immersion providing several functions;
- a docking station (DS) able to acquire and exchange data coming from different environmental sensors, a high-resolution camera and an acoustic localization system, that are physically connected to it;
- a remote server that hosts the cloud database and performs the 3D reconstruction from the photos captured during the survey.

The tablet is placed in an underwater case that ensures a fully functioning touchscreen. The Docking Station includes an embedded control for managing sensors and cameras and a Wi-Fi node for the communication with the tablet. During the mission the archeologist could collect a large quantity of data and images, for example for photogrammetric purposes; once the diver is out of water and an Internet connection is available, all the information acquired could be uploaded on an appropriate web server in order to launch a 3D reconstruction process using the uploaded photos and other materials. This latter data-processing system is based on DocusScooter technology ([6] and [8]) and DiRAMa ([7]), a partially developed system developed by authors in previous years, and the results can be stored in the most common three-dimensional formats like PLY (Polygon File Format), OBJ + MTL, DAE (Collada), and PDF. The possibility of choosing between low and high quality results, which means different elaboration time, allows the researchers to analyze the data collected before the next dives or mission in order to plan it in the best way. Cooperation between man and technology can represent a winning solution to overcome the difficulties of operating in harsh but fragile environments.

The developed product will be tested at pilot sites in the Mediterranean Sea, at several locations and at varying depths in order to ensure that it meets the requirements of underwater archaeologists working in the rich UCH environment of the Mediterranean Sea.

III. SYSTEM ARCHITECTURE

The distributed system that is going to be developed in the context of Lab4Dive project is composed of different elements. The general scheme derives from the typical configuration of a cloud system for the Internet of Things (IoT), where the underwater tablets used by the divers will be enriched with the capacity of gathering and presenting data on the field with a partial internet connection. Fig. 1 illustrates the system architecture, where it is possible to individuate three main modules: Cloud Server Module, Underwater Module and Local Module. The last one is an additional optional component which requirements have been analyzed but its implementation is left as a possible future development.

1. Cloud Server Module

This module is composed of a Remote Server (RS) that hosts the database and manages the 3D reconstruction. The Cloud Server software has the following functionalities:

- Manage a database
- Manage the communication interface with the tablet in the Underwater Module
- Perform a 3D reconstruction from the photos acquired during a mission through the 3D Engine Module
- Send a notification to the user about the 3D elaboration progress through the Cloud Manager

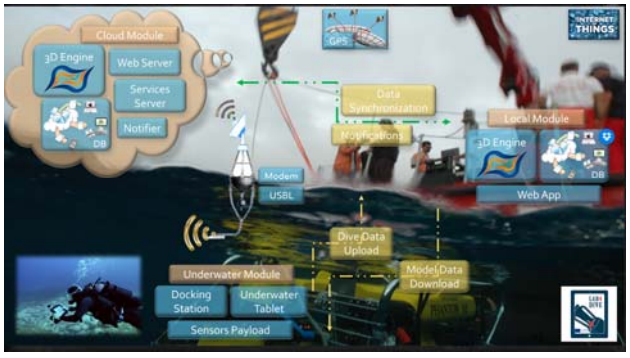

Figure 1 System Architecture

2. Underwater Module

The underwater module is based on two systems:

- an underwater tablet (UT) that supports the diver during the immersion providing several functions;
- a docking station (DS) able to acquire and exchange data coming from different environmental sensors, a high-resolution camera and an acoustic localization system, that are physically connected to it. It is provided with an embedded control board that manages all the electronics and that implements all the logic. The control board is integrated with a WiFi node for the communication with the tablet. This board will provide also a bridge to the high-resolution camera connected.

The Underwater Module is composed of the following software components:

- *Mission Planner (MP):* a web application developed using the framework Unity 3D. It enables a registered user to define a mission specifying all its properties like the bathymetry of immersion site and the targets list, i.e. the collection of points that the user wants to visit. All mission data are stored in the Cloud Server.
- *Navigation App (NA):* it presents an augmented navigation interface that guides the diver along the selected targets inside the underwater archeological site. Thanks to the 3D bathymetric model shown on the tablet display as a map, users can know their position in the underwater area, the path followed and the path to follow. Targets, which can be created and positioned directly by divers, are shown over the map as point to reach. NA can be easily turned into a drawing board where the divers can draw some sketch or take some notes of a specific point or area very quickly. Users have the possibility to control the action camera to take photo in high quality format. Both the notes and the high-resolution pictures can be geolocalized. After the immersion, NA can send all data collects over the internet to remote Cloud Server or to a local one located on the boat. NA can download new data like map, notes, sketches and targets generated in previous dives in order to use them as information for a new immersion.
- *Docking Station Control Software (DSCS*): It manages the communication between UT and DS through a WiFi channel, interacts with several environmental sensors and with different positioning systems to acquire in real-time the position of the diver.

IV. BLUE LAB

The Lab4Dive project has invested resources and effort for the establishment and operation of a Blue Lab. This is a distributed and virtual Laboratory supporting and encouraging multi-disciplinary cooperation among different research and engineering groups, business experts and local stakeholders at the sites where the

project results will be validated on the field. The Blue Lab will bring together both professionals (University teachers and Professors, ICT experts, business development fund-raising and exploitation professionals, archeology and UCH experts) and under/post-graduate students from Università Politecnica delle Marche (i.e. involvement in specific design, development and lab-testing tasks, under the technical supervision of tutors) in order to:

- Cross-fertilize knowledge among the involved teams.
- Capitalize on existing capacities and experiences of the versatile disciplines of the Blue Lab members.
- Develop a strong multidiscipline resource base to support the fulfillment of the challenging objectives of the project; and in the long-run, ensure the future sustainability of the Lab4Dive product.

Initial choices for the support of the Blue Lab operation, include:

- A cross-platform tool to target different O/S with the same basic code.
- An online platform for organizing collaboration among Blue Lab members.
- An online shared repository of documents (i.e. to facilitate archiving and exchange of docs).

V. FIRST RESULTS

The preliminary tests of the Lab4Dive system have been conducted on each module independently.

The navigation app running on the underwater tablet represents the software through which divers can locate themselves in the site area, take geolocalized photo, create notes and draw sketch in every moment of their dive exploration. Thanks to the 3D bathymetric model shown on the tablet display as a map, users can know their position in the underwater area, the path followed and the path to follow. Divers can directly interact with the map using the commons finger gesture like "pinch to in" for map zoom in, "pinch to out" for map zoom out, "pan" for map pan like Google Maps style application.

A mockup of the navigation app was made to show the interface of the software (Fig. 2).

The tablet system has been used in another project, i.e. VISAS (Virtual and augmented exploitation of Submerged Archaeological Sites), to promote diving tourism by improving the divers experience in the underwater site, and, on the other hand, to promote the induced tourist activity through the development of an innovative virtual tour of the site ([10]).

The overall architecture of the Docking Station consists of a NVIDIA Jetson TX1, which is connected to a Wi-Fi board through an Ethernet connection, to the battery, to the acoustic positioning system and to other sensors available. The general configuration is shown in Fig. 2.

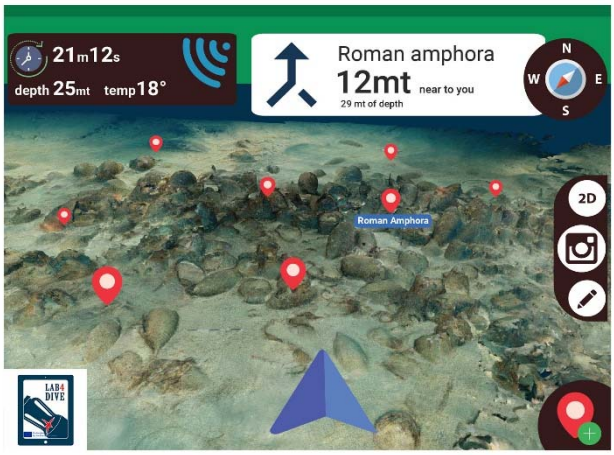

Figure 2 Mockup of the application interface running on the tablet

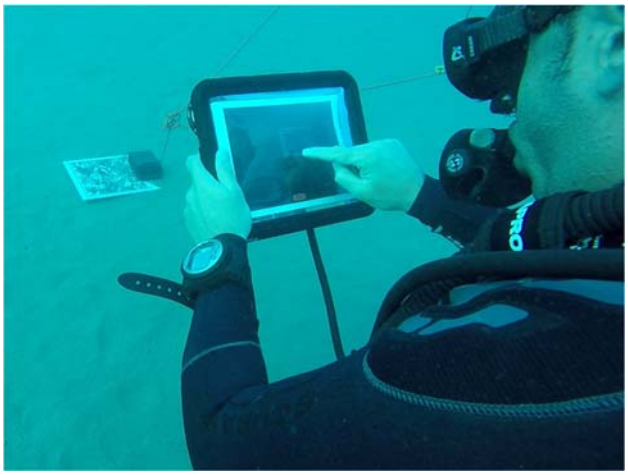

Figure 3 Underwater tablet and housing

At this moment, the first prototype includes only a depth sensor, an external IMU and a battery in order to power all the system. All the components have been positioned in a custom-made underwater box. The aim of this first test was to verify the connection and the communication between the components of the Docking Station in the underwater environment during a real mission. The system was tested at a depth of about 10 meters and the immersion lasted about one hour. Fig.3 shows the graphs obtained by the measurements from the depth sensor: the upper one reports the depth (y-axis) related to time (x-axis), while the lower one the temperature (y-axis) related to time (x-axis).

The measurements obtained from the external IMU connected to the Docking Station are illustrated in Fig. 4: the first graph refers to the accelerometer, the second to the gyroscope and the third to the magnetometer values.

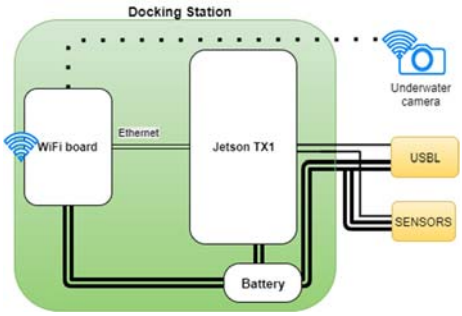

Figure 4

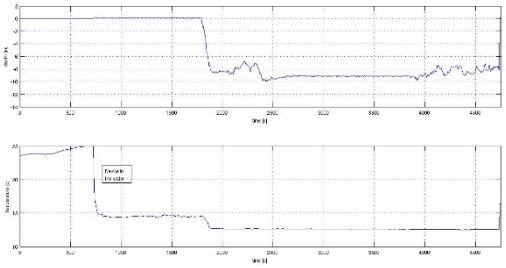

Figure 5 Depth sensor

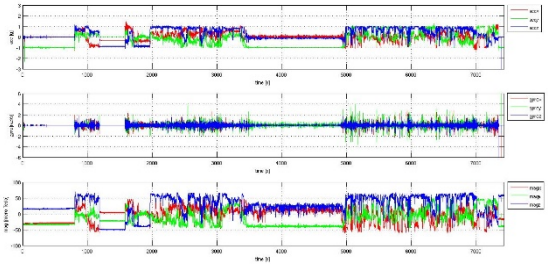

Figure 6 IMU

VI. CONCLUSIONS

In this article, has been presented the general overview of the Lab4Dive project, where partners from Greece and Italy are involved to design, develop, and validate an innovative, marketable and competitive product for surveying, documenting and preserving the Underwater Cultural Heritage of the Mediterranean Sea. The system architecture of the device that will be developed from this cooperation was illustrated, with the results of the preliminary tests performed in the first months of the project. The next steps will take into account firstly the integration of the two systems constituting the Underwater Module (the underwater tablet with the functioning app and the docking station) and then the integration with the cloud server module.

VII. ACKNOWLEDGMENTS

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REFERENCES

[1] 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

[2] Sorbi, L., Scaradozzi, D., Zoppini, F., Zingaretti, S., Gambogi, P., “Robotic tools and techniques for improving research in an underwater delicate environment”, *Marine Technology Society Journal*, 49 (5), pp. 6-17, 2015.

[3] 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.

[4] 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.

[5] 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.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] Bruno, F., Lagudi, A., Muzzupappa, M., Lupia, M., Cario, G., Barbieri, L., Passaro, S., Saggiomo, R., “Project VISAS: Virtual and Augmented Exploitation of Submerged Archaeological Sites - Overview and First Results”, *Marine Technology Society Journal*, Vol.50, 4, p.119-129, 2016.