Lab4Dive Mobile Smart Lab for Augmented Archaeological Dives

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Abstract. Lab4Dive project aims to design, develop, and validate an innovative, marketable and competitive product for supporting underwater archaeologists in surveying, documenting and preserving the underwater cultural heritage. These activities could be improved considerably with the introduction of new technological devices and tools, helping underwater archaeologists to collect data from the marine environment. The project will provide a solution by equipping divers with portable, low cost and relatively small sized data-gathering systems (i.e. environmental sensors, acoustic localization system, HD cameras, etc.), so they can significantly improve both the amount of data collected in a single mission and the management of time and human resources at disposal. In this paper, the preliminary developments and the tests of the Lab4Dive system will be presented, which is mainly based on two modules: Cloud Server Module and the Underwater Module. The latter is based on two systems: an underwater tablet, that supports the diver during the immersion providing an augmented navigation interface that guides the diver along the selected targets; and a Docking Station, to acquire and exchange data coming from different environmental sensors, a high-resolution camera and an acoustic localization system, physically connected to it.

1. Introduction

Underwater archaeologists during their missions make extraordinary discoveries that expand the vision of humanity's past. Drowned settlements may contain well-preserved artifacts that can provide important new information about how people lived or when they arrived at various locations. These studies require long and repeated diving explorations in the interested sites ([1] and [2]). Until recently, the only sites accessible to underwater archaeologists were those that could be reached by divers. In the last years, new set of tools incredibly helped them to survey submerged landscapes ([3]

and [4]). In fact, once a place of interest has been located, divers investigate the small targeted area to collect samples and take notes on what they see, just like archaeologists do on land. Given the number of tasks for each diver and limited bottom times at deep depths, larger areas cannot be surveyed manually and this represents the biggest difference between surveying on land and surveying underwater.

Underwater survey technology has reached great advance. Remotely operated vehicles (ROVs) help scientists a lot to survey the sites at major depths and to cover bigger areas, thanks to the possibility of remotely piloting it to explore the seafloor, sending live video back to the crew on the research vessel ([5] and [6]). Moreover, ROVs are quite simply to use and even inexpert pilots are able to operate them easily ([7] and [8]).

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 article presents the Lab4Dive project, co-funded by the EMFF programme of EU through the EASME and DG MARE call on "Blue Labs", and its preliminary results. 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 structured as following: Section II describes in detail the project and the features of the Blue Lab concept; Section III presents the designed system architecture of the Lab4Dive device and Section IV presents the preliminary results obtained.

2. Project overview and Blue Lab establishment

Lab4Dive project has the aim of designing, developing and validating an innovative, marketable and competitive product for surveying, documenting and preserving underwater cultural heritage. It promotes the active cooperation of business experts, young researchers, tutors, end users and local stakeholders coming from different scientific disciplines and industries. In fact, it intends to encourage the multi-disciplinary cooperation, training young researchers in the design and development of new and innovative technologies for underwater survey and documentation, with the establishment of a Blue Lab.

The project aims also to provide a valuable solution for the protection and preservation of underwater archaeologies and cultural heritage, contributing with special events for the raising of public awareness regarding these thematic.

This system can be referred to as a "portable smart lab" to support archeological divers in the survey and documentation phases. In fact, the development of a cost effective, innovative and user-friendly solution could boost innovation capacities of underwater archaeologists. 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 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 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 other members of the diving team and with the support personnel that supervise the operation from the boat.

2.1. Blue Lab

The Lab4Dive project has invested resources and effort for promoting innovative "laboratories”, called Blue Lab, to pilot novel way of working, where young scientists supported by researchers, industry and local stakeholders, team up to develop innovative solutions to support the development of a sustainable blue economy, while preserving marine resources and ecosystems.

The established Blue Lab is a distributed and virtual laboratory. It brings together professionals among different research and engineering groups, business experts, local stakeholders and under/post-graduate students, mainly from Università Politecnica delle Marche.

It provides the organizational space for collaborative and multidisciplinary activities involving people in specific design, development and lab-testing tasks of Lab4Dive system, under the technical supervision of tutors, leveraging young peoples’ skills and creativity and increasing awareness of marine challenges and opportunities.

The implementation of the virtual laboratory for the support of the Blue Lab operation included the choice of:

- 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 to easily archive and exchange documents.

3. Architecture for data survey

The general scheme of the Lab4Dive distributed system 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. It is composed of three main different elements, as shown in figure 1 and explained in detail in the following:

- Cloud Server Module
- Underwater Module
- Local Module.

The Local Module is an additional optional component which requirements have been analyzed but its implementation is left as a possible future development.

During the mission, the archeologists could collect a large quantity of data and images, for example for photogrammetric purposes; as soon as the diver is out of water and an internet connection is available, all the information acquired could be uploaded on an appropriate server in order to launch a 3D reconstruction process. This latter data-processing system is based on DocusScooter technology [3] and DiRAMa ([4]), 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, OBJ + MTL, DAE 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 system 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.

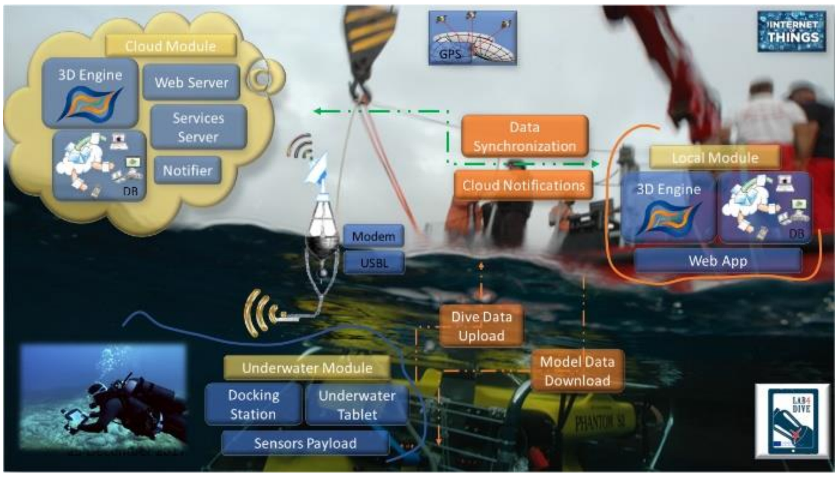

Figure 1 System architecture

3.1. Cloud Server Module

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

- a database MySQL
- a web interface for backend CRUD operations
- a RESTful API to interact with the other devices
- the 3D Engine Module

The Cloud Infrastructure has the following functionalities:

- Manage the database
- Manage the communication with the other modules/devices of the system
- 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

3.2. Underwater Module

The Underwater Module is based on two systems:

- an Underwater Tablet (UT), placed in an underwater case that ensures a fully functioning touchscreen, 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 provides also a bridge to the high-resolution camera connected.

The Underwater Module is composed of the following software components:

- Mission Planner (MP): an 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 provides 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. This application can be easily turned into a drawing board where the divers can quickly and easily draw some sketches or take some notes about a specific point or area. Moreover, it allows users to control the camera in order to take photo in high quality format. Both the notes and the high-resolution pictures can be geo-localized. After the immersion, NA can send all the data collected over the internet to the Cloud Server or to a local one located on the boat. It 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.

4. Preliminary results

The preliminary tests of the Lab4Dive system have been conducted separately to verify the functioning of the Navigation and Mission Planner apps and of the Docking Station. The Underwater Module in fact is now being integrating.

4.1. Software components of the Underwater Module

The Underwater Module is composed of two main Unity software components: Mission Planner (MP) and Navigation App (NA).

The Mission Planner (MP) is a Unity 3D application that allows to create Mission Models. A Mission Model correlates a 3D bathymetric model and an ordered collection of targets to visit during a dive. The first prototype of the MP is released both as mobile and web application in order to ensure greater flexibility during the practical use of the system. The mobile application can be installed on a mobile tablet, including the Underwater Tablet, and used on the boat in order to plan the dive. In this case, the Underwater Tablet must be able to communicate to the Cloud Server, hence, an internet connection is required. The web based application can be integrated into the Cloud Server as a JavaScript program which uses HTML5 technologies and the WebGL rendering API to run Unity content in a web browser.

The workflow of the Mission Planner is given below:

1. The user logs-in to the MP;
2. The user chooses the site of the mission;

3. The user imports an existing mission or chooses a 3D bathymetric model among the available ones;
4. The user adds targets, which can be related to a previously created content, such as textual notes, sketches, photos or 3D models;
5. The user is able to modify the position of already-added targets;
6. The user can choose an order for the targets;
7. The user edits the mission's information (name, description, etc.);
8. The user saves the Mission Model.

When the user saves the Mission Model, it is sent to the Cloud Server Module which stores it in the database. Then, it can be imported into the Navigation App in order to guide the diver during a survey.

The Navigation App (NA) is a mobile application that shows the diver's current position on a 3D bathymetric model representing the underwater archaeological site. The NA also shows the path to follow and the targets of a selected Mission Model. The Navigation App collects and stores the dive log, including geo-localized notes, sketches and photos taken by the diver during the survey.

The Navigation App implements three different communication protocols:

- One to communicate with the Docking Station Control Software, in order to get the diver's position and data from sensors;
- One to communicate with the Cloud Server, both before and after the dive. Before the dive, the NA requests information about the maps and the Mission Model. After the dive, the NA sends to the Cloud Server all gathered data, including the path followed, environmental data, notes, sketches and photos.
- One to communicate with the Underwater Camera, in order to control the acquisition of photos and to show a live-view.

Figure 2 Navigation App GUI

The Graphical User Interface (GUI) is shown in figure 2. The arrow represents the diver's position in the 3D representation of the underwater site. The diver can control the point of view of the map by using the left-side buttons. He can see the targets' list and the Underwater Camera live-view by using the right side buttons. He can also tap the button on the bottom right corner of the screen in order to add a new target (such as notes, sketches and photos). The GUI also provides a compass and an on-board computer which shows real-time information about the environment on the basis of the data received from the DS.

4.2. Hardware components of the Underwater Module

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 figure 3.

The first prototype includes a depth sensor, an external IMU, a GPS/USBL connection and a battery in order to power all the system. The depth sensor and the IMU are captured with a rate of 10 Hz while the USBL signal arrived one time per second. All the components have been positioned in a custom-made underwater box to allow performing several tests. The first tests aimed 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 indeed tested at a depth of about 10 meters and the immersion lasted about one hour. The second set of tests aimed to verify the tracking algorithm of the system: a custom Unscented Kalman Filter (UKF) has been designed for the application. The diver used an underwater scooter with attached the device. The system was indeed tested at a fixed depth of about 10 meters in order to have a stable positioning signal from an EvoLogics S2CR 18/34 system equipped with an Emlid Reach RS RTK GNSS GPS Receiver.

Figure 4 shows the tracking graph (blue line) obtained by the algorithm compared with the measurements of the USBL (red circles). During the navigation time, the errors between the computed diver's position and the real one measured with the USBL system are reported on Figure 5. The root mean-squared error (RMSE) between computed and real positions (when available) is 1.2541 m. The USBL signal, which was captured every second, was interrupted twice during the test to verify the positioning filter quality, about 10 seconds each time. During that period of time, the algorithm estimates well the diver's position.

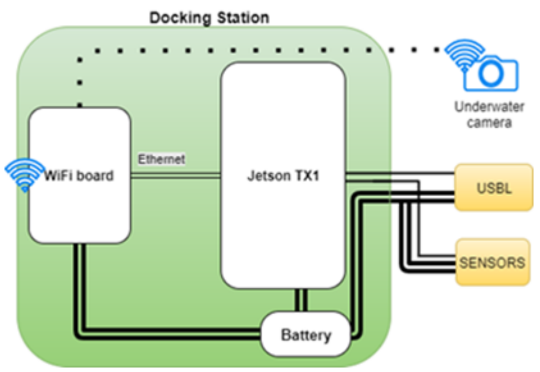

Figure 3 Docking Station

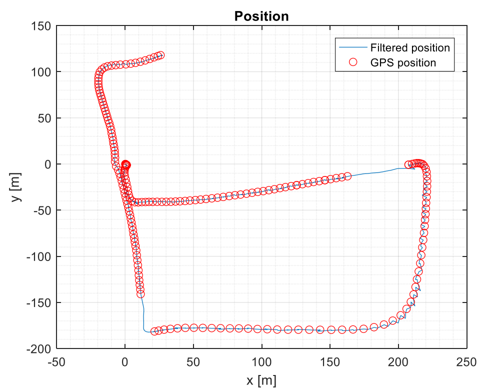

Figure 4 Diver's position

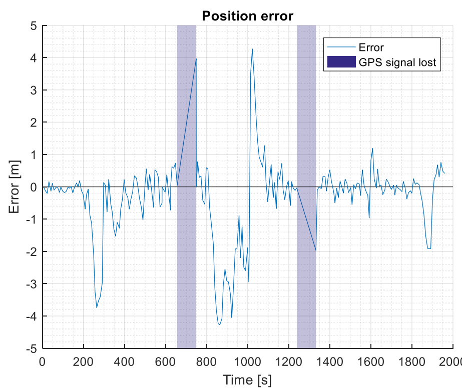

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Figure 5 Mean error

5. 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 and then the integration with the Cloud Server Module.

6. Acknowledgements

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7. 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] 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.

[3] D. Scaradozzi, S. Zingaretti, L. Panebianco, 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.

[4] 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.

[5] 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.

[6] 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.

[7] 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.

[8] 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