Documentation and Sampling Strategies in Underwater Archaeology. General Criteria and Specific Solutions

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Underwater archaeology is probably one of the most complex branches of our discipline, due to the fact that, more than in other specific fields (e.g. speleoarchaeology, glacial archaeology, etc.), the traditional and well tested methodologies have to be adapted to the peculiar characteristics of the area under examination. This paper tries to describe the common methodologies used to explore, document in 3D and analyse underwater archaeological environments, comparing them to specific case studies in which new solutions have been adopted to face logistical problems. More specifically will be analyse the use of the Open Hardware ArcheoROV during different archaeological missions in 2016 and 2017, from simple exploration projects to 3D documentation with Open Source SfM/MVS and SLAM techniques, both of horizontal (e.g. small shipwrecks) and vertical (e.g. submerged forests) archaeological context. Moreover other Open Hardware tools will be described, such as a modified underwater drill to collect sampling for wood science analysis. The main purpose of the paper is to open a discussion about the differences existing in underwater archaeology, focuses on the peculiarity of the missions in “internal waters”, which often presents specific problems in 3D documentation, derived by the surrounding landscape (such as low visibility or different decompression time tables for high altitudes).

Key words:
Underwater Archaeology, 3D Documentation, SLAM, Open Source, Open Hardware.

CHNT Reference:

INTRODUCTION

This contribution tries to analyse the methodology of underwater archaeology, especially considering documentation and sampling strategies, which often represent two difficult stages during the research process. In particular the goal of the article is to underline the specific adaptations imposed by peculiar logistic conditions of different projects. For a better understanding of the importance of versatile strategies and tools, a selection of three case studies will be presented, basing on the experience of the commercial archaeology company Arc-Team. This experience is focused on the exploration of inland waters of a mountain Italian region: Trentino Alto Adige / South Tyrol. Such a landscape represents a good example of variables which characterize lakes and rivers and which can influence an underwater archaeology project.

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As an example, Table 1 shows the last six underwater archaeology missions in Trentino, performed by Arc-Team in 2016 and 2017.

<table>
<thead>
<tr>
<th>Inland waters</th>
<th>Currents</th>
<th>Max. depth</th>
<th>Altitude</th>
<th>Temperatures</th>
<th>Visibility</th>
<th>Special operations</th>
<th>Logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Garda</td>
<td>no</td>
<td>-346 m</td>
<td>65 m a.s.l.</td>
<td>low</td>
<td>medium</td>
<td>no</td>
<td>simple</td>
</tr>
<tr>
<td>Lake Monticello</td>
<td>no</td>
<td>-17 m</td>
<td>2595 m a.s.l.</td>
<td>low</td>
<td>low</td>
<td>sampling</td>
<td>simple</td>
</tr>
<tr>
<td>Lake Mandrone</td>
<td>no</td>
<td>-7.3 m</td>
<td>2399 m a.s.l.</td>
<td>low</td>
<td>low</td>
<td>safety</td>
<td>difficult</td>
</tr>
<tr>
<td>Lake Tovel</td>
<td>no</td>
<td>-36 m</td>
<td>1178 m a.s.l.</td>
<td>low</td>
<td>low</td>
<td>sampling</td>
<td>simple</td>
</tr>
<tr>
<td>Lake Toblino</td>
<td>no</td>
<td>-15 m</td>
<td>245 m a.s.l.</td>
<td>low</td>
<td>low</td>
<td>no</td>
<td>simple</td>
</tr>
<tr>
<td>Brenta river</td>
<td>yes</td>
<td>-2 m</td>
<td>450 m a.s.l.</td>
<td>low</td>
<td>medium</td>
<td>safety</td>
<td>simple</td>
</tr>
</tbody>
</table>

The inland waters under investigation can be primarily divided between lakes and rivers, due to the strong current which is one of the main characteristics of mountain streams. Even considering only the lakes, it has to be noticed that they differ under some important aspects and, primarily, their altitude can be used to distinguish between low mountain lakes (up to 1000 m a.s.l.), medium mountain lakes (between 1000 and 2000 m a.s.l.) and high mountain lakes (over 2000 m a.s.l.). Very important is also the maximum depth of the inland waters, which, in our example, ranges between the -346 m of Lake Garda (deeper than the Adriatic Sea) and the few meters of the Brenta river. Other characteristics to take into consideration in planning an underwater archaeological expedition in Trentino are low temperature and visibility conditions, as well as logistics, which can be a simple or a difficult task depending on the surrounding landscape and on the need to perform special operations (required by sampling, documentation or safety strategies).

Among all these peculiarities, altitude, temperatures and visibility are the three main features that mark an outstanding difference, in the field of underwater archaeology of Mediterranean countries, dividing inland from coastal marine waters projects. The next chapter will summarize these differences, analysing the example of Lake Tovel, which is considered a medium mountain lake.

ALTITUDE, TEMPERATURE, VISIBILITY

As mentioned in the previous chapter, altitude, temperature and visibility are the first variables to take into consideration while planning underwater missions in inland waters, due to the fact that their values considerably differ from the ones of a Mediterranean marine cost.

Considering a medium mountain water environment as a comparison reference, like Lake Tovel (1178 m a.s.l.), it is simple to understand how even a modest altitude influences diving strategies, suggesting the use of bottom gas mixture to reduce decompression stops. Table 2 compares an underwater mission, with a run time of 30 minutes, at a depth of -30 meters, in three different scenarios: diving at sea level with air; diving at 1178 m a.s.l. with air; diving at 1178 m a.s.l. with EAN (Enriched Air Nitrox) gas mixtures. In the first case we have to consider two decompression stops (1 minute at -16 m and 16 minutes at -3 m). Trying to replicate the same diving strategy (air) at the altitude of 1178 m a.s.l. would take the overall diving time to 70 minutes (with 4 decompression stops), causing excessive difficulties for the mission. The use of EAN mixtures (with a gas mixture switch at -21 m and two more decompression stops) would take the overall diving time to 46 minutes, even less respect the 50 minutes of the mission with air at the sea level.
Table 2. Comparison between three underwater mission scenarios

<table>
<thead>
<tr>
<th>Depth</th>
<th>Run time</th>
<th>Deco</th>
<th>Depth</th>
<th>Run time</th>
<th>Deco</th>
<th>Depth</th>
<th>Run time</th>
<th>Deco</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30 m</td>
<td>00 - 30</td>
<td>1’</td>
<td>-30 m</td>
<td>00 - 30</td>
<td>1’</td>
<td>-30 m</td>
<td>00 - 30</td>
<td>1’</td>
</tr>
<tr>
<td>-16 m</td>
<td>31 - 32</td>
<td>1’</td>
<td>-17 m</td>
<td>31 - 32</td>
<td>1’</td>
<td>-21 m</td>
<td>31 - 32</td>
<td>Switch EAN 50</td>
</tr>
<tr>
<td>-3 m</td>
<td>34 - 50</td>
<td>16’</td>
<td>-10 m</td>
<td>33 - 35</td>
<td>2’</td>
<td>-16 m</td>
<td>32 - 33</td>
<td>1’</td>
</tr>
<tr>
<td></td>
<td>34 - 50</td>
<td>16’</td>
<td>-4 m</td>
<td>36 - 39</td>
<td>3’</td>
<td>-3 m</td>
<td>35 - 46</td>
<td>11’</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-3 m</td>
<td>39 - 70</td>
<td>31’</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bottom gas mixture: air | Bottom gas mixture: air | Bottom gas mixture: EAN 32

Another characteristic of mountain inland waters is the low temperature. It has to be said that, under this aspect, the continuous development of technical equipment, like dry suits, is helping in improving the performance during cold water diving missions. Nevertheless low temperatures are still an important factor which reduces underwater operating times, with consequences for the whole project. Moreover this feature is more problematic during warm season (especially summer) due to the presence of a thermocline, where temperature changes more rapidly with depth than it does in the layers above or below. This phenomenon requires adaptation skills and divers have to pay attention in crossing thermal layers more than in cold seasons, when low temperatures affect the whole lake, often under a frozen surface. The infographic of figure 1 shows the seasonal difference of Lake Tovel water temperatures in summer and in winter. In the first case, the surface layer can reach more than 20 °C, but the thermocline between -4 and -8 meters can drastically reduce temperatures till 6 or 5 °C; the deepest layer of the lake is normally around 6 or 4 °C, in any case not higher than 7 or 8 °C. In winter the situation is more stable and the water, under a frozen surface, is normally around 5 or 4 °C.

Fig. 1. Seasonal differences of Lake Tovel water temperatures in summer (a) and winter (b)

The last feature which characterizes inland waters is the low visibility, due to the higher turbidity which normally affects lakes and rivers, if compared to Mediterranean maritime coasts. This factor is strictly connected with the concentration of suspended and dissolved solid (both organic and inorganic) and can be difficult to evaluate in planning an underwater archaeological mission. Indeed, if a general idea of the visibility can be determined by the Secchi depth value, it has to be considered that real conditions are influenced by seasonal and weather factors:

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winter is normally associated with a general clarity of waters, while after a rainfall it is normal to deal with higher turbidity levels. However, during mission planning, a good risk management has to be defined, in order to take into consideration any possible hazard deriving from low visibility, which can reach extreme values (like in figure 2).

Fig. 2. Differences in visibility between the Mediterranean Sea (Capo Caccia in Sardinia), at almost -60 m (a), and Lake Tovel, at –10 m (b)

Altitude, temperature and visibility are not the only difficulties in inland water archaeology: other environmental conditions, especially in mountain landscape, can increase the risk of failure of any mission. The next chapters will present three different case studies to illustrate how the general criteria of archaeology have to deal with the peculiarities of inland water projects in order to find specific solutions and reach the expedition goal. Each case study represents a different typology of archaeological project (a targeted mission, an exploratory survey and a pluriannual research program) and will be analysed under different aspects, with a particular consideration for the environmental peculiarities.

LAKE MANDRONE

The first case study regards a glacial lake at 2399 m a.s.l., in the Adamello-Presanella Alpine group. Its name derives from the near Mandrone Glacier and its dimensions are not very large, with a length of 290 m and a width of 150, for a maximum depth of -7.3 m. Under optimal conditions, the visibility range can reach the bottom of the lake, with a Secchi depth value of 7.3 m [Tomasi 2004].

In summer 2016, the Italian company Arc-Team has been commissioned to support the expedition organized by Tiziano Camagna with the purpose of documenting a sunken boat dating back to the Great War. The boat was built by the Alpini of the battalion Edolo (the so-called “Adamello devils”), under the command of Captain Castelli [Viazzi 1981]. Two historical photos show the boat under construction and floating on the surface of Lake Mandrone (figure 3). In 2007 Camagna localized the wreck, with the help of family Gallazzini (manager of the mountain hut “Città di Trento”), and later photographed it for the first time, during an underwater expedition with the support of the divers Marco Valenti and Ilaria Clissura (Underwater Team Trento).
Fig. 3. The boat under construction (a) and floating on the surface of Lake Mandrone (b)

Under an archaeological point of view, the expedition of 2016 can be considered a targeted mission, with primary and secondary goals: the detection of the wreck site, its geolocation, an accurate 3D archaeological documentation and the evaluation of an Open Hardware Remotely Operated Vehicle (ROV) during a professional expedition.
Before to deal with the general issues of the underwater archaeology (the geolocation and the 3D documentation), it has been necessary to face the problems deriving for the peculiar logistical conditions of high mountain lakes. The equipment transport is often one of the most difficult task in altitude diving and also in this case the team had to find specific solutions: all the expedition devices have been taken to the mountain hut “Città di Trento” thanks to a ropeway (figure 4a), while the divers and the support staff reached the meeting point three hours later, through the only available path. Once arrived at the base camp, the divers could start their acclimatization to the altitude, which, over 2000 m a.s.l., took an whole day. This safety procedure is another of the specific issues of high mountain inland water expeditions and imposes an unavoidable dead time before the beginning of any kind of underwater operation. Luckily the extremely good weather conditions granted an incredibly clarity of water, considering the season. This factor allowed the team to accomplish the first mandatory task, localizing the wreck site with a simple exploratory survey around the lake. The day after the support team started the procedure to geolocate the boat, positioning the base station of a differential GPS over a geodetic point of the “Comitato Glaciologico Trentino” (Glaciological Committee of Trentino). At the same time a team of divers reached the wreck site (figure 4c), followed by two underwater archaeologists who accomplished an archaeological 3D documentations (figure 4e, 4f and 4g) through Structure for Motion (SfM) and Multiple View Stereo-Vision (MVS). Once completed these preliminary operation, some Ground Control Points (GCP) were placed around the boat, using a reel and a surface marker buoy (SMB) to locate them on the top of the lake, thanks to the low depth of the bottom. In the meantime, a diver attended to the geolocation of the GCP, stabilizing the buoy, while an operator on a kayak was collecting the geographic coordinates with the rover of the differential GPS (figure 4b). During these operations, another team performed and extensive exploration of the lake, which ended up with the discovery of a submerged tree (figure 4d). At the end of the underwater mission, due to the fact that all the divers consumed their gas mixtures, it was just possible to register the point of the find from the surface of the lake, without further investigation.

Once accomplished the primary mission, a secondary documentation has been performed without the support of divers, in order to test the performance of an Open Hardware ROV, in a real operative scenario. This device, named ArcheoROV, is the result of a joint project developed since 2014 by Arc-Team and WitLab (a Fab Lab based in Rovereto, Trentino), in order to produce an Open Hardware ROV for archaeological purposes (figure 8d). Its aim is to bypass human operators limitations in underwater vertical documentation and long range exploration and its main characteristic is the capability to run the Open Source Robot Operating System (ROS) directly on board, with the possibility to activate its powerful Simultaneous Localization and Mapping (SLAM) visual tools. The task to accomplish a redundant photographic documentation of the boat has been performed by the WitLab team. The positive end of the testing phase of the ArcheoROV marked the conclusion of the Mandrone mission itself, but the presence of the submerged tree imposed a second expedition in order to further investigate this discovery. Indeed, considering that the landscape surrounding the lake is nowadays composed by rocks, high alpine grasslands and bogs, while the wood ends 100 – 150 meters below, the submerged tree was suspected to be ancient and probably not connected with the Great War.

Also the second expedition can be considered as a targeted mission, this time focused on the dendrochronological sampling of the tree. Following the same procedure of the first mission, a team of divers collected a wooden core using dry land techniques. The low depth of the lake permitted the use of a Pressler gimlet without the risks deriving by heavy work activities in deep waters.
Once collected all the necessary data from the two expeditions, a processing stage ended with the 3D documentation of the boat wreck, thanks to the use of the Open Source archaeological operating system ArcheOS [Bezzi et al. 2013b]. More specifically the work-flow started with the software ImageMagick, used to partially recover original colours from the underwater photos. Indeed, despite the perfect visibility conditions, the pictures were unusable for SfM/MVS techniques without this pre-treatment. Then a dense 3D point cloud has been generated with the suite openMVG [Moulon et al. 2016] and converted into a 3D georeferenced mesh thanks to MeshLab [Cignoni P. et al. 2008] and CloudCompare. Finally a vector technical drawing has been produced within the software QuantumGIS, basing on the orthophoto obtained through MicMac [Rupnik et al. 2017], while Cesium (a WebGL Virtual Globe) has been used for a 3D geolocated visualization of the final model. Regarding the study of the submerged tree discovered during the first mission, the dendrochronological analysis of the sample, conducted by Dott. Mauro
Bernabei of the Institute of Tree and Timber at the Italian National Research Council (CNR – IVALSA), revealed the species, *Pinus cembra*, and the age of the specimen: almost 5000 years. More in detail, the wooden core collected during the second mission is composed by 60 rings, the last of which is 4948 years old (in 2017). The exceptional dating of the tree opens new perspective of research in high mountain water environment, especially in relation with paleoclimatic studies.

LAKE MONTICELLO

Lake Monticello is a small glacial lake in the western sector of the Presanella Alpine group, near the Presena Glacier (figure 5a). Its water has always attracted the attention of the so-called “recuperanti”, a term that in Italy indicates people who retrieve objects concerning World War I from the old battlefields. The first exploration dates back to the 60s and was performed by Emilio Serra, who was able to collect some interesting relics. The lake lays at 2595 m a.s.l., with a length of 200 m and a width of 140 m [Tomasi 2004]. No data about visibility and maximum depth were available in 2017, when an underwater expedition, led by Tiziano Camagna, took place to verify the possible persistence of Great War findings.

Also in this case Arc-Team was asked to give archaeological support to the mission, which can be considered as a simple exploratory survey. Nevertheless, the high mountain landscape imposed some specific solutions, in order to optimize the schedule of the project and reduce the dead time caused by the altitude acclimatization. Furthermore, the specific location of the lake required a particular attention to avoid detonation hazards due to the possible presence of unexploded ordnance.

Luckily the expedition did not encounter particular problems under the logistical aspect, thanks to the newly renovated gondola lift, which took the team and the equipment just some hundreds meters away from the lake. Moreover the near “Capanna Presena” Alpine hut granted the necessary support for the altitude acclimatization of the divers. However the first day of the mission has been spent in special operations which did not required divers, but were finalized to collect sensible data for a better planning of the upcoming underwater archaeological survey. Initially, through the use of a kayak and a towed buoy equipped with a low cost sonar device named Deeper PRO+, a complete bathymetric chart of the lake has been recorded (figure 5b). This strategy was tested for the first time during the Mandrone expedition, but the map was not completed due to the discovery of the submerged tree, which completely changed the mission priorities. During the Monticello expedition this technique has been refined, thanks to a good Internet connection which allowed uploading, on a cloud server, the raw data collected by the Deeper device: a graphic chart and a grid of points with longitude, latitude and depth values (figure 5c). Through a web-coworking project, the technicians of Arc-Team GIS Laboratory were able to process the data almost in real-time, using GRASS [Neteler and 2008] to develop a 3D model of the bathymetry of the lake and to combine it with the LIDAR model of the surrounding landscape (figure 5d). Finally, thanks to the connection between GRASS and QuantumGIS and to the Python plugin Qgis2threejs, a 3D web model of the environment to explore was available online, to help the divers for a better planning of the mission. Once defined the bathymetry of the lake, a first survey has been performed with the ArcheoROV, to verify the possible presence of unexploded ordnance and to define operative areas for the human exploration.

Thanks to these precautions, the underwater archaeology mission ended positively, maintaining good safety conditions.
LAKE TOVEL

Lake Tovel is a natural barrier lake, caused by a landslide dam occurred in historical times (figure 6a). It is considered one of the main touristic attraction of Trentino, not only for the surrounding landscape, defined by dense forest of the Adamello Brenta Natural Park and by the majestic peaks of the Brenta Dolomites, but also for the algal reddening phenomenon which characterized its water during the summer period, until 1964. The so-called “Red Lake” is a medium mountain environment, placed at 1178 m a.s.l., with a length of almost 1000 m and a width of 570 m. Its maximum depth is -39 m and the visibility in normal condition can reach 10 meters [Tomasi 2004]. Another peculiarity of the lake is the presence of a submerged forest (figure 6d), whose higher trunk has been noticed several times during the nineteenth century, when its height was still exceeding the water surface. Some preliminary studies concerning the forest have been carried on in the beginning of the 80s [Biondi et al. 1981], but only in 1985 the divers Enrico Cova and Gino Mazzoleni (of the team “Rane nere”) observed some rooted trunk on...
the bottom of the lake, giving a new impulse to scientific research and capturing the interest of the geomorphologist Carlo Otheimer [Otheimer 1992]. In 2005 Tiziano Camagna started a new pluriannual project about the forest, with the support of Arc-Team.

The primary target of the Red Lake Project is a first census of the submerged trees (figure 6b), supported by their geolocation and by a wide range dendrochronological sampling. Secondary a 3D documentation is carried on with SfM/MVS techniques.

Fig. 6. Lake Tovel (a); an example of data recording sheet for the submerged forest (b); a rooted submerged tree (c); another tree of the submerged forest (d).

The main issues of such a program derive from the wide extension of the area to explore, from the necessity to perform some special operations, like 3D vertical documentations and deep water drilling to obtain dendrochronological core samples, and from the need to integrate legacy data with new acquired evidences.
Fig. 7. The original bathymetry by Edgardo Baldi (a) and the derived digital model by Arc-Team (b); available geographic Open Data from the Autonomous Province of Trento and from the company e-GEOS through the platform RealVista.

For logistical characteristics, underwater missions in Lake Tovel do not need specific attentions, thanks to a direct driveway which ends near the shores. The altitude does not require an acclimatization time, but its depth suggests diving with specific Enriched Air Nitrox gas mixtures (EAN) instead of normal air. As mentioned above, the main
problem regards the wide extension of the lake surface. To face these difficulties, Arc-Team used some solutions derived by a research branch activated by the company in 2006, informally called archeorobotics, focused on the development of Open Hardware robotic archaeological devices [Bezzi et al. 2008]. In particular an Unmanned Aerial Vehicle (ArcheoDrone, figure 8a), already tested in operative scenarios [Bezzi et al. 2013], has been used for some preliminary remote sensing operations (figure 8b), while a new prototype of Unmanned Surface Vessel (ArcheoBoat, figure 8e) has been tested to cover some long range sonar survey. This device is currently under active development by WitLab and Arc-Team as a support platform for the ArcheoROV (figure 8c): originally conceived as a simple Wi-Fi buoy, has been later equipped with a Radio Controlled guiding system and with low-cost sonar, after the positive test performed with the Mandrone expedition. Obviously also the ArcheoROV has been used for some exploratory tasks, but its main target has been a special operations of vertical 3D documentations. Indeed one of the biggest submerged trunks is currently still rooted in the lake bottom (figure 6c). This tree exceeds the 10 meters of height, which means that the water pressure changes of the value of 1 bar from the top to the bottom of the trunk. Considering this fact, it is impossible for a human diver to perform a complete SFM/MVS documentation in safety conditions, since it would be necessary a continuous ascending and descending movement, with dangerous consequences for the health. ArcheoROV achieved positive results in performing such documentation, with the only limitation of the bad light conditions of the photos collected on the side against the sun. Another special operation required by the project needed the development of an open hardware device: the dendrochronological sampling with drilling tools in deep water. In this case the solution does not consist in a robotic system, but in simpler mechanical tool, applied to an underwater drill. Technically the tool is a planetary epicyclic gear, designed by Mauro Turri and produced by Roberto Anzelini (figure 8f). It can be used as a speed reducer which connects an underwater drill with a Pressler gimlet, allowing divers to perform dendrochronological sampling, without risks deriving by fatigue hazards in deep waters.

All these specific solutions allowed the team to collect several new evidences regarding the submerged forest of Lake Tovel. Most of them have been geolocated combining the use of a differential GPS, a direct reflex total station, a reel connected with a SMB and a support boat. All the new acquired data have been managed within ArcheOS, thanks to the GIS GRASS, QuantumGIS (figure 7b) and to the DataBase Management System (DBMS) PostgreSQL, with its spatial extension PostGIS. With the same system all available legacy data, like the bathymetric chart (figure 7a) produced by limnologist Edgarbo Baldi in the 30s [Baldi 1941], have been integrated with the Open Data Cartography, released by the Autonomous Province of Trento (figure 7c). Some of the submerged trunks have been also documented in 3D with SFM/MVS techniques, using the software openMVG and PPT [Moulon and Bezzi 2011]. After a pre-processing stage, for mesh-editing, with MeshLab and CloudCompare, the geolocated 3D models have been integrated into the Virtual Globe Cesium. The histological analysis on the core samples, as well as the dendrochronological dating, has been performed by Mauro Berabei (CNR – IVALSA) and led to the recognition of different species (Fagus sylvatica L., Abies Alba Mill. And Pinus sylvestris L.), most of them death in 1597, the year when probably occurred a landslide which raised the level of the lake. Dendrochronological analysis, carried on with the R packages Dplr and DetrendeR, gave as a result 200 years master chain for the European Beech (Fagus sylvatica L.) and a 509 years master chain for the European Silver Fir (Abies alba Mill.), which was used in dating one of the historical phase of the Baptistry of St. John in Florence [Bernabei et al. 2016].
CONCLUSIONS

The three case studies described above indicate how general criteria of underwater archaeology have to be adapted to the peculiar characteristics of the environment under investigation, especially for the particular logistical conditions like mountain inland waters. In order to achieve the prefixed targets of this kind of missions, it is essential to define versatile strategies, based on equipment which can be modified to face unforeseen needs. Basing
on the experience of Arc-Team, Free/Libre and Open Source software (ArcheOS) and Hardware (archeorobotic devices) granted a good level of adaptation to different working environments, becoming a suitable solution to reach acceptable results in different conditions. Open Hardware in particular is able to meet the needs of a fast development, with frequent minor adjustments which can be also performed directly on the site, to optimize stability, floatation, light positions and other aspects which can change with altitude, water salinity or turbidity. On the other hand, Open Software maintenance and modification can take longer times without consequences for underwater missions, being often demanded on a data processing stage in the laboratory.

The meeting point between Open Hardware and Open Software is often represented by Single Board Computer (SBC) equipped with ROS, which can be mounted directly on board, like in the ArcheoROV, or externally, like in the ArcheoBoat. This configuration allows for the use of SLAM algorithm not only to improve autopilot solutions, but also to produce real-time low-quality 3D models with a technique which is currently accepted, by the local Superintendence of Trentino (figure 9a), for dry-land particular situations: negative archaeological controls, small excavation surveys, or extreme conditions in working places (speleoarchaeology, high mountain or glacial archaeology).

![Fig. 9. The use of SLAM algorithm during a small excavation surveys (a); a closer photo of the device, mounting ROS and RTAB-Map (b).](image)

One of the best benefits of ROS in this field is the possibility to use different software solutions (figure 9b) for SLAM (RTAB-Map, LSD-SLAM, REMODE, Cartographer, etc…), combined with different sensors (monocular or stereo cameras, laser modules for LIDAR, sonar, etc…). Up to now, Arc-Team tests in underwater SLAM did not reach an acceptable level of quality to meet the archaeological tolerance of an underwater project, giving as a results 3D models characterized by a high accuracy, but with a low precision. These models cannot be compared to the ones obtained via SfM/MVS, but future improvements of SLAM techniques could help in reaching low quality real-time 3D acquisitions, useful for mission planning. Moreover the possibility to use different sensors for SLAM opens new perspectives for those archeorobotic devices which have been designed for aerial archaeology and could improve their remote sensing devices with water penetrating capabilities. This is the case for the ArcheoDrone, which is currently under a new development stage in order to be equipped with a lightweight altimeter based on a green laser (532 nm). Indeed, the advantages of UAVs drones (and USVs), over ROVs is the possibility to connect water penetrating signals with geographic coordinates collected by a GPS over the lake surface. This is the principle that led to the improvement of ArcheoBoat with the Deeper system, allowing real-time 3D bathymetric mapping. The future archaeological mission, planned by Arc-Team for summer 2018, should give new feedback to guide the research in order to develop more versatile strategies and equipment.
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