Tools and techniques for underwater archaeological sites documentation

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Abstract— **The amount of data required for a virtual reconstruction of an underwater archaeological site requires automatic systems for collecting data, based on the use of robots and unmanned underwater vehicles, which can work for a long time, in a hostile environment, without risk to human operators and with acceptable costs. However, such systems have often to be driven by expert pilots, adding costs to the usual Data gathering campaigns. This paper shows solutions found through subsequent campaigns, thanks to the expertise of a multidisciplinary team and in collaboration with several research institutions. In particular, this work presents the added value of technology within the data collection process from underwater archaeological sites, describing an assisted guidance system for a MicroROV developed in order to help unskilled pilot. Results of 3D reconstructions from images taken during real field mission with the above technology are described.**

Keywords—ROV, Underwater Archaeology, Force Feedback Controller, Virtual Reconstruction.

**** This paper is dedicated to Mauro Della Monaca, tireless member of Gruppo Ormeggiatori del Porto di Piombino and unforgettable friend.***

I. Introduction

During last years, there have been growing interests in developing efficient subsystems for underwater research areas, dealing with the challenging problems of data gathering, filtering and 3D reconstruction.

Underwater sites are inevitably difficult to access, and more hazardous, compared with working on dry land. Specifically, regarding archaeological applications, great efforts have been focusing on the documentation, preservation and conservation of our cultural heritage, which is an important part of underwater archaeologist's work.

The studies on ground archaeological sites, as well as shipwrecks sites, have been always aimed at obtaining very accurate graphical representations of reality.

Up until recently, underwater site reconstruction were represented by drawings, produced by archaeologists after a survey diving, and the geometric measurements were taken by divers with hand-held instruments, but surveys with these techniques require a considerable effort in terms of time and economic resources, limiting the inspection possibilities to a short period, and they lack of precision.

As soon as appropriate tools became available, there was also a trend towards obtaining 2D maps and 3D representations on graphic displays. Over recent years, the field of archaeology has witnessed increasing interest in Virtual and Augmented Realities, or more generally Mixed Reality.

The use of photographs and subsequent 3D computer reconstruction with photogrammetric tools is, in itself, a great improvement; divers, taking photographs of the site, after laying out an appropriate set of calibrated markers, grades, and/or grids to be used during the reconstruction process usually did reconstructions.

All these topics have been presented and discussed during specific workshops (see for instance [1]) focused on recent advances in underwater location and inspection of shipwrecks; however, from the published literature, most of the case-

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studies belong to one of the two following situations: technologies specifically developed in other fields (as for instance military or off-shore) and used in archaeological surveys; development of special purpose tool developed specifically for archaeological applications [2]. The situation just introduced have not the potential of becoming a sustainable technological growth of underwater archeology activities because of the costs associated to the instrumentation. More useful for archaeologists is a set of low-cost, easy-to-use, plug&play technological tools and procedures that can help in reducing the overall cost of site inspection and documentation. During the last ten years, a team from Laboratory of Modeling, Analysis and Control of dynamical Systems (LabMACS) of Università Politecnica delle Marche and SBAT (Italian Ministry of Culture, Superintendence of Archaeological Goods of Tuscany - Soprintendenza per i Beni Archeologici di Toscana) have been working toward automation of the survey process [3], working on getting technologies accessible and usable by archaeologists [5], [7].

The principal aim is the development of low-cost, easy-to-use and non-invasive systems and methods to obtain a geo-referenced augmented map of a wreck site.

The VENUS project [3] improved the accessibility of underwater sites by generating precise and exhaustive 2D and 3D records for virtual exploration, but the presence of expert pilots and engineers were always unavoidable. Following the work done in VENUS, in the last years, UNIVPM's and SBAT's teams have continued developing new technologies and validating techniques. For these reasons, engineers have been developing a new vision in the development and control of underwater robots, consisting of a portable sets of sensors, controlled by a microprocessor, for acquisition of geographic and attitude data, together with images and videos [8]. This new vision is more addressed to researchers who are not confident with technologies or robot piloting.

The problem considered in the present work concerns the design, testing and development of a set of procedures and best practices for collecting data from underwater archaeological sites. In particular, the attention is focused on the technological benefit coming from an assisted guidance system for a MicroROV, designed and developed with the final aim of helping unskilled pilot in data gathering missions, thanks to the use of a force-feedback joystick. The practical use of the assisted guidance system is presented, performed during a recent documentation campaign of an important archaeological site: the *dolia* wreck (Marciana Marina, Elba), took as a model for its position and depth features. Several dives made on this site and a program of remote scouting using a MicroROV with a mounted camera was made. In addition to these explorations, a 3D reconstruction of the whole site has been created using images captured thanks to the described system.

The paper is organized as follow: Section II presents the traditional methodology used in underwater archaeological surveys, following with the description of the benefit brought by the use of technology; then, the MicroROV assisted guidance system and its functionalities are described in Section IV. Results from the field are presented in Section IV, following with conclusions and future works

II. METHODOLOGY USED IN THE ARCHAEOLOGICAL SURVEY

Underwater archeology can provide valuable information about practically all aspects of life and organization of the societies, which developed maritime activities or interacted in some way with the marine environment.

A primary interest of the archaeological investigation is to extract, in a non-invasive way, as much information as possible with minimal expenditure of time and of expensive resources. The study of shipping trade, sea ways, or naval architecture represents an important research filed, with the main goal of prevention. Destroying activities, such as trawling or robbing, continuously threaten important underwater archaeological areas, (i.e., ship wrecks); this has made a systematic recording and mapping necessary, and it has been sponsored by cultural heritage public institutions. An accurate documentation has to be provided at each stage of the methodology. A scheduled and constant check of the goals achievement to be reached during different project stages is as fundamental part, and it is performed by the evaluation of the produced documentation quality.

In the present section, the traditional underwater archeology methodology for studying sites is presented together with the surplus value derivable from the introduction of technological innovation in the documentation process (see VENUS wp3r1 final document).

Traditional techniques

Analyzing the different stages carried out during an underwater archaeological site survey, based on scientific objectives and available means, the following steps can be drawn:

1. Choice of an interesting area

The first step consists in identifying an area where an interesting archaeological site is potentially present; the choice is performed by comparing several information coming from different sources: reports made by divers or fishermen after they discover the presence of artifacts and historical sources, geographic information, geologic information, morphology, nature of the sediment of the seabed, biologic aspects and meteorological information.

2. Site localization

When the aforementioned area is chosen, archaeologist usually delimits a sub-area to explore, where the concentration of artifact materials is relevant: this sub-area becomes a site, starting to represent a part of the archaeological record. Knowing the location of an archaeological site is fundamental to start its investigation. Historically, sites within sight of the shore would have been located using transects. A site may also be located by visually surveying some form of markers (such as a buoy) from two known (mapped) points on land. At present time, the site is precisely 2D geo-referenced by the spherical coordinates (longitude and latitude of one point in the surface), using a GPS.

3. Cleaning the archaeological site

The recognition of artifacts may be poor because they may be covered. Dredges and/or crane are used for removing organic materials like algae, dead "posidonia", sand and a thick layer of sediment in general, in order to improve the recognition of artifacts within the site.

4. Site outline

A preliminary observation of the site is performed by the archaeologist divers in order to have a general view of the site: positions of the artifact's, relative orientation of the objects (the ones with respect to the others), shape of the seabed and position of the flora and the presence of enough light for photosynthesis. A central position of the site is chosen, where a buoy is placed and tentatively geo-referenced from the surface.

5. Cataloging

Before surveying the site, the objects are numbered and labeled, for example, with small PVC tablets.

6. Positioning a referencing system on the sea-bottom

In order to effectively reconstruct the archaeological site further, it is important to establish a referential system by geo-referencing an origin point and two axes.

The choice of landmarks has been always very important during a site study, since it has been used to reference the discovered artifacts position.

Usually, the origin and the axes are fixed by divers with buoys, moorings and halyards. There are several referencing systems; however measures are manually performed according to linear measurement or linear measurements with angles. According to the density of the archaeological material a reference system (grid, square, triangle, base line) is installed on the site. The most conventional technique is to place an orthogonal quadratic grid of 2 x 2 meters or 4 x 4 meters, of nylon cables, metal or PVC pipes. From this grid a sub-area is defined in squares creating lattices which help the divers and the archaeologists to find their bearings and to label the artifacts. Different points of the squaring are marked by moorings for helping the divers to easily locate the objects and the archaeologists to register without troubles the object positions for mapping the area. This procedure could only be performed in case of shallow water and it is, however, very time consuming and expensive.

The introduction of technological innovation has changed both the way the referencing system is marked and the way measures are performed.

An USBL transponder is leaved for a certain measurement time in the central point identified during the second stage thanks to previous campaign information. At the end of the chosen period, latitude, longitude and depth at the referenced point are obtained, and they became useful to geo-positioning the final map, further produced with survey data.

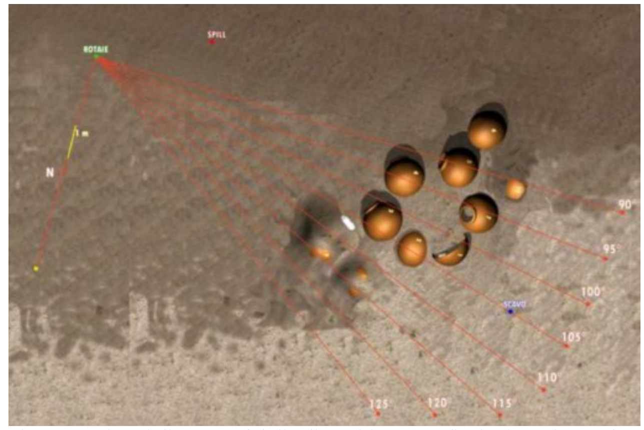


Figure 1. Virtual diagram of dolia disposition. (Grafical misure by Andrea Daviddi e Stefano Cipriani)

7. Surveying the site

With traditional methods, an archaeological site is manually surveyed and referenced thanks to linear and angular finds measures and there are several methods [12]. One of these methods is constituted by triangulation: after selecting three points on the objects, the divers measure the Cartesian coordinates of these points with respect to the reference system of the archaeological site. The archaeologists usually perform scale drawings of the objects with simple pencils and whiteboards.

The technological contribution can significantly make the survey stage more efficient, with custom electronics improving the way photos and videos are acquired.

8. Restitution: mapping

While the survey is performed underwater, the restitution is performed back to ground. According to manual surveying method, a map, that is a 2D representation of the underwater site, is produced in a form of gradually improved sketch. This map aims at obtaining very accurate graphical representations of reality. The map is firstly carried out reporting the origin and the axes of the reference system, then the Cartesian coordinates of the objects with respect to the reference point.

The technological support can be significant during this stage. In order to produce geo-referenced and large-to-medium 2D-3D scale maps of the underwater explored sites, software suites can integrate and fuse acoustical, optical and platform navigation data.

9. Exploration

Further explorations, investigations and interpretations can significantly take advantage from the previous stage output, that is the whole site map and the work done during each campaign. The methodical site exploration leads to the identification of new objects and to the systematic recording of the referenced and identified finds, especially in previous maps. After the methodical exploration of the surface layer, intrusive excavation, stratum by stratum, is carried out inside the grid. Silt and sediments can be removed using water dredges. The artifacts recovery from underwater sites destroys the archaeological context, which remains preserved only in the notes (typically on the archaeologist's notebook), drawing, and photographs made by archaeologists in the field. Careful recording is necessary, and documentation is crucial during all stages of the investigation.

Technology added value

As prefaced above, during last years we decided to introduce engineers, data manager experts and new technologies in the traditional methodology to make the process more efficient and accurate in the documentation phases. In particular, computer scientists and engineers have been introduced directly into the line of the site study since the first day of field work. With the use of the AUVs or ROVs (when the economic resources allow it), acoustic positioning systems and improved photo-camera, it has been possible to obtain a very precise geo-referenced map or 2D geo-referenced reconstruction of large areas of the seabed, instead of daily sketches. Such maps, obtained by optical, acoustical and position data correlation are innovative and important because they are not dependent from divers' memories; they also can be inserted in real time on GIS tools and, later, with appropriate filtering, in 3D virtual reconstructions of the site. In the figure 2 the technology introduced during the traditional analysis process and the relative output documentation are presented.

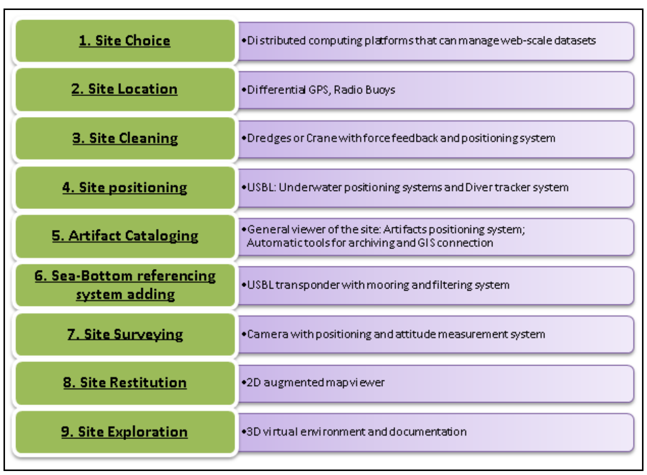


Figure 2. Classical site analysis phases and the introduced technology.

Modifying the classical way to proceed, directly using the gathered data in order to automatically, and daily improve the output maps have brought to a sort of self-assessed work cycle, where the operation planning is performed directly on the electronic format of the site visualization.

Maps allow understanding if some data have not been documenting yet and if some areas have to be deeply investigated. In this way, archaeologists can dynamically change the plans during the campaign, optimizing costs and time. Figure 3 illustrates a typical work cycles with the final output map. These self-documented cycles are very useful when the digging implies some site layers to be wrecked: in fact, with the methodology just described, the destroyed strata will keep being visible and accessible as virtual levels in the 3D site reconstruction.

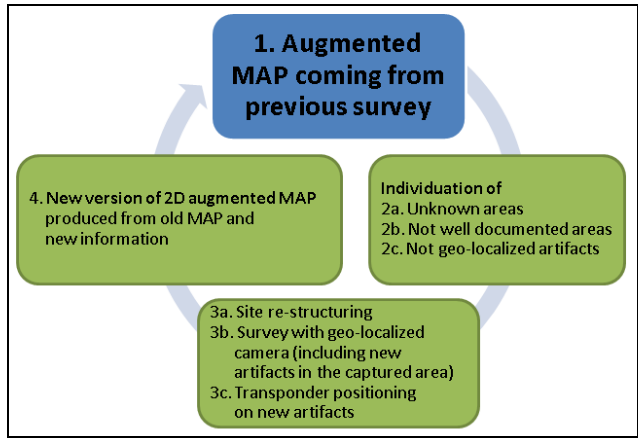


Figure 3. Typical work cycles for producing augmented map in archaeological campaign.

In the *dolia* case study both traditional and innovative techniques of acquisition have been used. The research scenario has seen technical stuff and sport divers working together and with acoustical and optical sensors.

III. MicroROV Assisted Guidance System

Within the general data acquisition process, a MicroROV Assisted Guidance System is developed to support the robot operator. Essentially, the Assisted Guidance System works modifying the MicroROV response to the pilot's commands depending on the vehicle position within the work area, forcing the pilot to keep the robot inside it.

The Assisted Guidance System increases the joystick reaction force as the distance from the boundary decreases, generating automatically a feedback command, which aims at driving the MicroROV toward the work area inner part.

The main scheme representing the Assisted Guidance Module is characterized by 3 principal functional blocks:

a) the **Reference position parameters block** is responsible of defining the MicroROV work area in terms of suitable parameters;

b) the **MicroROV position block** supplies the guidance system with the MicroROV actual position and orientation in the chosen reference coordinate system;

c) the **Force Feedback computation block** computes the appropriate force feedback signal, acting on the joystick used by the operator to drive the vehicle, on the basis of the information coming from the other two blocks.

Blocks just described and their interaction are represented in Figure 4.

The MicroROV work area is defined as a rectangular region on the MicroROV work plane, with a smaller region inside. The bigger rectangle defines the overall limits for the vehicle's

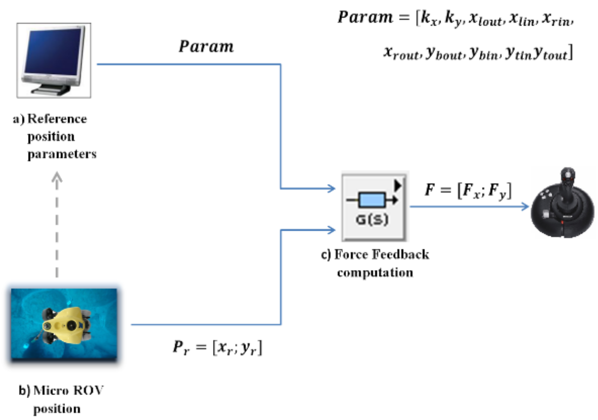


Figure 4. Micro ROV Assisting Guidance System scheme

movement; the inner rectangle, instead, represents the area where the vehicle can move without constraints.

The simplest example for the outer boundaries rectangle can be represented by the archaeological site area if researchers decide to fix the surface deploying ship and to move only the MicroROV; similarly, if the deploying ship moves with the robot, the outer rectangle is chosen based on the details wanted for each transit over a certain part. It is important to notice that ths choice is the most common, being the surface deploying ship positioned not exactely above the site. Figure 5 represents the force concept just described.

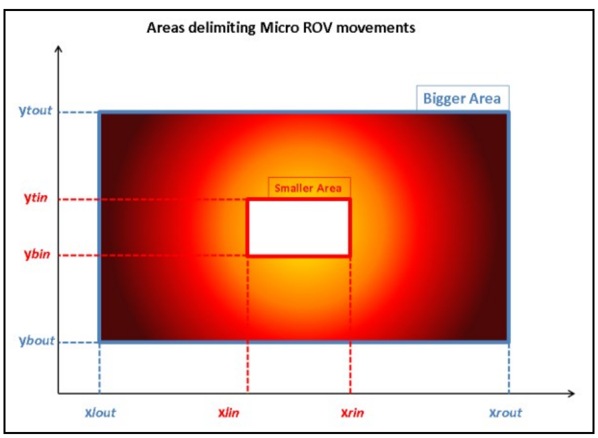


Figure 5. Forces representation

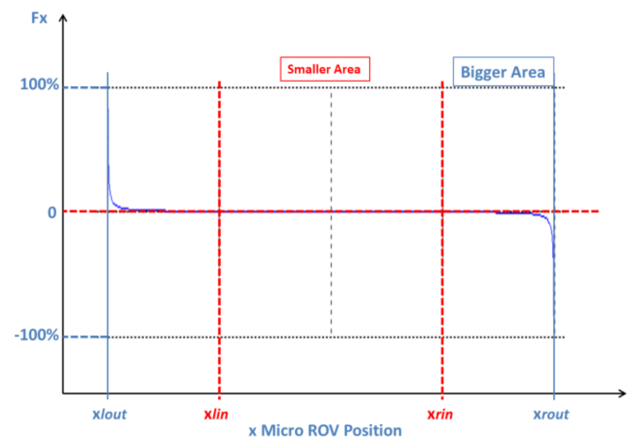
Keeping into account the above remark, we define the feedback force ***F,*** acting on the joystick only when the Micro ROV is out of the smaller rectangle, as follows:

$$F = \begin{bmatrix} F_x \\ F_y \end{bmatrix} = \begin{bmatrix} k_x \frac{x_r - x_{lin}}{x_{lout} - x_r} - k_x \frac{x_r - x_{rin}}{x_{rout} - x_r} \\ k_y \frac{y_r - y_{bin}}{y_{bout} - y_r} - k_y \frac{y_r - y_{tin}}{y_{tout} - y_r} \end{bmatrix} \quad (1)$$

where:

- F_x, F_y are the feedback force components;
- k_x, k_y are parameters, to be chosen in designing block c);
- x_r, y_r represent the actual Micro ROV position;
- x_{lout} , x_{rout}, y_{bout}, y_{tout} represents the values of the coordinates of the vertices of the work area;
- x_{lin} , x_{rin} , y_{bin} , y_{tin} represents the values of the coordinates of the vertices of the inner rectangle.

Fig.5, representing F_x trend inside the work area, shows how **F** will act in order to keep the vehicles far from the boundaries and inside the smaller rectangle. Saturation will be applied in practical implementation of (1).



Note that the force **F** can be viewed as generated by an Artificial Potential Field (APF) of specific structure; we refer the reader to [6], where APFs are used in order to represent the relations between underwater robots and the environment, and to the reference therein for a complete documentation on APFs.

IV. RESULTS

The Micro ROV Assisted Guidance System has been tested during several survey missions of archaeological underwater sites. In [4], authors show results obtained using the system in a bigger framework, while Fig.5 shows the 3D reconstruction of the Dolia shipwreck in Elba Island obtained using images gathered with the use of the described system.

The **shipwreck of Dolia** of Punta del Nasuto (Marciana Marina, Elba Island) can be placed within the framework of commerce and navigation between the end of Republican Period and the beginning of the Imperial Period. This important site collocated within the Tuscany Archipelago, which constituted a great crossroads of commercial trades between the Italian population and Orient, and between Gaul and Iberian population on the other side, presents a load of ten big dolia in a different position respect to the original stowage location. The shipwreck is dated in a very limited time span, between 50 B.C. and 50 A.C. that is in the transition between the Republic and the Empire, when the central regions of the peninsula send large amounts of wine to Gaul and the Iberian coast.

Figure 6. DOLIA shipwreck at Marciana Marina, Elba Island
A detail of dolia oriented in the same direction. (Photo by Adriano Penco, 2010)

Up to now, sea trials have been useful in order validate the proposed solution from a general point of view. Next campaigns will be used to optimize both the structure and the parameters of the system.

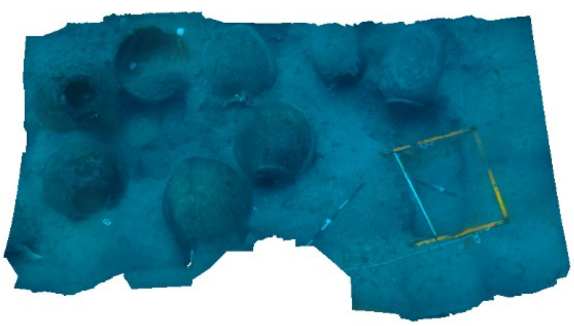


Figure 6. 3D virtual representation of the dolia wrecksite

Figure 6 shows a screenshot from the 3D virtual reconstruction of the whole site. The big *dolia* are clearly distinguishable and can be compared to several instruments positioned on the seabed.
Figure 7 is another result of the 3D reconstruction, obtained taking the central *dolium* as the central point of the force region and moving the ROV controlled with a virtual spring, in order to reconstruct with major details.

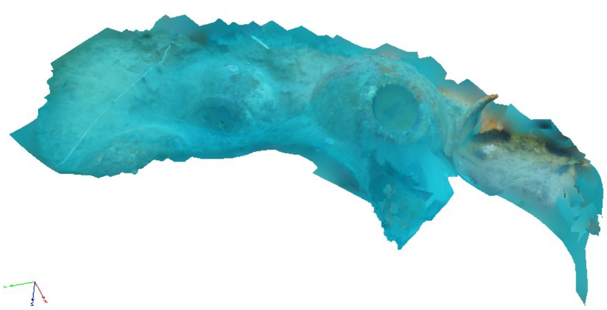


Figure 7. 3D virtual representation of the dolia wrecksite: a detail from video frames

V. CONCLUSIONS

This paper discussed the design and realization of an Assisted Guidance System for the robotic structure consisting of two cooperating ROVs of different dimensions. The developed system aims at making substantially simple the task of guiding the micro ROV in achieving the mission's goals, coping with constraint, limitations and environmental conditions. This will make possible to operate directly the micro ROV to pilots who have limited skill and experience, making it a user-friendly tool and facilitating its use at general level. Scientists like marine biologists and archeologists can potentially benefit of the Assisted Guidance System in the framework of the considered robotic structure or of others. Future works will concern tests and validations of the whole structure in field missions.

ACKNOWLEDGMENT

Missions on the DOLIA wreck of Marciana Marina have been possible through the sinergy of institutions, associations and volunteers. Authors want to point out contributions of the Municipal Administration of Marciana Marina, Association Team Explorer Chimera, of Soc. Group and Boatmen of Piombino, the Hoteliers Association and of the Sailing Club of Marciana Marina, Cantieri Marinesi, of Elba Diving Center.

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