Survey and Intervention HROV

P. Ridao, M. Carreras, D. Ribas, N. Gracias, R. Garcia

Resumen

Traditional underwater archaeology is performed via SCUBA diving but is constrained by the practical depth that a diver can work (normally limited to 50 meters) and the time that can be spent underwater. New technologies, like manned submersibles, remotely operated vehicles (ROVs) and quite recently autonomous underwater vehicles (AUVs) allow archaeologists to survey deeper, dramatically increasing the number of underwater sites reachable for archaeological study. While technology plays a significant part in this work, it must be combined with archaeologists? research methodology so that archaeology in deep water conforms to the required standards. In this paper we discuss how HROVs may become the perfect tool to assist archaeologist in their work.

1 Introduction

From the last few years of deep-water archaeology it has been clearly demonstrated that archaeologists can benefit from new underwater technology but their requirements pose new and sometimes fundamental problems for engineers [2]. Manned submersibles have the unique advantage of allowing scientists to physically reach the deep and perform systematic observation on sites of particular interest as well as recovering artifacts [14]. However, because of their operational costs and complexity, their availability is very limited. A big leap towards deep-water archaeology was given by the use of ROVs. With continuous power supply from the deployment ship, they can support a wide range of sensors, uninterrupted operations and can recover artifacts with heavy but precise manipulators [1, 5, 12]. ROVs are generally powered and controlled from a tether cable. While this provides unlimited autonomy in terms of power and time, it limits the range of the ROV and as the depth operations increase so increases the deployment and usage costs (e.g. bigger support ship). Although limited in power, AUVs alleviate some of these drawbacks such as avoiding the tethering range limit, thus increasing the efficiency of archaeological UUVs over the last decade, for both commercial and scientific applications. Early uses of AUVs in marine archaeology were reported in [8]. In 2004, Meo [9] discussed the applications of new technologies in the study of underwater archeological sites, emphasizing the advantages of AUVs in such scenarios. More practically, Foley et al. [6] provided a detailed description of the archaeological study of two 2000-year-old ships. Due to the depth of the sites (70m) the use of divers was not practical. As an alternative, the research team successfully used AUV systems to map and study the sites. An extensive review of the AUVs usage and deepwater archaeological techniques can be found in [2], [**?**]. The experience of our team applying AUV technology to marine archaeology is based on our participation in the survey of two shipwrecks described in the following subsections.

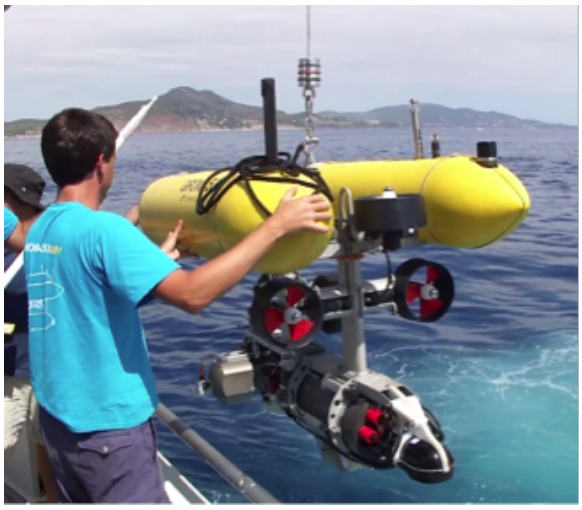

Figura 1: GIRONA AUV deployed to survey La Lune Shipwreck (toulon-France).

1.1 La Lune XVII century shipwreck

La Lune Shipwreck is a XVII century wreck lying in 90m of water, of the coast of Toulon in France. Accidentally discovered by IFREMER in 1993 the wreck was assessed soon after its discovery by the French DRASSM and considered to be one of the best preserved in the world. During August 2012, GIRONA500 AUV [11] (Fig. 1) was deployed to

Figura 2: Fig. 2. Photomosaic of a XVII century shipwreck La Lune build during in August 2012 using GIRONA500 AUV

Figura 3: 2.5D multimodal map of la Lune Shipwrek consisting on a photomosaic rendered over the microbathymetry of the shipwreck.

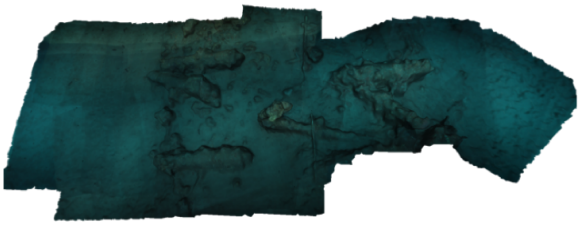

Figura 4: 3D reconstruction of the anchor and some of the canons.

create a preliminary optical cartography of the site [7], to serve as the base map for posterior archaeological intervention by DRASSM. The data were collected in two consecutive dives of one hour each. Different data products were produced: 1) a high-resolution (1 mm x pixel resolution) 2D photomosaic of the seafloor (Fig. 2), 2) a 2.5D bathyme4ry textured with the photomosaic (Fig. 3) and 3) 3D reconstructions of objects of interest (Fig. 4).

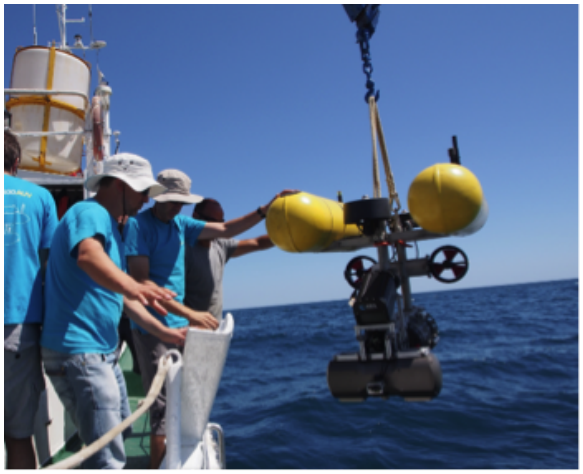

Figura 5: GIRONA AUV deployed to survey Cap del Vol Shipwreck.

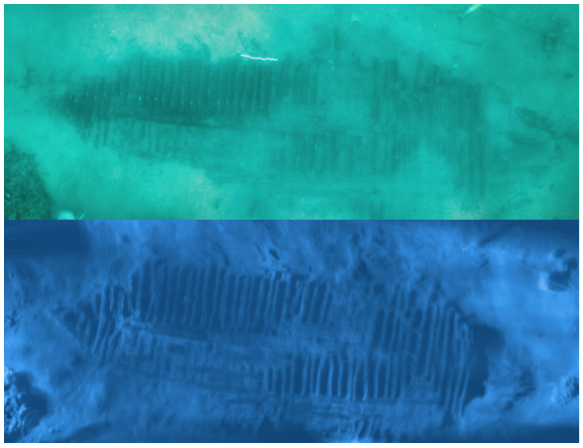

Figura 6: (Top) High resolution (1 mm/pix) Photo-Mosaic. (Bottom) Sonar mosaic.

1.2 Cap de Vol 10 BC shipwreck

The Cap del Vol Shipwreck cruise (Fig. 5) took place in August the 30th and the 31th at Port de la Selva (Costa Brava-Spain) on board the THETIS ship of the Catalan Centre of Underwater Archaeology (ACdPC). This was a joint effort between the ACdPC and UdG teams to evaluate the use of advanced underwater robotics technologies for submerged cultural heritage applications. During the cruise the GIRONA500 AUV systematically

targeted the shipwreck. Four dives were carried out during a two days cruise, three of them in autonomous mode and one operated as a ROV. During the two first missions the robot gathered optical data using a high resolution stereo pair designed and developed at CIRS-VICOROB. The 3rd mission acquired optical and acoustic data. The 3rd mission was teleoperated, with the main aim of exploring the shipwreck at very low speed while gathering forward looking sonar imagery. It demonstrated us the potential of the HROV concept for cultural heritage applications. In this case, 2 data product were produced: 1) a High resolution (1 mm/pix) Photo-Mosaic (Fig. 6 - Top) and 2) a Sonar mosaic (Fig. 6 - Bottom) obtained through the registration of sector images gathered with ARIS multibeam forward looking sonar. The acoustic imagery was gathered while manually piloting the surge and sway DOF while automatically keeping heading and altitude (3 m) to ensure a consistent shadow effect across the scene.

Based on this experience, we advocate for the use of a light weight HROV system easily deployable from small ships, like those commonly used by marine archaeologists. The HROV is reconfigurable to operate as an AUV to perform autonomous opto/acoustic shipwreck surveys, as those described above, and as a smart ROV to perform site intervention and light excavation. In this paper we further develop these concepts.

2 Technical Description

This section describes the proposed lightweight survey and intervention HROV (section 2.1) as well as how we think it can be applied to marine archaeology (section 2.2).

2.1 HROV System

Conceptually a HROV is an AUV system which may optionally be tethered, with a thin cable for communications only, to be operated as a ROV. Its capability to work as an AUV, as well as an ROV, makes it a very attractive design. Moreover, it perfectly fits our concept of facing the survey phase autonomously and the intervention phase semi-autonomously under the supervision of an human operator, taking profit of the broadband communications to provide a high definition sensory feedback of the operational environment. By targeting semi-autonomous intervention, we expect to be able to achieve a system smarter than pure teleoperated ROV style manipulation. The proposed HROV will be based on the GIRONA 500 platform complemented with a thin broadband communications Tether, a TMS, and an electrical robot manipulator.

2.2 Operational Concept

We foresee three different modes of operation which are described in the next sections.

2.2.1 Discovery of new sites:

Archaeologists look for new sites in places where they have an historical evidence of a shipwreck or, alternatively, in areas where fishermen or divers have detected evidences of ship remains. Normally, they dive in the place seeking wreck artifacts. UUVs can contribute to the location of new wrecks, by significantly extending the bottom time as well as the coverage of the explorations. Conventional Side Scan Sonar (SSS) and Multibeam bathymetry mapping, as well as optical imagery can be collected during the search. Moreover, after the dives, the imagery can be automatically processed by an offline classifier looking, for instance, for ceramic remains. This will point out candidate areas to carry out a 100% coverage opto/acoustic survey.

2.2.2 Site Survey

When the site coordinates are known, the box to be surveyed can be estimated and a survey trajectory obtained. Next, the HROV will be deployed in tether-less mode. The robot will dive and follow the pre-programed path at a constant altitude (¡5m) while gathering data with the cameras and sonars. At the end of the mission the robot will be recovered and the data downloaded. After downloading the panoramic camera imagery, a topological panoramic map can be made available to the archaeologists, allowing for a virtual tour of the shipwreck, similarly to google street view. In the meantime, an offline mapping tool can be used to set-up accurate photo or sonar mosaics producing a high resolution (less than 1 mm/pixel in the case of optical and 10mm/pixel when acoustic) maps of the site. These maps will be used to plan accurately the next day excavations by the archaeologist divers if the operation takes place shallow water. It is worth noting that we do not plan to replace the archaeologist divers by the robot operation in shallow waters, but provide them with a tool which will allow them to devote their time only to the tasks that may not be automated.

2.2.3 Site Intervention

The HROV will operate in tether mode. An HMI will be used to provide the archaeologist with an Augmented Reality view of the operation site. It will render in real-time the Photo/Sonar Mosaic

together with an out-of-body representation of the HROV. The archaeologist will be able to guide the vehicle or, alternatively, the end effector. In the last case, the system will automatically decide whether to move the arm, the vehicle or jointly move both to achieve the desired motion. The robot will be able to perform station keeping, and the panoramic camera will allow the archaeologist to visually explore the 360º using the VR headset. Two main intervention tasks are foreseen: 1) grasping objects and 2) performing light excavation of selected objects. Using a force torque sensor, the archaeologist will be able to perceive the applied force, allowing for a careful manipulation of the objects. For the excavation, it will be possible to mount the air lift in the arm, as well as to mount it in a fixed position while using the arm to help in the cleaning of the area by smoothly moving the water, and hence the sand, around the object being excavated.

2.3 Key Challenges

To achieve the functionality described in the technical description, several fundamental challenges have to be faced as described hereafter.

2.3.1 Immersive presence

Archaeologist are used to dive to do intervention directly over the site. Hence, one of the challenges is how to bring them virtually to deep sites which are inaccessible to them. Although conventional ROVs provide remote views over HD screens, new technologies exist which may potentially improve the experience to immerse the archaeologist in the site. For instance, we are using hemispherical cameras during autonomous surveys to provide offline maps similar to those of "google street view" underwater, allowing the archaeologist to freely navigate between the omnidirectional views using an immersive head-mounted display (HMD). Another challenge is to provide this immersion during the intervention. In this case it is necessary to track the operator's head attitude to estimate its vantage point in order to extract the necessary pictures from the hemispherical camera, transport them in realtime through the tether, and render them on the HMD. In this case latency should be kept very small to reduce the motion sickness.

2.3.2 Semi-autonomous Intervention

Besides allowing the users to teleoperate the HROV using a joystick for the vehicle and a haptic for the arm, more advanced end effector (EE) guidance methods would be pursued. For instance, it would be allowed to ask the HROV to autonomously navigate to a certain waypoint, or the EE to adopt a certain pose. It should also be necessary to teleoperate the EE directly, allowing the system to decide if the vehicle, the arm, or both have to be moved to achieve the goal. It will be necessary to establish constrains, avoiding for instance vehicle collisions with the ship remains on the seafloor. More advanced manipulation skills based on the perception of the environment and the joint motion planning of the HROV and the arm have to be studied in order to allow the system to navigate within the site while performing light intervention task programmed at high level.

2.3.3 Automated Classification

Underwater imagery, both optical and acoustic, has become a widespread tool for seafloor studies, owing to the rapid advancement in imaging electronics. However, the advancements in the analysis have not kept pace with the improvements in image acquisition systems. For the vast majority of optical surveys, a human analyst must still inspect every frame to extract relevant information. A clear challenge lies in the capacity to automate this process. This is further pressing for the case of optical imagery where the higher spatial resolution, when compared to other sensing modalities, translates to very large amounts of data. Progress has been attained by several research groups in automated classification of underwater imagery using texture information, mostly on the habitat mapping realm ([10, 3, 15], but no single technique is yet widely accepted as robust. A midterm research challenge lies on the use different sensors (such as SSS, microbathymetry from both MBES and from high resolution optical stereo, and magnetometers), in order to exploit their complementarity in providing discriminative cues for the classification. An example of the impact of automated classification on HROV-assisted archaeology, would be the ability to detect and characterize the artifact distribution in large-area surveys around areas of prior archaeology evidence, eventually leading to the discovery of new sites. For existing sites, it would also be valuable in characterizing the mobility of small artifacts and the impact of natural or human disturbances over time.

2.3.4 Multimodal 2D/3D Mapping

How to combine data coming from different sensor modalities into a single and consistent model of the environment is one of the main challenges. Advancing towards the co-registration of several 2D/3D maps, potentially from surveys in different periods of time is also necessary.

2.3.5 Benchmarking

Marine archaeologists are very exigent about the resolution and accuracy of the maps of the submerged sites they build. After years of work, they have come up with a methodology for mapping manually with high accuracy and resolution the shipwrecks they survey. It is necessary to develop metrics to assess the accuracy of their current methods and to compare them with the maps builds automatically with the help of robots. At the same time it is necessary to develop benchmarks to assess the intervention tasks, defining metrics in order to quantify the progress.

3 The Future

In this section, future foreseen technological advances that may have an impact on the concept of the survey and intervention HROV system are discussed:

- Wireless Operation: Getting rid of the thin tether, using an opto/acoustic communications was recently demonstrated at short distance [4] For the next years, the advances in underwater wireless communications technology, are expected to increase this distance, as well as the communication bandwidth, enabling online reconfiguration from AUV to ROV and vice versa.
- Multi-vehicle Operation: With the evolution of modems high speed communications at short distances (electromagnetic or optical, for instance), will be possible, to exchange considerably larger volumes of information among vehicles. This will foster new operational concepts base on tight cooperation among vehicles. For instance, we can think on using an small AUV as a flying camera providing alternatives views which are not possible from the HROV cameras due to occlusions.
- Intervention using semantic information: Advanced 3D imaging methods (stereo, laser scanners) will allow gathering 3D point clouds of the site of interest. Next, prior models of the expected objects (amphorae, for instance....) will be used for object recognition to enable semantic mapping, providing a more elaborated world model for manipulation planning. Semantic maps pave the way to scene understanding, where the feasibility of accomplishing a task may be evaluated on the fly, as well as the risk for the robot.

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