Innovative Technologies for the Investigation of Deep Water Archaeological Sites

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Abstract. Recent experiences in the combined use of underwater tethered robots (ROVs – Remotely Operated Vehicles) and sonar systems in archaeological search operations are reported. The experimentation reported has allowed the evaluation of current state-of-the-art technology vis-a-vis operational requirements of archaeological field work at sea. The involvement of a multi-partner, multi-disciplinary group has in particular allowed the comparison in operation of the performances of two ROVs, one powered by an on-board battery, the other powered from the surface ship through the umbilical cable. Sonar systems performance has also been evaluated, as well as automatic navigation and positioning systems. From an archaeological point of view, the cruise program described in the paper has allowed the survey of relatively large areas of the Tuscan Archipelago, North Tyrrhenian Sea, the repeated monitoring existing archaeological reservoirs in the region, and the detection and documentation of two new relicts from a Roman imperial age.
Keywords: Underwater archaeology; Remotely Operated Vehiclse; Sonar

1. Introduction

The field work typical of underwater archaeological research is characterized by specific challenges and difficulties due to operation in an hostile environment. Localization of archaeological underwater sites is difficult, and most of the time it is driven by occasional findings. Inspection and documentation of a discovered site require the work of experienced divers and mobilization of appropriate surface support platforms, with heavy economic costs and non negligible risks for human life. Moreover, diving for scientific archaeological purposes is limited to shallow waters, with depths less than 50–60 meters. The risks and costs of survey operations prevent repeated monitoring of underwater sites, so that the found artifacts are in most of the cases recovered and stored on land, destroying the specificity and unicity of the site. Public at large is very seldom offered the opportunity of visiting an underwater site, missing a great opportunity from both an educational and a recreational point of view.

Innovation and development in the field of computer science, and, more in general, of ICT applications (Information abd Communication Technology), seems to held the promise of mitigating and eventually solving most of the above problems. ICT appications may range from automatic search and inspection with autonomous robots to virtual reality rendering of the underwater environment, including the archaeological remnants. Several recent success histories have clearly shown the advantages of the application of state-of-the-art underwater technology to the archaeology domain (Ballard et al. 2002; Grand Ribaud 2002; Gambogi 2003; Mindell et al. 2004; Vettori et al. 2004). The instrumentation used, however, has rarely been designed with archaeology as its primary application: more common is the case of adaptation to archaeological needs of equipment designed for industrial, commercial or military purposes. There are some notable exception, particularly in the case of Autonomous Underwater Vehicles (AUVs): (Mindell and Bingham 2001) have proposed specific design guidelines for an archaeology-specific robot; however, they also recognize that the various operations required by a complete archaeological mission are unlikely to be fulfilled with a single “universal” instrument.

Prior to any design attempt, however, it is necessary to critically evaluate what can be offered to underwater archaeology by current innovations in ICT research. Building on the experience gained in a systematic archaeological research cruise program started in 2001, this paper has the aim of providing such evaluation as for the use of sonar systems in site search and underwater robots in site inspection. The development of specific, archaeology driven, methodologies and technologies is the subject of a companion contribution by Caiti et al. in these proceedings.

The paper is organized as follows: in the next section, the North Tyrrhenian Sea cruise program is briefly reviewed; in the third section the procedure employed and the results obtained with the use of different sonar and ROV systems are illustrated; the results obtained are discussed in section 4, and finally conclusions are given.

2. The North Tyrrhenian Sea Cruise Program

The North Tyrrenian Sea (NTS) cruise program has started in the year 2001 as part of a collaborative effort between the Italian Ministry of Cultural Heritage and the Italian Navy. A team of different Institutions has since participated on a yearly basis in search and inspection archaeological cruises in the waters of the Tuscan Archipelago, at water depths between 40 and 200 meters. The team is composed of:

- Soprintendenza Beni Archeologici Toscana, with leadership in the definition of archaeological goals, area selection, preservation and monitoring tasks;
- MuVITA (Live Museum of Technology for the Environment, Arenzano (GE), Italy), making available a Phantom Remotely Operated Vehicle (ROV) equipped with broadcast quality cameras, multimedia recording and visualization tools;
- ISME, Italian Interuniversity Center of Integrated Systems for the Marine Environment, for navigation and control of the Phantom;
- Lerici Ocean Science & Technology Association, taking care of logistics, liason with the Italian Navy and with other organizations.

The Italian Navy has made available a Mine-Hunting ship for each cruise, equipped with her search sonar and with her own Pluto ROV. In some of the cruises, teams from the NATO Undersea Res. Ctr., La Spezia, from the Oceanic Engineering Department, MIT, and from the American Academy in Rome have also participated.

The NTS cruises program has seen so far four operations (Baratti 2001, Argentario 2002, Marciana 2002, Follonica 2003), all in the Tuscan Archipelago area, in the proximity of Elba Island. These areas are well known for the presence of ancient wrecks from Etruscan and Roman age (Gambogi et al. 2000). The main objective of the NTS operations is the monitoring of existing archaeological sites and the systematic search of uncovered areas for the localization of possible new sites.

3. Operational Procedures

The operations were divided in two stages:

1 search and localization

2 classification and inspection

No attempt has been made so far in photogrammetric reconstruction and excavation with automatic instrumentation. In some of the explored sites, divers from Soprintendenza Beni Archeologici Toscana have conducted excavation and recovery operations as part of the joint program activities. The operational procedures adopted at each of these stages are now described.

3.1 Search and Localization

Two different procedures have been employed. In the first procedure, a preliminary side-scan sonar survey has been conducted, with Differential GPS geo-referentiation. The side-scan sonar data have been analyzed in order to detect bottom features that could be associated to non-geological structures. Subsequently, the identified features have been re-localized with the aid of DGPS information and with a mine-hunting sonar. for Classification and inspection operations were conducted after re-localization. In the second procedure, the side-scan sonar has not been utilized, and the search operation has been conducted directly with the mine-hunting sonar. In this latter case, classification and inspection were performed immediately after sonar detection.

The side-scan sonar used is a Klein 5000, operated by the Saclant Undersea Res. Ctr., on agreement with Soprintendenza Beni Archeologici Toscana. The mine-hunting sonar used is the SQQ 14IT, on equipment of the Italian Navy mine hunters. Two relevant examples of side-scan sonar data are in Figures 1–2. Figure 1 refers to the remnants of the “Pozzino” relict, in the Baratti gulf, excavated in the ‘80s and subsequently refilled with sand sediment strata. The site is among a posidonia sea-grass prairie: the excavation depression, though, is still clearly identifiable from the sonar trace. Figure 2 refers to a new relict, first reported in (Gambogi 2003), in the northern Follonica gulf. Also in this case the site is among a posidonia prairie: the bottom anomaly corresponding to the archaeological site is detectable because of the absence of posidonia on parts of the bottom. Should the posidonia have completely covered the area, the detection of the site would have been much more problematic.

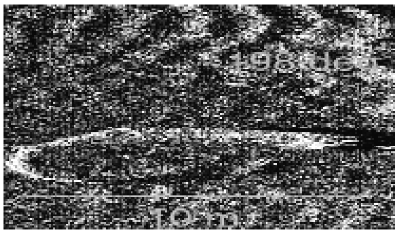

Fig. 1. Klein 5000 side-scan sonar image acquired at the “Pozzino” excavated relict site, Baratti Gulf.

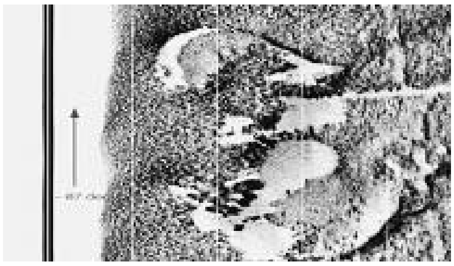

Fig. 2. Klein 5000 side-scan sonar image acquired at the Follonica Gulf site.

3.2 Classification and Inspection

Once an acoustic bottom anomaly has been detected, either from the side-scan sonar or the mine-hunting sonar, camera inspection with Remotely Operated Vehicles (ROVs) was conducted. Two vehicles were available: the Pluto and the Phantom. The Pluto, built by the Italian company Gaymarine, is a standard ROV for Italian Navy mine hunting purposes. It is a 4-Degrees Of Freedom (DOF) vehicle, with an on board battery for propulsion power, and a b/w frontal orientable camera as payload. The fiber optic umbilical cable is used for data transmission. The Phantom has been built by the American company MacArtney, and customized on ISME design to meet the needs of MuVITA. It is a 3 DOF vehicle, equipped with three colour broadcast-quality cameras: one orientable frontal camera and two fixed lateral ones; it can accommodate additional payloads on the vehicle frame. The umbilical cable is used both for data transmission (through fiber optic) and for power supply: the vehicle is powered from the surface ship. The Phantom data (both from navigation instrumentation and cameras) are sent to a recording and visualization station, with four parallel display screens. Navigation of both ROVs toward the classification location has been performed using the mine-hunting sonar and exploiting the ship's dynamic positioning system (Caiti 2002): the ship hovers in proximity of the object to be classified, orienting the sonar toward the object; the ROV dives from sea surface into the sonar field, and then it is navigated by the sonar. When the object is reached, video inspection is used to classify it.

In the Baratti 2001 cruise, in collaboration with the MIT team, a different navigation procedure was tested, with the use of the GIB – underwater GPS system (Bechaz and Thomas 2000). This system, developed by the French company ACSA, is based on the use of surface buoys (moored or floating – at least three), equipped with a DGPS receiver antenna, a receiving hydrophone, and a radio transmitting facility. An acoustic pinger is installed on board the ROV, transmitting acoustic pulses at pre-programmed time intervals (typically every second), synchronized with the GPS clock. Each buoy, on reception of the pulses, can compute its own range from the ROV by time-of-flight measurements. The range information, together with the absolute position of the buoys, is radio transmitted to a central station on board the ship, where the absolute geo-referenced position of the ROV can be determined. Substantially, the GIB system is a Long Base Line system (LBL) with surface instead of bottom-moored transponders.

The GIB system has been tested for two different purposes: as a tool for georeferentiation of the ROV images in post-processing stage, and as a direct mean of vehicle navigation in substitution of the previously reported procedure. The results obtained through this latter mode of operation have not been as satisfying as expected, mainly because of the presence of a time-lag of 8 seconds in the position determination before feedback to the ROV pilot. The post-processing procedure, on the contrary, fulfilled the expectations, allowing us to get precise georeferentiation of the video images. This was not possible with positioning from the mine-hunting sonar: the ship has DGPS positioning, to which range and bearing reading from the sonar must be added. The two systems, however, are not and could not be possibly integrated without interference with the ship's operational system.

4. Discussion

The discussion now summarized refers to two distinct aspects: the use of sonar systems in search and localization; robot positioning and maneuvrability issues in classification and inspection.

As for sonar systems, both the side-scan and the mine hunting sonar are substantially blind over posidonia or similar seabed vegetation. Moreover, they can only explore the seabed surface, and do not penetrate within the sea bottom. Standard sub-bottom echosounders (not employed in the NTS cruise) do not have the necessary definition to be useful for archaeology field work, due to the well known trade off between resolution (that requires high acoustic frequencies) and bottom penetration (that requires low acoustic frequencies in order to mitigate attenuation effects). This is a relevant point, since an acoustic instrument, together with the associated signal analysis tools, able to image sub-bottom features at the required resolution would be of great benefit to archaeological exploration. An additional drawback has been noted as for the interpretation of the acoustic images. In particular, mine-hunting sonar images require a skilled, trained interpreter. Side-scan imagery is somewhat easier to be inspected visually, it allows to obtain grey scale "images" of the seabed, that can eventually be rearranged in mosaic form to obtain a complete seabed map, but it still requires training and experience. Among the two instruments, however, side-scan sonar was definitely better suited for archaeological purposes.

As for ROV operation, the mine-hunting sonar based positioning and navigation system has again shown severe drawbacks against the acoustic background produced by a sea grass covered bottom. The GIB system has a performance that may depend on the acoustic environmental conditions, it may require a reduced repetition rate in the presence of strong acoustic multipath arrivals, and it may give erroneous ping detections in the presence of faster acoustic arrivals through the seabed waveguide. All this seems to indicate that the positioning problem for underwater robots has not yet been satisfactorily solved, at least as for what archaeology is concerned. As for vehicle manoeuvrability, the Pluto ROV has shown a better performance, due to the almost negligible drag of its umbilical cable; in the inspection task (complete video recording of the site), the Phantom had better performances, due to the longer diving time (theoretically limitless – in our cruises the maximum uninterrupted diving period was slightly over three hours) and to a camera and video rendering system more appropriate for the archaeological inspection work. To be fair with the Pluto, it must be remarked that last generation vehicles have battery systems that allow uninterrupted diving for more than eight hours, which is more than enough for archaeological applications in the range of depths considered in the NTS program.

In one of the NTS cruises (Argentario 2002), the MIT group has also tested the use of Autonomous Underwater Vehicles (AUVs), equipped with side-scan sonar, for a completely automated search mission. The results of the test may be reported by the MIT group elsewhere; however, for the purposes of the present paper, it can be fairly said that although AUVs held the promise of becoming the tool for tomorrow operations, at present they are still far from satisfying the requirements of operational underwater archaeology.

5. Conclusions

The experience gathered within the NTS program in the use of state-of-the-art technology in underwater archaeology search and inspection tasks has been reported. We think this experience valuable in particular because it has allowed a multi-disciplinary group, including archaeologists, engineers, oceanographers, maritime professionals, to work closely together and to share the perspective of each one discipline.
The focus of this paper has been mainly on the technological side of the NTS program. However, the focus of the NTS program was on archaeology. In addition to the monitoring of several reported relicts in the area, the program has led so far to the discovery of two previously unreported wreck sites, one of which at depths well below 60 meters depth, and whose inspection and exploration would not have been possible without robotic technology (see Figures 3–4).

Fig. 3. amphora at the newly discovered Gulf of Follonica wreck site (Gambogi 2003); superimposed on the image the control panel of the Phantom ROV system.

Fig. 4. “dolia” from a roman cargo ship (I century?) at the North Elba newly discovered site.

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