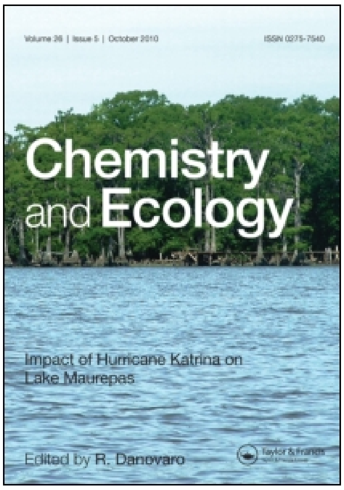

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Innovative technologies in underwater archaeology: field experience, open problems, and research lines

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The exploitation of marine technological innovations in the field of underwater archaeology has been mainly associated in the past with the exploration phase, in a sort of 'treasure-hunt' fashion. However, the combined progress in such diverse fields as underwater acoustics, robotics, image processing, computer graphics, and decision support systems has not yet been directed towards the need for underwater archaeological research. Starting from the field experience gathered in a series of archaeological cruises in the North Tyrrhenian Sea, in which the combined use of state-of-the-art underwater tethered robots and sonar systems has been tested by a multidisciplinary group, the paper reviews some ongoing technological developments that may be merged toward the final goal of fully automated detection and inspection of an archaeological site. In particular, current advances in 3-D acoustic backscattering measurements for remote inspection of buried artefacts and vision-based robot control methodologies for fine positioning and accurate site survey are described.

Keywords: Marine technology; Underwater archaeology; Underwater acoustic; Submarine robotics

1. Introduction

The application of ICT (Information and Communication Technology) to the activities and problems of underwater archaeology is relatively recent and has mainly emphasized the possibility of making new discoveries. Recent succesful accounts have shown that, by using unmanned equipment, it is possible to explore depths far beyond those usually reached by archaeological diving, and that this can lead to important, if not fundamental, discoveries [1]. Though certainly of scientific relevance, and also valuable from the point of view of fundraising, this 'treasure hunt' approach may shadow another potential of ICT applications to marine archaeology, namely the possibility of automating much of the fieldwork required for the exploration of an underwater site, in order to greatly reduce the costs and risk to human life associated with this operation. Although in itself less spectacular, this application is the one

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that may eventually have the greatest impact on archaeological research. Experiences and field examples of this second kind of applications have been reported [2–4]. However, in most of these works, the technology in use has originally been developed for purposes different from those of underwater archaeology. Moreover, some of the equipment in use requires skilled engineers for its proper operation, and its cost may prevent its use from most of the archaeological research groups operating in the field. In this paper, we start from our experience in the field as a part of a multidisciplinary group in a series of archaeological search cruises in the North Tyrrhenian Sea [4, 5]: from a technological point of view, the cruises had the aim of critically evaluating state-of-the-art equipment vis-à-vis the need for archaeological work. More specifically, the use of sonar systems in site searches and underwater robots in site inspections is reported. Notwithstanding the findings and results obtained, the field experience has shown that archaeologists need cheap, affordable equipment that can be operated by a non-expert with a minimum amount of training: a sort of 'plug and play' system, specifically oriented toward archaeological needs. Some existing search and inspection systems are now approaching this goal (for simplicity of use, if not for the cost): this is the case for multibeam echosounders and, to some extent, side-scan sonars. More difficult, it is still the situation regarding two specific problems that, if solved, may lead to a considerable pay-off in terms of applicability in archaeological research. These problems are the collection of photogrammetric data with automatic equipment and the non-invasive imaging of buried artefacts.

Automatic collection of photogrammetric data can in principle be performed with Autonomous or Remotely Operated Vehicles (AUVs or ROVs), properly equipped with camera and positioning sensors. Autonomous navigation over an archaeological site maintaining the precision requirements for a photogrammetric survey needs to be used, at least if one does not want to rely on very specific, expensive, and difficult-to-calibrate equipment (such as underwater acoustic navigation with Long Base Line systems). In this paper, we report our experience on a visual-feedback approach, in which an underwater robot is precisely positioned on the basis of the camera data. Such a positioning approach has the advantage of being applicable to any robot equipped with some basic navigation sensors (compass, depth meter) and a camera; it does not need any other external equipment or facility, and it is a natural component of a SLAM (Self-Localization and Mapping) approach to area mapping, similar to those already employed by robots or team of robots in the exploration of other hostile environments [6].

The problem of detection and subsequent remote inspection of buried remnants is very relevant to archaeological research in order to decide whether and where to start an underwater excavation. Existing sub-bottom echosounders do not have the necessary resolution for archaeological work, while standard side-scan sonars or multibeam echosounders do not have the necessary penetration. Incidentally, the same concern in terms of buried artefacts detection/inspection is shared by other user groups with different needs, such as mine-hunting research and environmental/waste management research. In this paper, we report recent results from the environmental field that may have a long-lasting impact on archaeological research as well. In particular, the results have been obtained as a part of the European Union funded research project SITAR [7], devoted to the risk assessment of sea-bed dumping sites where most of the dumped material is buried on the sea bottom.

Although the two applications presented here are independent from each other, it should be made clear that both are basic components of a future system able to complete the inspection and the collection of scientific archaeological data at a given site in a fully automated manner.

The paper is organized as follows: in the next section, the background and general goals of the North Tyrrhenian Sea cruises programme, together with the operational procedures employed, are reviewed. In section 3, the procedure employed and the results obtained with the use of different sonar and ROV systems are illustrated. In section 4, the visual-feedback approach to the positioning of underwater robots is reported, with some field data obtained by trial tests. In section 5, results from the SITAR project are reported, in particular regarding the prototype of a new generation side-scan sonar based on the so-called parametric effect, and on a 3-D acoustical imaging methodology. Finally, some conclusions are given.

2. North Tyrrhenian Sea cruise programme

The North Tyrrenian Sea (NTS) cruise programme was started in 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 searching for and inspecting archaeological cruises in the waters of the Tuscan Archipelago, at water depths between 40 and 200 m. The team is led by the Soprintendenza per i Beni Archeologici della Toscana, with responsibilities for the definition of archaeological goals, area selection, preservation and monitoring tasks; the MuVITA (Live Museum of Technology for the Environment, Arenzano (GE), Italy), has made available a Phantom remotely operated vehicle (ROV) equipped with broadcast-quality cameras, multimedia recording, and visualization tools; ISME, the Italian Interuniversity Centre of Integrated Systems for the Marine Environment, is responsible for navigation and control of the Phantom. The Italian Navy has made available a mine-hunting ship for each cruise, equipped with a search sonar and 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 programme has so far seen 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.

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. The operations were divided into two stages:

(1) search and localization;
(2) classification and inspection.

So far, photogrammetric reconstruction and excavation with automatic instrumentation have not been attempted. In some of the explored sites, divers from Soprintendenza Beni Archeologici Toscana have conducted excavation and recovery operations as part of the joint programme activities.

As for 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 analysed in order to detect bottom features that could be associated with non-geological structures. Subsequently, the identified features have been re-localized with the aid of DGPS information and with a mine-hunting sonar. 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 NATO Undersea Res. Ctr., in agreement with Soprintendenza Beni Archeologici Toscana. The mine-hunting sonar used is the SQQ 14IT, using equipment from the Italian Navy mine hunters. Two relevant examples of side-scan sonar data are shown in figures 1– 2. Figure 1 refers to the remnants of the 'Pozzino'

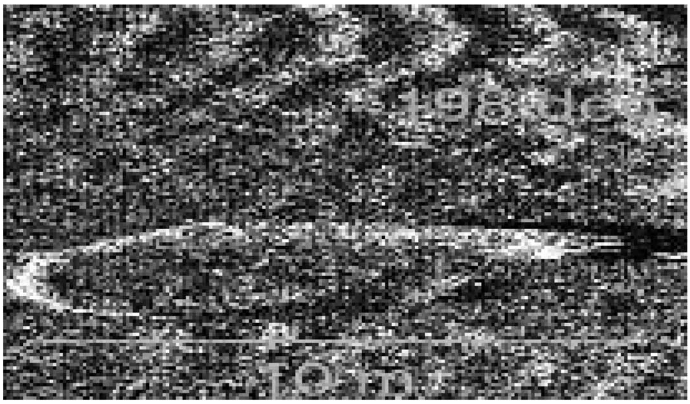

Figure 1. Klein 5000 side-scan sonar image acquired at the 'Pozzino' excavated relict site, Baratti Gulf.

relict, in the Baratti gulf, excavated in the 1980s 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 [5] 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 covered the area completely, the detection of the site would have been much more problematic.

Once an acoustic bottom anomaly has been detected, either from the side-scan sonar or from the mine-hunting sonar, camera inspection with 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 onboard battery for propulsion power, and a b/w frontal orientable camera as payload. The fibre-optic umbilical cable is used for data transmission. The Phantom has been built by the American company MacArtney and customized in 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 cameras; it can accommodate additional payloads on the vehicle frame. The umbilical cable is used for both data transmission (through

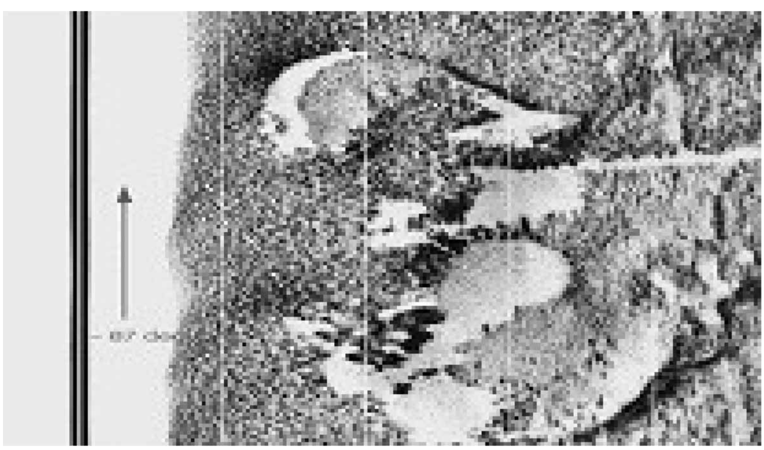

Figure 2. Klein 5000 side-scan sonar image acquired at the Follonica Gulf site.

fibre optics) and power supply: the vehicle is powered from the surface ship. The Phantom data (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 [8]: the ship hovers in the proximity of the object to be classified, orienting the sonar toward the object; the ROV dives from the sea surface into the sonar field and then 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. 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 georeferencing of the ROV images in post-processing stage, and as a direct means of vehicle navigation as substitution for 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 s in the position determination before feedback to the ROV pilot. The post-processing procedure, on the contrary, fulfilled our expectations, allowing us to obtain a precise georeferencing 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 readings from the sonar must be added. The two systems, however, are not and could not possibly be integrated without interfering with the ship's operational system.

3. Evaluation of state-of-the-art techniques

In the NTS cruises, available state-of-the-art equipment has been tested together with archaeological scientists. The equipment, however, was operated by a team of engineers and marine technology experts; one of the goals of the experience was also to evaluate if and how the same procedures and analysis methods could be applied by a team of archaeologists only. The discussion now summarized refers to two distinct aspects: the use of sonar systems in search and localization; robot positioning and manoeuvrability 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 sea-bed vegetation. Moreover, they can only explore the sea bed 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 fieldwork, due to the well-known trade-off between resolution (which requires high acoustic frequencies) and bottom penetration (which requires low acoustic frequencies in order to mitigate against attenuation effects). This is a relevant point, since an acoustic instrument, together with the associated signal-analysis tools capable of imaging 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; using this techinque, one can obtain grey-scale 'images' of the sea bed that can eventually be rearranged in mosaic form to obtain a complete sea bed map, but this still requires training and experience. Of 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 yield erroneous ping detections in the presence of faster acoustic arrivals through the sea-bed waveguide. All this seems to indicate that the positioning problem for underwater robots has not yet been satisfactorily solved, at least as far as 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 3 h) and to a camera and video rendering system more appropriate for the archaeological inspection work. To be fair with the Pluto, it must be noted that last-generation vehicles have battery systems that allow uninterrupted diving for more than 8 h, which is more than enough for archaeological applications in the range of depths considered in the NTS programme.

Both sonar equipment and ROV systems required the presence of skilled technical personnel. The existing systems, mainly designed for offshore industry or military needs, are not as user-friendly as an archaeologist team may expect. In the next sections, some research lines currently investigated toward automation of the inspection operation are reported, with the ultimate goal of allowing the operations to be performed by a non-expert by increasing the autonomy of the system. Although the above is a brief summary of the NTS programme from the point of view of technological applications, the programme itself was mainly focused on archaeological needs. In particular, in addition to the monitoring of several reported relicts in the area, the programme has led so far to the discovery of two previously unreported wreck sites, one at depths well below 60 m depth, and whose inspection and exploration would not have been possible without robotic technology (see figure 3).

Figure 3. 'Dolia' from a roman cargo ship (I century?) at the newly discovered North Elba site.

4. Towards automation of inspection tasks: ROV positioning via visual feedback

The basic component of an underwater robotic system able to fulfil several complex tasks in automatic mode is the Navigation, Guidance and Control (NGC) module. A fairly general block diagram for such a module is depicted in figure 4. From the bottom of the block diagram, it can be seen that the data from the vehicle sensors are fed back to a set of different modules, each having the task of processing the raw sensor data for a specific purpose (obstacle avoidance, position/speed determination, etc.). In the figure, a visual signal processor module has been purposely introduced that elaborates the vehicle camera data, and this is central to the visual positioning system described in the following. Additional modules can be introduced on a case-by-case basis, depending on the specific robot tasks and on the specific payload sensors available. The output from the various modules is relayed to the navigation module, where they are merged in order to determine where the vehicle is (in both absolute and relative positioning systems) with respect to where it should go (input from the supervisor module). The discrepancy computed by the Navigation module between the current vehicle position and the scheduled position is relayed as input to the Guidance module, which in turn computes a command signal (where to go next, with whatever velocity and orientation) to be given to the Control module. The Control module computes the actuator signal (drives voltage input) of the vehicle in order to be close to the Guidance module command within a pre-specified accuracy, which can be task-dependent. The scheme is iterated for each new sampling from the vehicle sensors. It is important to emphasize that the conceptual scheme depicted is not dependent on the specific control law implemented or on the specific sensor suite available

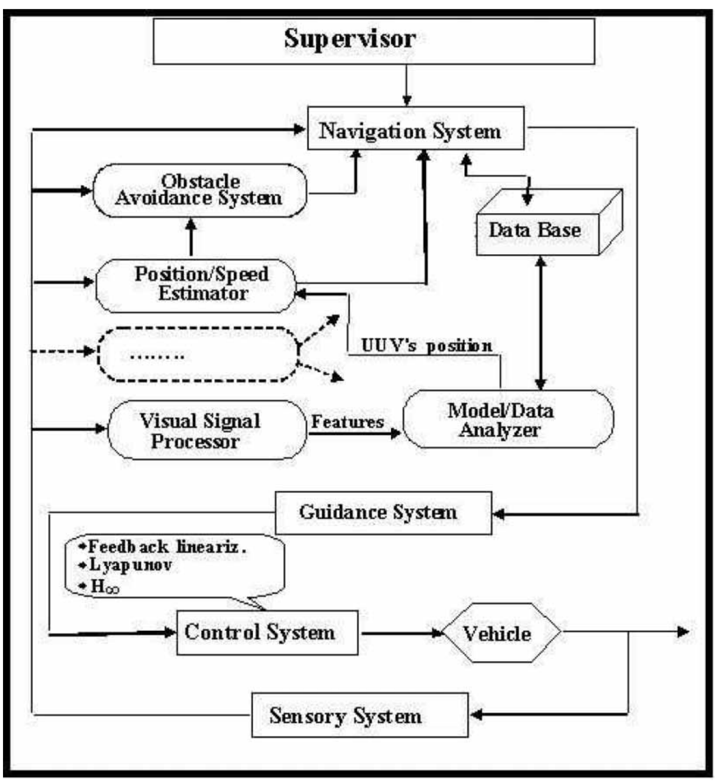

Figure 4. Block diagram of the Navigation, Guidance, and Control module of a generic autonomous underwater robot with visual feedback.

to the vehicle. These (sometimes critical) implementation decisions are embedded in the various modules of the block diagram. It is also worth noting that the supervisor module can either be a pre-programmed, very high level module or a human operator, building even fairly complex robot behaviours by specifying a sequence of basic robot tasks. In figure 4, the visual signal processor block has been expanded, also indicating the presence of a model/data analyser that compares the feature extracted from the visual processor with those present in the system database. This functionality is at the core of the visual feedback positioning now described.

Autonomous vehicle positioning is defined as a task in which the vehicle moves in such a way that a given object recorded in the camera image is positioned at the centre of the image. When the object is resting on the sea bed, the operation is done at a constant vehicle altitude over the sea bed (or equivalently, assuming a flat sea bed, at constant water depth). In addition to the camera image, a depth meter and compass are used as part of the sensory system for this task. The assumption of object resting on the sea bed suits archaeological applications well, but the proposed scheme does not rely on this assumption, as illustrated in [9], where the same approach is described in more general terms, with additional experimental data with objects both on the sea bed and in the water column.

The image-processing part takes place in three successive steps. The first is the acquisition of a grey-level image (figure 5). It is assumed that at this stage, the supervisor has already driven the robot in a position such that at least one object of interest is present in the image. In the second step, the image is filtered, and contours are extracted (figure 6). Filtering consists essentially in grey-level equalization in order to reduce the effect of different lighting conditions, while contour extraction is performed through Canny edge detection algorithm to select candidate contour points and then by application of a segmentation algorithm that groups candidate contour points in connected sets. Finally, in the third step, the extracted contours are compared with a set of predefined geometrical shapes by means of a Hough transform. The contours consistent with those of the geometrical shapes presented in the system database, within the appropriate dimension range, are associated with the appropriate geometrical shape. Figure 7 shows the output of this processing step, in which the amphora-like object of figure 5 is finally associated with an elliptical shape. In the case in which, in the same image, more than

Figure 5. Original image from the Phantom S2 vehicle camera, including an amphora-like object, from a pool test.

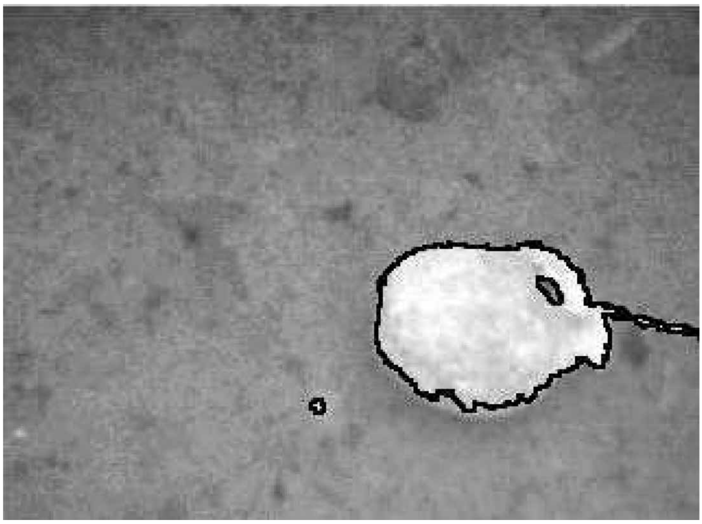

Figure 6. Image filtering and contour extraction from the image of figure 2. Contour extraction line emphasized to enhance figure reading.

one object associated with the database geometrical shapes is present, the supervisor decides on the positioning of the vehicle with respect to some of the extracted objects.

The images in figures 5–7 have been acquired by a CCD camera installed on the DIIGA Phantom S2 ROV. The vehicle is also equipped with a fluxgate compass, with 0.1° accuracy, and with a pressure gauge depth sensor with 1 m accuracy. The vehicle is actuated by four thrusters and has 4 DOF: surge, heave, yaw, and sway. The data from the vehicle sensor are transmitted to a PC station through the vehicle umbilical cable. The PC station, using suitable software procedures developed at the Polytechnic University in Ancona, performs the NGC processing and then transmits the actuator control signal to the vehicle through the umbilical cable. The functions of the supervisory module are presently performed by a human

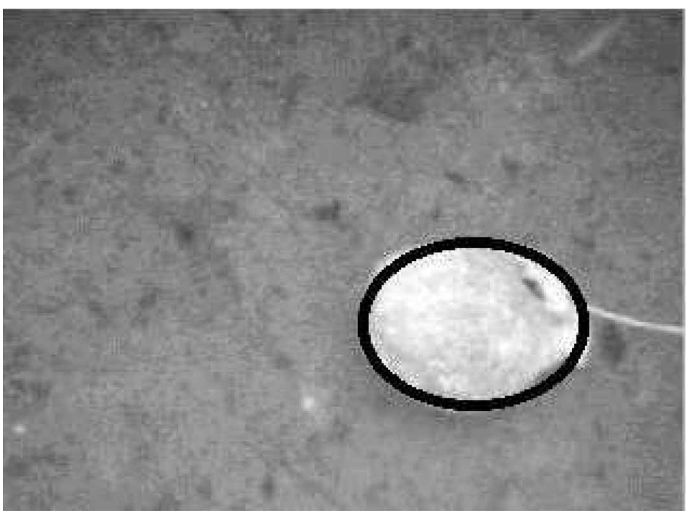

Figure 7. Matching of the contour of figure 6 with a predefined geometrical shape (ellipses) in the system data-base.

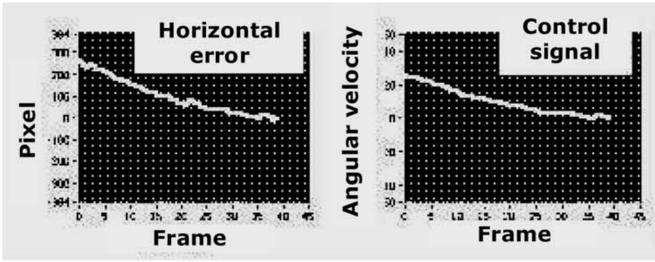

Figure 8. Left: error in the horizontal position of the object with respect to the centre of the image, as a function of the frame number (frame sampling: 1 Hz). Right: control signal (angular velocity of the trhusters' shaft) during motion, both figures from a pool test.

operator. The experimental results reported here, for both the image processing and the control algorithms, have been obtained under controlled conditions in a pool.

After determining the geometrical shape, the target now becomes that of positioning the vehicle so that the shape is centred in the camera image. In the case of the ellipses, for instance, the centre is taken as the intersection point, in pixels coordinates, of the two axes. The control action is performed directly in the camera coordinate system, *i.e.* with respect to the image pixels. The control problem is decoupled in a sequence of two independent control problems, one for the vertical position and one for the horizontal position, that are tackled in sequence. During the motion, the ROV is kept at a constant depth by an auxiliary control module that exploits the data coming from the depth meter. Horizontal and vertical position errors are evaluated by processing the camera images and are made available at a rate of 1 Hz for generating the control signal. Simple PI control laws have been implemented for the two control problems, thus guaranteeing practical asymptotic stability for the system. Experimental results confirm the theoretical expectations, as shown in figure 8, where it can be seen that the horizontal positioning goal is indeed reached with exponential convergence toward zero of the error in the camera-based coordinate system. The same figure also shows the control signal, expressed in terms of angular velocity of the thrusters' shafts, as generated from the guidance module. It can be seen that the control signal has a rather smooth behaviour, ensuring that the object of interest is kept in sight during the ROV motion.

5. Acoustic detection of buried objects

In this section, a different development is described, with the aim to design an instrument able to survey a portion of the sea bed and to detect possible buried artefacts at a depth and resolution compatible with archaeological needs. In particular, results from the development of a prototypal parametric side-scan sonar instrument are reported. The instrument development is part of the SITAR project [7] that has the overall goal of providing instrumentation and methods for assessment of risk of seafloor dumpsites, when most of the dumped material is buried in the bottom. Along this line, one of the SITAR activities is that of devising acoustic methods for detection and inspection of containers buried at a maximum depth of 1 m, and with minimal dimensions equivalent to that of a cylinder of 1 m length and 0.1 m diameter. Such a specification seems compatible with those required by an archaeological search.

One of the instrumentations developed within SITAR is a side-scan sonar that, contrary to the standard instrumentation, exploits the so-called parametric effect, a consequence of nonlinear acoustic propagation in water: if an acoustic source transmits high-energy acoustic signals in water at two different frequencies f_1 and f_2, the dependence of the sound speed

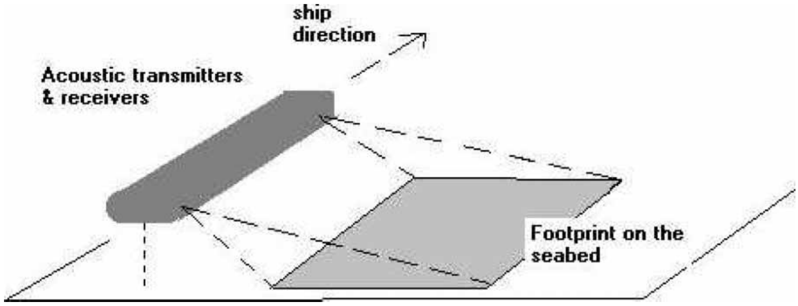

Figure 9. Geometrical configuration of a side-scan sonar instrument.

on the signal pressure level causes the generation of harmonic and sub-harmonic signals, in particular the generation of the so-called difference frequency $f_0 = f_2 - f_1$. The advantage in this situation is that, with a high-frequency source, it is possible to generate a low-frequency signal with the same beam pattern of the high-frequency signals (*i.e.* a very narrow beam with negligible sidelobes), and with a transducer of reduced dimension (high-frequency generation can be obtained with transducers whose size is smaller than that of low-frequency

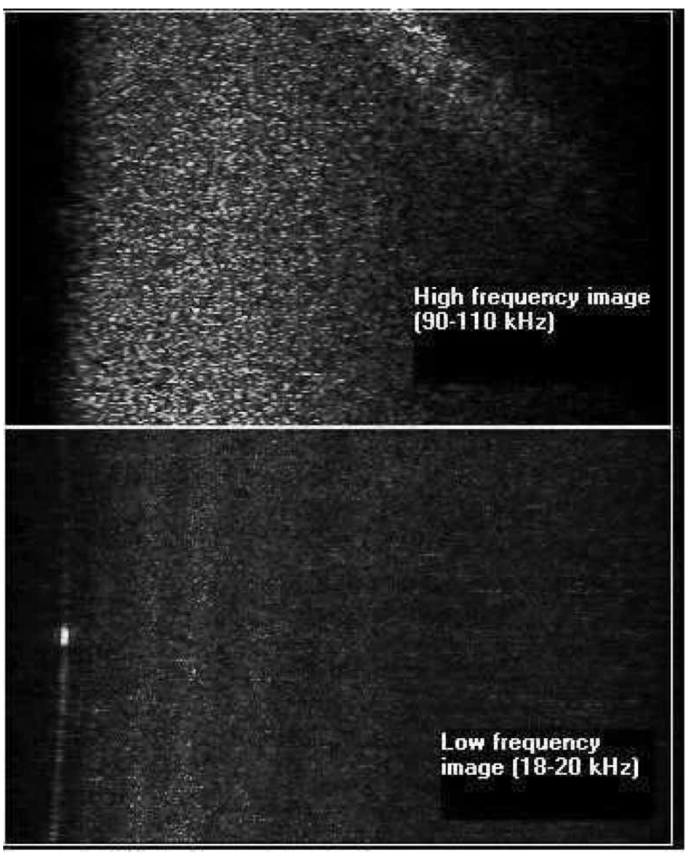

Figure 10. High- (top) and low-frequency co-located sea-bed images from the parametric side-scan sonar, field data. The bright spot visible only in the low-frequency image corresponds to a buried object. The image dimension is c. 100 m in the vertical, and 160 m in the horizontal.

generators). The advantage of a sub-bottom profiler built on the parametric effect principle for shallow geophysical investigations has been discussed in [10]. Within SITAR, the same effect is exploited in a side-scan sonar configuration; the traditional side-scan sonar configuration is depicted in figure 9: the instrument, towed or installed on the ship hull, is composed of an array of co-located transmitters and receivers, and directed in order to acoustically illuminate a region of the sea bed in the direction transverse to that of ship motion (the instrument 'footprint'). In the SITAR-developed prototype, the acoustic transmitters have been designed to generate the parametric effect: with an array of parametric transducers, the instrument is able to record co-located acoustic images at both high and low frequency, with the beam pattern of the high-frequency components. By comparing the high- and low-frequency images, it is thus possible to detect buried anomalies that can be associated with buried artefacts. The transmitting frequencies in the developed prototype have been selected in order to fulfil the size requirements on the objects to be detected. The system has been tested in a field trial in the Baltic Sea, Stockholm Archipelago, in the autumn of 2003, over an abandoned munitions dump site. An example of the data gathered by the instrument is reported in figure 10. The most striking effect of figure 10 is that of the 'bright spot' visible only in the low-frequency image, an indication that the acoustic reflection is coming from an object buried within the sub-bottom. Additional data and examples from the same field trial have been reported in [11].

With the parametric side-scan sonar, one can detect a buried object, but not inspect it, in order to determine, for instance, whether it is a man-made object or a natural geological feature (*e.g.* a rock). Within SITAR, additional tasks are devoted to the development of the Multiple Aspect Scattering technique: this is essentially a repeated application of bi-static scattering measurements at varying azimuthal and elevation angles, in order to recover the full 3-D acoustic scattered field. Assume a geometry as in figure 11, which can be obtained by a sequence of bistatic configuration: acoustic signals are sent from the transmitter, and the scattered returns from the sea bed and from the target are recorded at the various receiving positions. The received data are deconvolved, in order to associate each arrival with a given point in space (the scatterer), using knowledge of the source-receiver geometrical configuration [12]. At each volume element ('voxel'), it is then possible to associate a scattering strength or a relative scattering intensity. Through this procedure, a 3-D acoustic image can be produced. In figure 12, slices of the resulting volumetric image from a tyre-like buried object are shown. The volume image can then be given to a segmentation and feature-extraction algorithms for final classification [13].

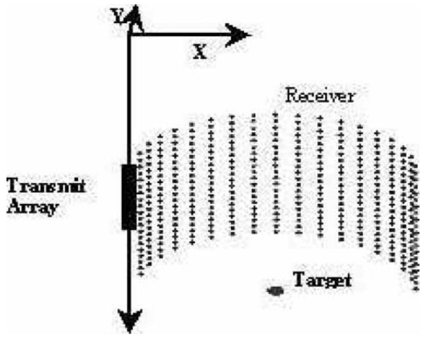

Figure 11. Geometrical configuration for the Multiple Aspect Scattering Measurement technique. The configuration has been implemented by having the transmitting array installed on an ROV and rotating around the target position, and with a vertical fixed receiving array. Knowledge of the target position (a prerequisite of the method) is available from parametric side-scan sonar data.

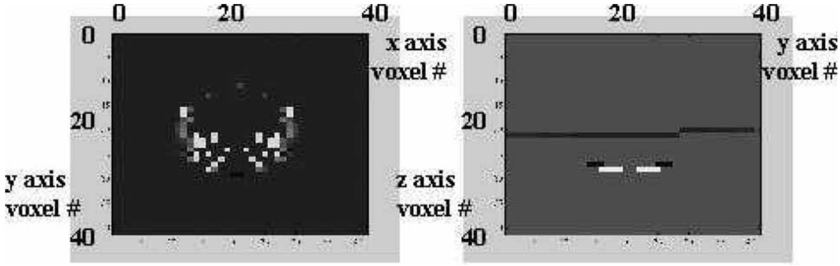

Figure 12. Top and side view of the relative scattering intensities (arbitrary scale) associated with the $x-y-z$ coordinates of the acoustically illuminated area. The data refer to a tyre-shaped object, 1 m in diameter, buried 40 cm in the sediment.

6. Conclusion

The experience gathered within the NTS programme in the use of state-of-the-art technology in underwater archaeology search and inspection tasks has been reported. We consider this experience to be valuable, in particular because it has allowed a multi-disciplinary group, including archaeologists, engineers, oceanographers, and maritime professionals, to work closely together and to share the perspective of each discipline. Although successful with respect to the preliminary plans, the NTS programme has revealed several technological gaps to be filled by oceanic instrumentation in order to allow underwater archaeologists to fully exploit the potential of ICT. The research reported in the field of oceanic engineering, and in particular in autonomous guidance and control of underwater vehicles and in classification and inspection of buried objects by acoustic techniques, has the long-term goal of providing the archaeology community with a user-friendly, simple-to-operate instrumentation, powerful enough to conduct systematic surveys and inspections at depths greater than those usually reached by divers.

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