MARTA: AN AUV FOR UNDERWATER CULTURAL HERITAGE

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Abstract: *MARTA, acronym for MArine Robotic Tool for Archaeology is a small-sized Autonomous Underwater Vehicle (AUV) developed in the framework of the ARROWS project. The ARROWS project (start September 2012, end August 2015) is funded by the European Commission in the framework of the FP7 call ENV-2012, challenge 6.2-6, devoted to Development of advanced technologies and tools for mapping, diagnosing, excavating, and securing underwater and coastal archaeological sites. MARTA will operate in a heterogeneous team of vehicles with a common mission to perform and a distributed and shared world model updated based on non-synchronous information collected by each of the vehicles of the team. Each of the vehicles will be equipped with acoustic communication means in order to be able to communicate when submerged. The University of Florence is in charge for the design and construction of the MARTA AUV, according to specifications written in compliance with the requirements formulated by the Archaeological Advisory Group, including archaeologists both from inside and outside the ARROWS consortium. MARTA will be moderate in cost, with respect to commercially available AUVs, and light enough in order to be deployable by two people from a small boat. MARTA will operate at a maximum depth of 150m and, in addition to a pair of acoustic modems for inter-vehicular communication and USBL localization, it features two different payloads, i.e.: a pair of synchronised digital TV cameras with visible light as well as structured light (blue laser) illuminators; a Multibeam echo-sounder.*
The paper illustrates the vehicle concept and the use of on-board acoustic instrumentation for communication, localization, and sea-bottom imaging. Preliminary experimental data from the field are presented.

Keywords: *Underwater Robotics, Underwater Acoustic Measurements, Autonomous Underwater Vehicle, Underwater Cultural Heritage*

1. INTRODUCTION

The ARROWS project challenge is to provide the underwater archaeologists' with technological tools for cost affordable campaigns. Several technologies, originally developed for military use and the Oil&Gas industry, have been successfully adapted to underwater archaeology (e.g. acoustic communication or sub bottom profiling). However, the cost of underwater missions involving a surface ship and Remotely Operated Vehicle (ROV) is in excess of 50000€/day; therefore, there is a strong motivation for archaeologists to reduce the costs associated with underwater campaigns otherwise impossible to perform without the support of private sponsors and/or foundations.

ARROWS project is funded by the European Commission in the framework of the FP7 call ENV-2012, challenge 6.2-6. The project is coordinated by the University of Florence (IT) and its consortium is composed of several research institutions and companies dealing with Underwater Robotics: CNR-ISTI (IT), Tallinn University of Technology (EE), Heriot-Watt University (UK), Edgelab s.r.l. (IT), Albatros Marine Technologies (ES), Nesne Elektornik (TR), TWI (UK), Soprintendenza del Mare – Regione Sicilia (IT), Estonian Maritime Museum (EE). The ARROWS Steering Board is supported by the Archaeological Advisory Group, composed of European archaeologists whose task is to guide and follow the strategic developments of the project.

ARROWS adapts and develops low cost autonomous underwater vehicle technologies to reduce significantly the cost of archaeological operations, covering the full extent of archaeological campaign. The project aims to deal with underwater mapping, diagnosis and cleaning tasks. ARROWS formalizes the archaeologists' requirements in all the phases of the campaign, identifies problems and proposes technological solutions with technological readiness levels that predict their maturation for exploitation within 3-5 years. ARROWS also addresses the issue of training archaeologists to the use of new equipment and techniques.

The systems and methodologies developed within ARROWS comply with the "Annex" of the 2001 UNESCO Convention for the protection of Underwater Cultural Heritage (UCH). The system effectiveness will be demonstrated in two places, different as regards the environment and the historical context, the Mediterranean Sea (Egadi Islands) and the Baltic Sea.

ARROWS is dealing with the development of a team of new heterogeneous AUVs to support archaeologists in all the phases (mapping, diagnosing, cleaning, and monitoring) of underwater campaigns. The components of the system will be easily deployable by a team of archaeologists during a mission with limited support by technicians. The archaeologists will be trained to use the innovative tools produced in the framework of the ARROWS project. Three classes of new AUVs are springing up according to archaeologists' needs.

Innovative AUVs, developed in the framework of ARROWS, are (Fig. 1):

- MARTA AUV: MArine Robotic Tool for Archaeology – modular AUV, easily adaptable to the various types of mission according to its configuration;
- U-CAT – small biomimetic AUV, usable for shipwreck penetration;
- A-sized AUV – small torpedo-shaped vehicle, easily manageable thanks to its reduced size.

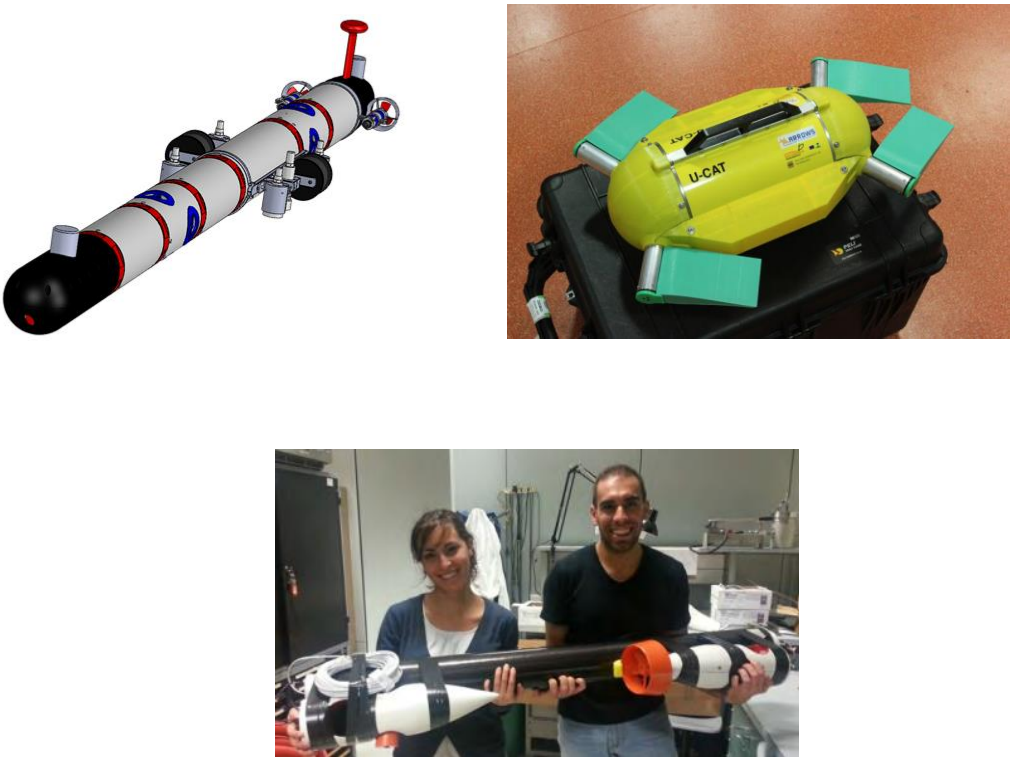

Fig.1: ARROWS AUVs: (a) preliminary MARTA CAD – Optical Payload configuration by University of Florence (b) U-CAT prototype by Centre for Biorobotics at the Tallinn University of Technology (c) A-sized AUV by EL during pressure test.

After a brief description of the general architecture of ARROWS team of AUVs (Section 2), the paper focuses on MARTA vehicle description (Section 3) and the use of its on-board acoustic instrumentation for communication, localization, and sea-bottom imaging. MARTA is a low cost vehicle, compared to commercially available AUVs, and light enough to be deployable by two people from a small boat. The maximum operating depth is equal to about 150 m; concerning its payload for patrolling and mapping, MARTA mounts a pair of synchronised digital TV cameras with visible light as well as structured light (blue laser) illuminators and a Multibeam echo-sounder. Finally, preliminary experimental data from the field are presented (Section 4).

2. GENERAL ARCHITECTURE OF THE TEAM OF VEHICLES

ARROWS project proposes a team of heterogeneous autonomous underwater vehicles capable of satisfying all the needs of a complete archaeological campaign. The differences among the AUVs involved in ARROWS are related to the different roles that have to be covered within the cooperating team. In particular, three main roles have been identified:

- **Search AUV:** AUV equipped with acoustic sensors such as Side-Scan Sonar (SSS) or Multibeam Echo Sounder (MBES) to be used for fast and large surveys, searching for points of interests (candidate points);
- **Inspection AUV:** the role of the inspection AUV is to reach the points, identified as potentially interesting thanks to the data acquired by the Search AUV, and to acquire optical

and/or acoustic images in order to confirm or not the candidate points and to obtain more details;

- **Biomimetic Robot (BR):** its main role is the wreck penetration to get images from hardly accessible areas; the main features of BRs are small sizes and high manoeuvrability in addition to low cost, considering the not negligible risk of loss.

All the vehicles cooperate thanks to the distributed High-Level Control System (under development at the Heriot-Watt University) that exploits a distributed world model built on board each vehicle through the acquired knowledge and information received by the other vehicles. This way, by exchanging only few synthetic information (to not saturate the communication band), the AUVs will be able to conduct a common mission with a common goal. Because of their simplicity and because the target environment (inside shipwrecks) is not the same of the AUVs (outside the wrecks), the world model will not be implemented on the BRs (U-CAT); this allows also a reduction of the required performance and, thus, of costs, for their on board pc.

According to the ARROWS Archaeological Advisory Group (AAG) requirements, stated in the first phase of the project, one of the main design criteria for MARTA is the modularity. Depending on the mission to be performed, MARTA is designed to be configured with several payloads and different propulsion systems.

This way, MARTA can play both the role of search and inspection AUV. In the framework of the ARROWS project, the payloads on MARTA will be of acoustic and optical type, in particular:

- **Acoustic payload:** a Multibeam Echo Sounder (MBES) can be mounted in the bow of MARTA; a bow module for the integration of a Teledyne BlueView M900 has been designed and will be soon built;
- **Optical payload:** a section of MARTA houses the optical payload devices (a couple of Basler Ace cameras, a C-laser Fan from Ocean Tools, four illuminators produced at the University of Florence, a SBC Commell LS-378 for data acquisition and processing).

As concerns the underwater communication means, MARTA will be equipped with two different acoustic modems:

- **Evologics 18/34:** it will be used for communication between the conventional AUVs of the team, allowing a high data transfer rate (13.9 kbit/s) and a high functioning range (3500 m); it will be used along with an USBL transducer by Evologics for localization and navigation purposes;
- **AppliCon SeaModem:** it will be used for communication with the BRs; U-CAT role justifies the use of a different communication means, characterized by a considerably lower cost although with lower performances (data transmission rate and operating distance).

Thanks to this configuration, MARTA will represent a bridge node in the communication between the AUVs and the BRs. An acoustic communication and localization protocol, oriented to the optimization of the exchanging data rate and of the accuracy in sensory data georeferencing, will be developed, tested and demonstrated during the final experimentation of ARROWS. The protocol will take into account the constraints in terms of acoustic channel sharing among a variable number of different acoustic nodes (Evologics USBL, Evologics modem, AppliCon SeaModem). A TDMA (Time Division Multiple Access) protocol will be the first solution; then an iterative procedure will bring to the definitive version according to the feedback coming from the simulation results and the testing activity outcomes.

3. MARTA AUV

MARTA prototype will be easily deployable from a small boat; the vehicle is modular and has a total length of about 3 m (as concerns its longest configuration – including the Optical Payload), an external diameter of 7 inches and an in-air weight of about 70 kg. The vehicle has 5 degrees of freedom fully controllable by means of 6 actuators (electrical motors + propellers): 2 rear propellers, 2 lateral thrusters and 2 vertical thrusters. In Fig. 2, the final 3D CAD of MARTA AUV is shown.

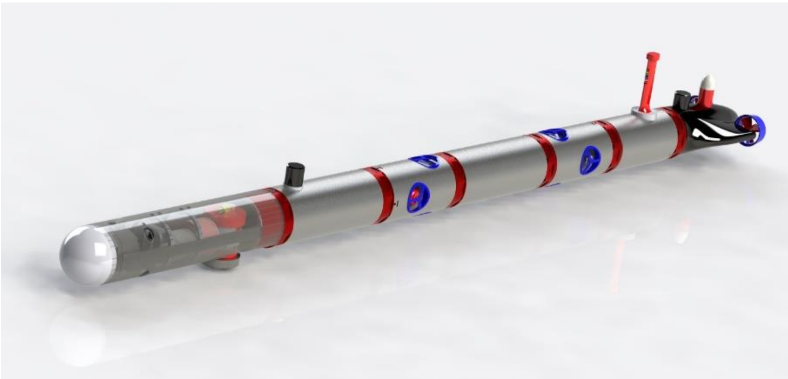

Fig. 2 – MARTA final CAD

In summary, the vehicle characteristics are:

- Reachable depth: 150 m;
- Vehicle longitudinal speed: maximum reachable speed of 4 knots;
- Autonomy: about 4 hours;
- Dimensions: length of about 3 m, external diameter equal to 7 inches;
- Weight: about 70 kg;
- Power supply - voltage: 24 V;
- Modularity: the archaeologists involved in ARROWS looked for specialized vehicles, i.e. suitable AUVs with specific sensors for specific missions. MARTA is thus configurable thanks to its different modules;
- Redundant propulsion system: the vehicle is equipped not only with thrusters. The vertical translation can be performed also by means of the 2 buoyancy modules (placed one in the bow and one in the stern);
- Hovering capability: the vehicle is able to perform hovering. It has 5 DOFs (not roll) fully controllable.

MARTA is composed of several modules in Al Anticorodal housing the following components: 2 buoyancy control modules developed by AMT, 2 main vital computer ODROID-XU, 2 acoustic modems, 1 depth sensor by SensorTechnics, 1 IMU Xsens MTi-G-700 GPS, 1 DVL NavQuest 600 Micro, 1 Radio modem, 6 LiPo batteries by MaxAmps, magnetic activation switch, motor drivers developed by NESNE and the acoustic and optical payload devices already described in Section 2. All these components have been, or are going to be, integrated into the prototype mechanically, electrically and in low-level software. The basic functionality of many components and the waterproofness of the first prototype module (at 12 bar, i.e. at a depth of 120m) have been already verified.

4. PRELIMINARY EXPERIMENTAL DATA FROM THE FIELD

The complete version of MARTA is planned for September 2014; at the moment, the experimental activities are thus oriented on single sensors or other devices. Particularly, all the AUV acoustic sensors are ready to be tested; therefore, it has been decided to perform some preliminary data acquisition campaigns independently by the use of MARTA AUV.

The first occasion for the acoustic testing activity is the necessity of a bathymetric campaign at the Lake Roffia, San Miniato (Pisa – Italy). Lake Roffia is a small artificial basin (2x0.2km) working as an Arno river expansion; it is also used for rowing and canoeing training and competitions. The bathymetry of the lake is a strong necessity of the local community; the mapping of the obstacles, above and below the lake surface, became a fundamental safety need after the Arno river flood of February 2014 that brought a lot of objects, mainly tree trunks, in the Roffia basin. MARTA AUV will have on board different devices for navigation and acoustic localization&inspection, such as:

- Teledyne BlueView M900 (MBES);
- MTi-G-700 GPS (GPS and Inertial Measurement Unit);
- NavQuest 600Micro (Doppler Velocity Log).

These devices were tested together through their use for the bathymetry and the obstacle mapping purposes; this system has been fixed to a wooden structure in a relative pose similar to the one it will occupy on board MARTA. In this occasion, a preliminary version of the software, based on the Robot Operating System (ROS) middleware, necessary for navigation and acoustic inspection, has been also tested. The wooden structure was mounted on a small catamaran able to navigate the lake surface (Fig. 3). Fig. 4 represents the path planned to cover the whole lake surface.

Fig. 3 – Part of the navigation sensors and acoustic payload tested during the bathymetric campaign at Lake Roffia (Pisa - Italy)

Fig. 4 – Path planned to cover the whole Lake Roffia surface

The full campaign will be performed in coming weeks; actually, some preliminary tests have been performed in order to evaluate whether the selected sensors are suitable or not for the purpose. One of the images acquired through the MBES is shown below, in Fig. 5: in the upper right corner, the echo due to a tree trunk in front of the catamaran is easily identifiable.

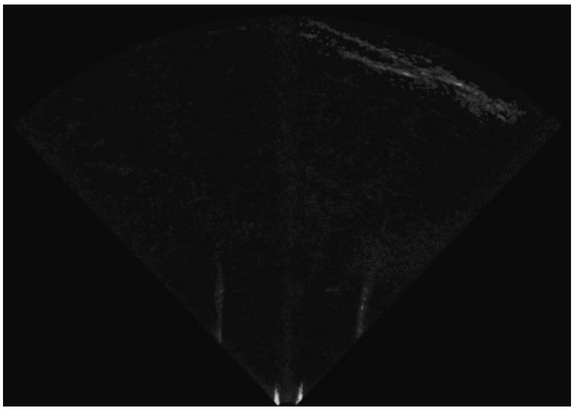

Fig. 5- MBES image showing a tree trunk in front of the catamaran

The preliminary obtained results are encouraging both for the completion of the Lake Roffia bathymetry and obstacle mapping. They are very encouraging too considering the use of the sensors on MARTA AUV such as the navigation and acoustic inspection system and for object recognition and frontal obstacle avoidance.

5. CONCLUSIONS AND FURTHER DEVELOPMENTS

The paper describes MARTA AUV, acronym for MArine Robotic Tool for Archaeology: it is a small-sized Autonomous Underwater Vehicle (AUV) developed in the framework of the ARROWS project. The paper summarizes the main characteristics of the vehicle and preliminary experimental data from the field, concerning its acoustic payload, are given.

MARTA AUV will be ready soon and the sea trails are scheduled for September 2014.

6. ACKNOWLEDGEMENTS

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