Archaeology oriented optical acquisitions through MARTA AUV during ARROWS European project demonstration

Benedetto Allotta[1,5], Riccardo Costanzi[2,5], Alessandro Ridolfi[1,5], Marco Reggiannini3, Marco Tampucci3, David Scaradozzi[4,5]

[1] *Department of Industriai Engineering University of Florence (UNIFI) Florence, Italy email: a.ridolfi@unifi.it*

[2] *Department of Information Engineering and Centro Enrico Piaggio University of Pisa Pisa, Italy, 56122*

[3] *Institute of Information Science and Technologies - CNR Pisa, Italy, 56124*

[4] *Department of Information Engineering Polytechnic University of Marche Ancona, Italy, 60131*

[5] *ISME - Interuniversity Center of Integrated Systems for the Marine Environment, Italy www.isme.unige.it*

Abstract **- The three-years European FP7 ARROWS project (ARchaeological RObot systems for the World's Seas) concluded at the end of August 2015. A heterogeneous team of cooperating AUVs has been created in the framework of ARROWS: these are both new prototypes and well known commerciai vehicles. In the paper MARTA modular AUV is described: MARTA is a new prototype specifically designed during the project. Its navigation and payload capabilities are discussed and some of the results, mainly optical acquisitions for the archaeologists, reached during the first officiai demo of the ARROWS European project (Sicily, ltaly, May and June 2015) are reported and commented.**

Keywords - Autonomous Underwater Vehicles, Marine Robotics, Underwater Robotics, Underwater Cultura/ Heritage.

I. INTRODUCTION

ARROWS project (2012-2015), www.arrowsproject.eu [1], proposed to adapt and develop low-cost Autonomous Underwater Vehicle (AUV) technologies to reduce the cost of the operations of a typical underwater archaeological campaign. The researchers followed the suggestions of the project Archaeology Advisory Group (AAG), composed of many European archaeologists, to develop innovative technological solutions. A heterogeneous team of cooperating AUVs has been created in the framework of ARROWS: these are both new prototypes and well known commercial vehicles. The AUVs involved in ARROWS have different roles during a cooperating mission:

Search AUV: equipped with acoustic payload, e.g. Side-Scan Sonar (SSS) or Forward-looking sonar, and used for fast and large surveys, looking for potential targets;

Inspection AUV: the inspection AUV has to reach the targets, near the seabed and identified by the Search AUV, and to get optical images to obtain more details;

Biomimetic Robot (BR): its main role is the wreck penetration to get images from hardly accessible areas. BRs are small sizes and low cost, taking into account the risk ofloss.

The main outcome of the collaboration between the AAG and ARROWS researchers is MARTA (MARine Tool for Archaeology). MARTA is an AUV designed and developed by the University of Florence. According to the **ARROWS** Archaeological Advisory Group (AAG) requirements, one of the main design criteria for MARTA is the modularity. Depending on the mission to perform, 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. MARTA, developed and built from scratch, proved to be able to autonomously navigate at sea and to cooperate with commercia! AUVs, e.g. with the IVER3 by

OceanServer. MARTA effectiveness was demonstrated in two places, different as regards the environment and the historical context, the Mediterranean Sea (Aegadian Islands) and the Baltic Sea. After the vehicle description, some results from on-field missions are discussed within this paper.

II. MARTAAUV

MARTA is composed of several modules, each one dedicated to a particular task (e.g. propulsion, sensor payloads, power supply, etc.). This way, MARTA AUV can be easily customized according to the mission profile to perform. MARTA prototype (see Figure 1) has a total length of about 3.5 m (depending on its configuration), an extemal diameter of 7 inches and an in-air weight of about 80 kg. The vehicle has 6 actuators: 2 rear propellers, 2 lateral thrusters and 2 vertical thrusters. The main characteristics of the developed prototype are: reachable depth 150 m, maximum longitudinal speed 4 knots, autonomy of about 4 hours, power supply voltage 24 V, modularity, hovering capability. lt is worth noting the hovering capability of the vehicle, since many commercia! AUVs, low cost or expensive ones, do not have this possibility.

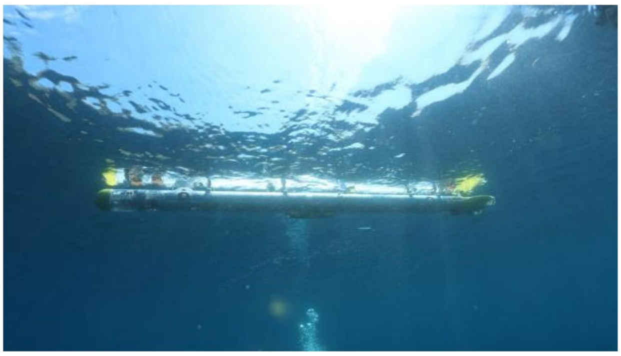

Figure 1: MARTA AUVat sea in Sicily, Italy {May-June 2015)

MARTA's modules, manufactured by TWI Ltd and STERN Progetti s.r.l. (Italy), are in Al Anticorodal type 6082 T6; such material constitutes indeed a good trade-off among workability, lightness and mechanical strength. To have high resistance against salt water a hard anodizing process is mandatory. The modules are connected together with suitable plastic wires: the assembling and disassembling phases are very simple and fast. MARTA AUV becomes watertight only after the modules are connected together (the only wet sections are the final part ofthe bow and the final part ofthe stero): two radial O-rings are placed at the end of each module and assure a watertight connection. lt is worth noting that expensive underwater connectors are mandatory only at the interfaces of the bow and the stero. After the whole vehicle assembly, a depressurization of 0.3 bar is created inside by means of a vacuum pump to ensure a better alignment between the modules and to provide an adequate stiffuess. The aluminum structure houses these main components: 2 main vital computers (ODROID-XU and an i7 board), 2 different acoustic modems, 1 depth sensor, 1 Inertial Measurement Unit (IMU) Xsens MTi-G-700 GPS and 1 Single-axis Fiber Optic Gyro (FOG) DSP-1760 by KVH, 1 Doppler Velocity Log (DVL) NavQuest 600 Micro, 6 22.2V LiPo batteries by MaxAmps, a magnetic activation switch, and the acoustic and optical payload devices. As regards the vehicle actuation, the default propulsion layout of MARTA AUV is composed of six motors with fixed pitch propellers (two main propellers on the vehicle stero, two lateral thrusters and two vertical ones) used to control all the degrees of freedom of the vehicle, except the roll one. A brushless motor coupled with a fixed pitch propeller through an epicycloidal gearbox controls each thruster [4] [5].

MARTA answer to the archaeologists' requirements is mainly represented by its modularity. MARTA modularity is ensured also from an electrical point of view. The electrical interfaces of each MARTA module are standard on both the sides in order to permit each module to occupy the desired position within the whole vehicle and to be added or removed according to the necessity of each mission. In particular, at each interface, two power supply cables (GND and +22.2V) are present with a standard connector that prevents potential polarity inversion. Data exchange through the several modules is ensured by means of an Ethemet cable present at each interface. Finally, the CAN bus connectors are present ensuring the possibility of controlling the actuators of each module through the bow or the stero PC. Some modular AUVs were already commercially available [2] [9] [10] [11] but on MARTA this feature has been pushed to the extreme allowing an easy and quick reconfigurability. MARTA can currently house onboard the following payload devices: *Acoustic payload:* a 2D forward-looking sonar Teledyne BlueView M900 is mounted in the bow of MARTA; *Optical payload:* a couple of Basler Ace cameras for stereo vision and suitable illuminators.

Ili. MARTA NAVIGATION AND MISSION PLANNING INTERFACE

In order to be able to autonomously navigate, MARTA AUV exploits the following sensors: 1 GPS receiver, used on surface to quickly localize the vehicle; 1 IMU (Inertial Measurement Unit), Xsens MTi-G-700 GPS: it provides data from 3D internal accelerometer, gyroscope and magnetometer. lt is connected through its own USB cable; 1 FOG (Fiber Optic Gyroscope), KVH DSP-1760: a single axis gyroscope with high precision used to improve the pose estimation (in particular the yaw measurement). lt uses a RS-422 protocol and is connected through a serial-USB adapter; 1 DVL (Doppler Velocity Log), NavQuest 600 Micro: it provides a 3-axial linear speed measure referred to the seabed exploiting the Doppler effect on acoustic waves produced by the sensor itself and reflected by the sea bottom. lt uses RS-232 protocol and it is connected through a serial-USB adapter; 1 depth sensor.

During the **ARROWS** project, the researchers of the University of Florence developed suitable navigation algorithms for MARTA to reach a good position accuracy for the underwater archaeological missions to perform. All the details about these algorithms can be found in [6] [7] [8] [12].

The software of the vehicle is based on ROS (Robot Operating System), running on Ubuntu 14.04. Such a modular software architecture allows to easily control the data flow and to monitor the state of the vehicle; in addition, such structure well combines with MARTA's own modularity: indeed, it is very easy to change the control and navigation architecture of the vehicle according to the specific modules employed for each particular rnission. The state of the vehicle during the rnission can be monitored in real time using a suitably developed graphical interface (see Figure 2): the user is not only able to view the real time position of the vehicle on the map, but can also query the vehicle for additional information (through WiFi or radio on surface, acoustically underwater).

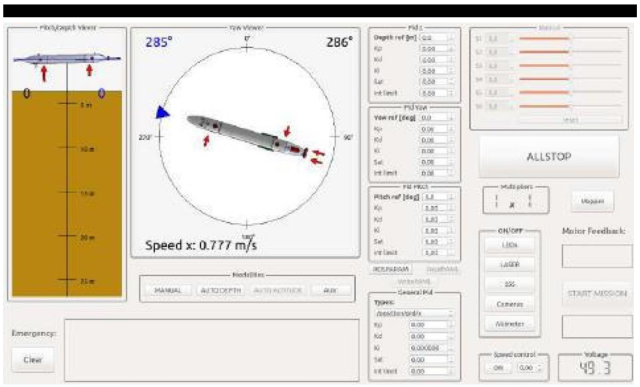

Figure 2: AUVmission contro/ interface

In addition, another interface has been developed for an easy rnission planning: the user can insert new waypoints of the path directly on the map (see Figure 3), and it is possible to select the sensor payload to be used during the rnission. This way, the planning phase of an autonomous rnission becomes very quick and easy, also for the end users (e.g. archaeologists).

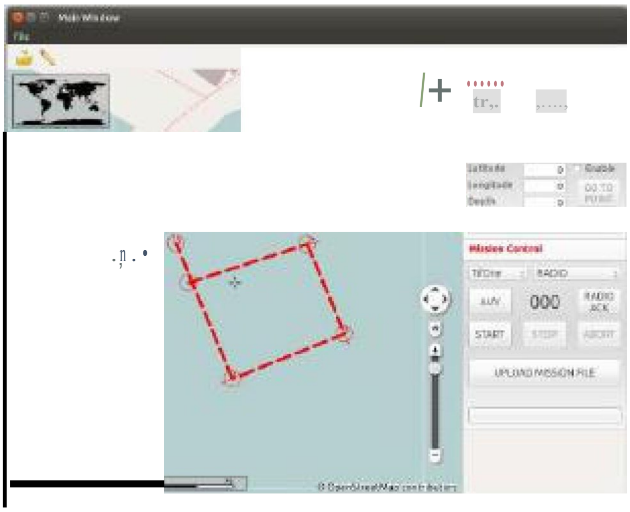

Figure 3: AUV mission planning interface

IV. RESULTS AT SEA

The official ARROWS final demonstrations held in Sicily and in Estonia during Summer 2015. These rnissions at sea were an experimental proof of the validity of the developed robotic tools.

The first set of trials were performed in Sicily, at Cala Minnola site: in Figure 1, MARTA AUV is navigating at sea during the first official demo performed in Sicily, Aegadian Archipelago, during May and June 2015. All the ARROWS robots were involved in this first demonstration including AUVs previously developed by some partners (e.g. TifDne and Tiffu AUV developed within the Tuscany regional project THESAURUS at the University of Florence [3]). Cala Minnola site was known to contain archaeological artefacts of amphorae: all the tests in Sicily were coordinated and supervised by La Soprintendenza del Mare della Regione Sicilia. The Search phase was performed through a commercial IVER-3 AUV, that obtained good SSS acoustic images at an altitude ofbetween 5-8 metres from the sea floor. After the acoustic search phase that identified the targets of interest, MARTA was used as the inspection vehicle to acquire optical images of the site. MARTA autonomously followed a transept-shaped path, shown in Figure 4. The transept consists of 16 waypoints (from WPl to WP16) and its sizes were about 27x55 m. MARTA navigated underwater at a depth of about 25 m whereas the longitudinal speed was around 0.5 m/s.

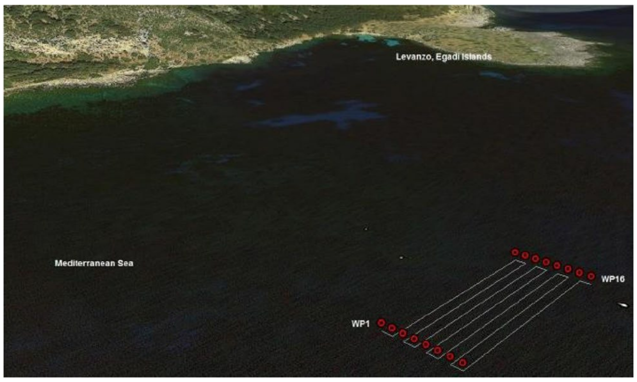

Figure 4: transept-shaped path followed by the AUV during the sea tests near the Cala Minnola site

Images of the field of amphorae in the Cala Minnola site were thus collected during MARTA autonomous rnissions (e.g. a single frame is given in Figure 5) and in Figure 6 the related 3D reconstruction is reported (please see also http://www.arrowsproject.eu/media-center/trials/3d-reconstructions-levanzo-sicily-and-rummu-guarry-estonia/). The optical reconstructions made available useful information for the archaeologists.

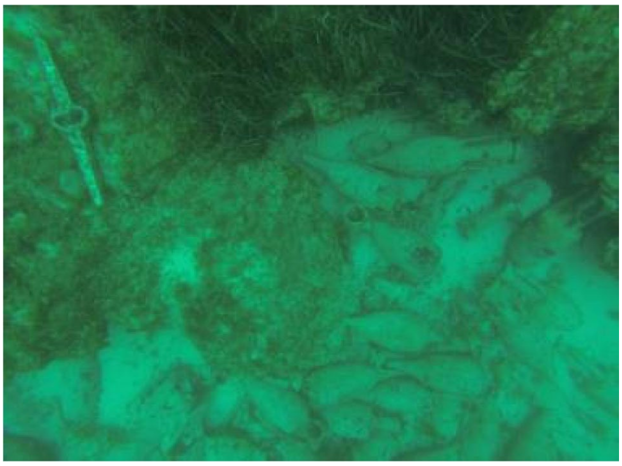

Figure 5: an opticalframe captured by MARTA during the mapping of the archeologica/ site ofthe Cala Minnola

Figure 6: 3D reconstruction of Cala Minnola site (Sicily, ItalyJ from the optical images acquired by MARTA AUV

V. CONCLUSIONS

The paper described MARTA AUV, acronym for MARine Robotic Tool for Archaeology, a modular Autonomous Underwater Vehicle (AUV) developed in the framework ofthe European ARROWS project (2012-105). The paper summarizes the main characteristics of the vehicle, its navigation and payload sensors. ARROWS final demonstrations took place in Italy (Sicily) and in Estonia: in the paper some results related to the first sea campaign are given and discussed. Finally, it is worth noting that during the **ARROWS** demonstrations performed in Sicily and in Estonia, the archaeologists belonging to the consortium bave been trained to use AUVs to perform acoustic and/or optical surveys.

ACKNOWLEDGMENT

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