# Autonomous Manganese Fields Exploration with a UVMS: the ROBUST project


Enrico Simetti
*ISME*
*Univ. of Genova*
Genova, Italy
enrico.simetti@unige.it

Giovanni Indiveri
*ISME*
*Univ. of Genova*
Genova, Italy
giovanni.indiveri@unige.it

Giuseppe Casalino
*ISME*
*Univ. of Genova*
Genova, Italy
giuseppe.casalino@unige.it

Daniele Di Vito
*ISME*
*Univ. of Cassino*
Cassino, Italy
d.divito@unicas.it

Gianluca Antonelli
*ISME*
*Univ. of Cassino*
Cassino, Italy
antonelli@unicas.it



***Abstract*—This extended abstract presents the main results of the H2020 ROBUST project, whose goal was the development of an autonomous system to execute exploration and in-situ sampling of underwater mananganese nodule fields.**



***Index Terms*—autonomous underwater vehicles, exploration, underwater mining**


## I. Introduction

Europe is repeatedly looking at the sea as a source of raw mineral deposits, due to lack of surface ones [1]. In the past two decades, approximately twenty-seven exploration contracts have been approved by the International Seabed Authority for international sea areas, for the exploration of manganese nodule fields, cobalt rich ferromanganese crusts or seafloor massive sulfides.

Performing seabed mining efficiently, but also in an environment friendly way is thus receiving a greater interest by the European Union. In fact, exploration of deep sea deposits was the target of the H2020 ROBUST project, whose aim was the development of key technologies to enable in-situ analysis of new mineral deposits. Among the possible mining resources, the project focused on manganese nodule fields. The disruptive idea of the project was to equip an a Underwater Vehicle-Manipulator System (UVMS) with a novel Laser Induced Breakdown Spectroscopy (LIBS) sensor, allowing for an in-situ inspection of the nodule and element identification.

The project screenplay was envisioning the following steps of a complete mission:

- First, the UVMS performs a bathymetric survey of the area of interest, collecting Multi Beam Echo Sounder (MBES) data. The latter is processed to form bathymetric and backscatter data, which are then matched with historical data to estimate the sub-area that could contain manganese nodule fields with highest probability [2].
- The UVMS reaches the area with highest probability of finding nodules, and descends at a few meters of altitude. At this stage, video data is collected and analysed in real-time, as the UVMS performs a survey of the area. A Convolutional Neural Network is employed to identify features similar to a manganese nodule [3].


This work was supported by the EU through the Horizon 2020 Research and Innovation Programme under grant agreement n. 690416 (ROBUST project).

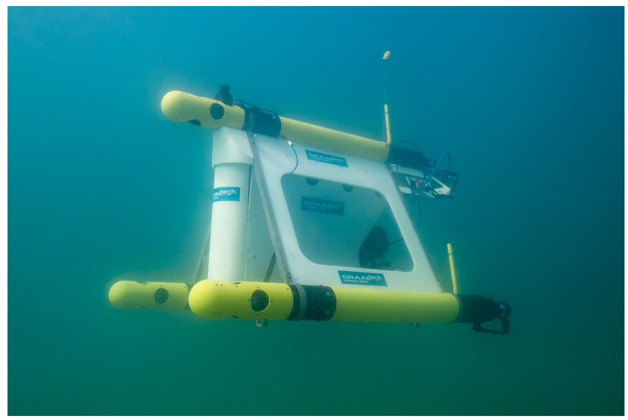



Fig. 1: The ROBUST UVMS during the sea trials in Sardinia.

- Whenever the deep-learning method signals a possible nodule, it is tracked in the image plane and the control system drives the UVMS to precisely land in front of the nodule, maintaining it in the camera and manipulator workspaces. Once landed, a laser-scanning system is first used to create a 3D model reconstruction of the nodule, and estimating a point near the surface of the nodule to perform the in-situ analysis. Then, the manipulator is unstowed, and moved toward that point. Once in the required position, the LIBS is commanded to perform the measurement, and the associated spectroscope performs the in-situ analysis. At the end of this phase, the manipulator is stowed again, and the UVMS takes off to resume the survey. This whole step is repeated for a sufficiently high number of times to gather enough data for a statistical analysis of the area.

## II. Major Challenges

### A. Modeling

The developed ROBUST UVMS is shown in Fig. 1. As it can be seen, its basic skeleton is composed by three AUVs (X-300 manufactured by Graal Tech s.r.l.) interconnected by a frame. This configuration was chosen to exploit pre-existing AUVs, combining them with minimal hardware changes, while still carrying the ROBUST mission payload (the MBES and the manipulator with the LIBS sensor) and minimizing the costs charged to the project [4]. A novel idea that was explored during the project was to derive the hydrodynamic model of the overall ROBUST UVMS as the composition of the (previously identified) models of the basic AUVs [5], [8].

### B. Control

In terms of control, the goal of the project was to support all the phases of the complex ROBUST mission without resolving to separate laws. To this aim, the project developed a task-priority approach [6], [7], and developed a framework encompassing 16 basic control tasks, combined in 9 ways, generating 9 different control actions [5].

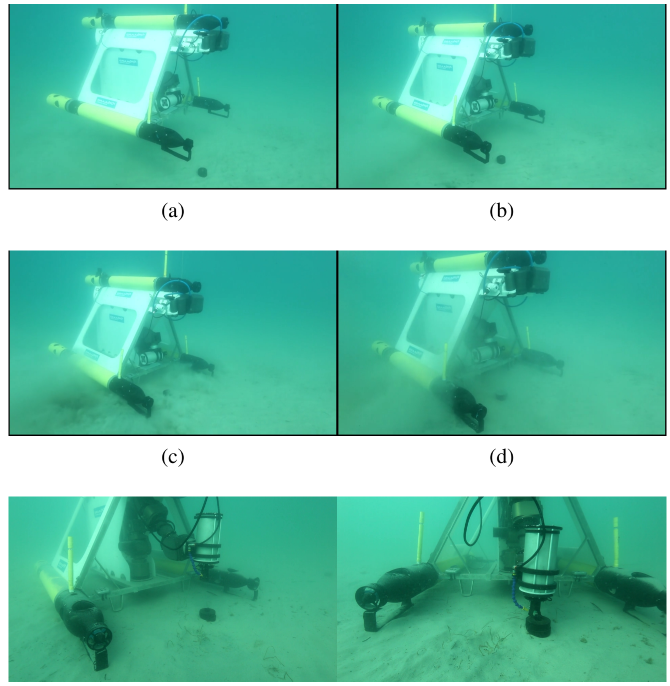
### C. Perception

The perception subsystem is composed by two synchronized color cameras, mounted in a converging stereo configuration, and a triangulation laser. The former are used for detection by the CNN and for tracking the nodule during the landing maneuver. The latter is instead exploited for generating a high resolution 3D point cloud of the surface of the nodule, which is then used to generate a good sampling point for the LIBS system [4].

## III. Experimental Results and Conclusions

Several experimental campaign where carried out through the project. A first series of tests where executed in La Spezia, Italy, within its harbour area, to identify the hydrodynamic parameters of the vehicle and to compare them to those compute a-priori through the clustering approach [8]. The experimental results have shown that most of the values computed a priori have the same order of magnitude of those experimentally identified. Numerous tests were conducted in La Spezia to fine tune the dynamic controller, based on an adaptive approach, the kinematic control layer [7] and the navigation filter integrating the hydrodynamic model in an Extended Kalman Filter solution [5].

Once the basic components proved to be working, a week long experimental campaign took place in Cagliari, Italy, to the aim of executing the overall ROBUST mission, at least concerning the optical survey, identification and tracking of the nodules, landing and inspection with a mockup LIBS sensor. One of the experiments is shown in Fig. 2, depicting the moments of the landing (a-d) and the inspection with the mockup LIBS sensor (e-f). The figure reports a few frames extracted from the video available at `https://youtu.be/tl4zZptrOtg`. The video shows how the overall framework (modelling, kinematic, dynamic control and navigation using a hydrodynamic model-based EKF) sucessfully executed and a ROBUST mission, validating its concept by performing the identification and tracking of a manganese nodule, allowing the UVMS to land in front of it and performing a mockup in-situ inspection, paving the way for the employment of autonomous technologies for the exploration of mining sites.



(a) (b) (c) (d) (e) (f)

Fig. 2: Snapshots taken by a diver showing the ROBUST UVMS as it performs the landing, maintaining the nodule within the perception system and manipulator workspaces.


## Acknowledgment

Our sincere thanks go to all the members of the ROBUST consortium for their tireless commitment, and contributions to the project.


## References


[1] (2014) Report on critical raw materials for the eu. [Online]. Available: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_it

[2] J. Quintana, R. Garcia, L. Neumann, R. Campos, T. Weiss, K. Köser, J. Mohrmann, and J. Greinert, "Towards automatic recognition of mining targets using an autonomous robot," in *OCEANS 2018 MTS/IEEE Charleston*. IEEE, 2018, pp. 1–7.

[3] C. Sartore, R. Campos, J. Quintana, E. Simetti, R. Garcia, and G. Casalino, "Control and perception framework for deep sea mining exploration,," in *IROS 2019*. IEEE, 2019, pp. 1–6.

[4] E. Simetti, R. Campos, D. Di Vito, J. Quintana, G. Antonelli, R. Garcia, and A. Turetta, "Sea mining exploration with an uvms: Experimental validation of the control and perception framework," *IEEE/ASME Transactions on Mechatronics*, 2020.

[5] D. Di Vito, D. De Palma, E. Simetti, G. Indiveri, and G. Antonelli, "Experimental validation of the modeling and control of a multibody underwater vehicle manipulator system for sea mining exploration," *Journal of Field Robotics*, 2020.

[6] E. Simetti and G. Casalino, "A novel practical technique to integrate inequality control objectives and task transitions in priority based control," *Journal of Intelligent & Robotic Systems*, vol. 84, no. 1, pp. 877–902, apr 2016.

[7] E. Simetti, G. Casalino, F. Wanderlingh, and M. Aicardi, "Task priority control of underwater intervention systems: Theory and applications," *Ocean Engineering*, vol. 164, pp. 40–54, 2018.

[8] R. Ingrosso, D. De Palma, G. Avanzini, and G. Indiveri, "Dynamic modeling of underwater multi-hull vehicles," *Robotica*, vol. 38, no. 2, pp. 1682–1702, 2019.