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Control and Perception Framework for Deep Sea Mining Exploration

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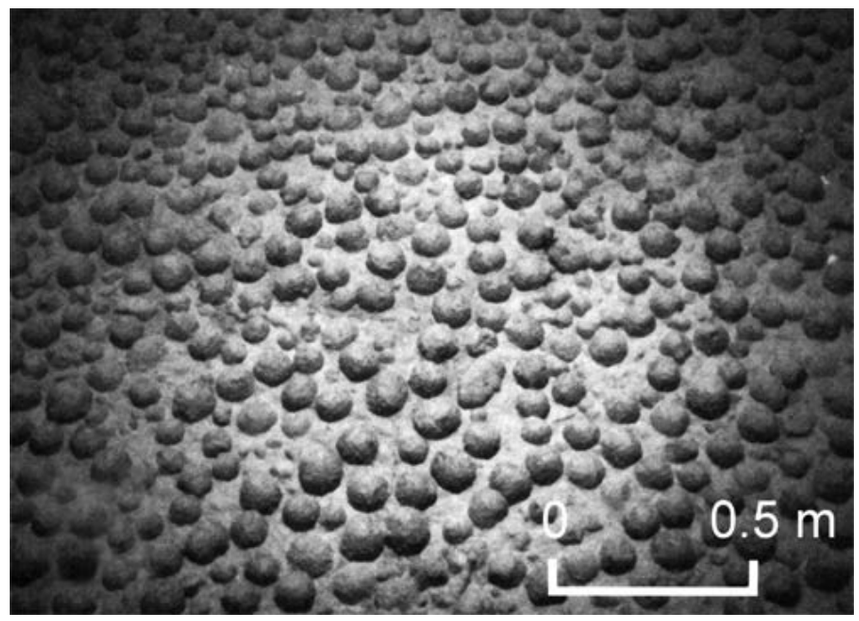
The H2020 ROBUST Project

EU funded project under the Horizon 2020 program

Aims to develop an underwater Vehicle Manipulator System (UVMS) capable of autonomously scanning a large area and performing in-situ material identification using the Laser Induced Breakdown Spectroscopy (LIBS), focusing on a use case of manganese nodule fields exploration



The ROBUST Consortium

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Integrated Systems for Marine Environment

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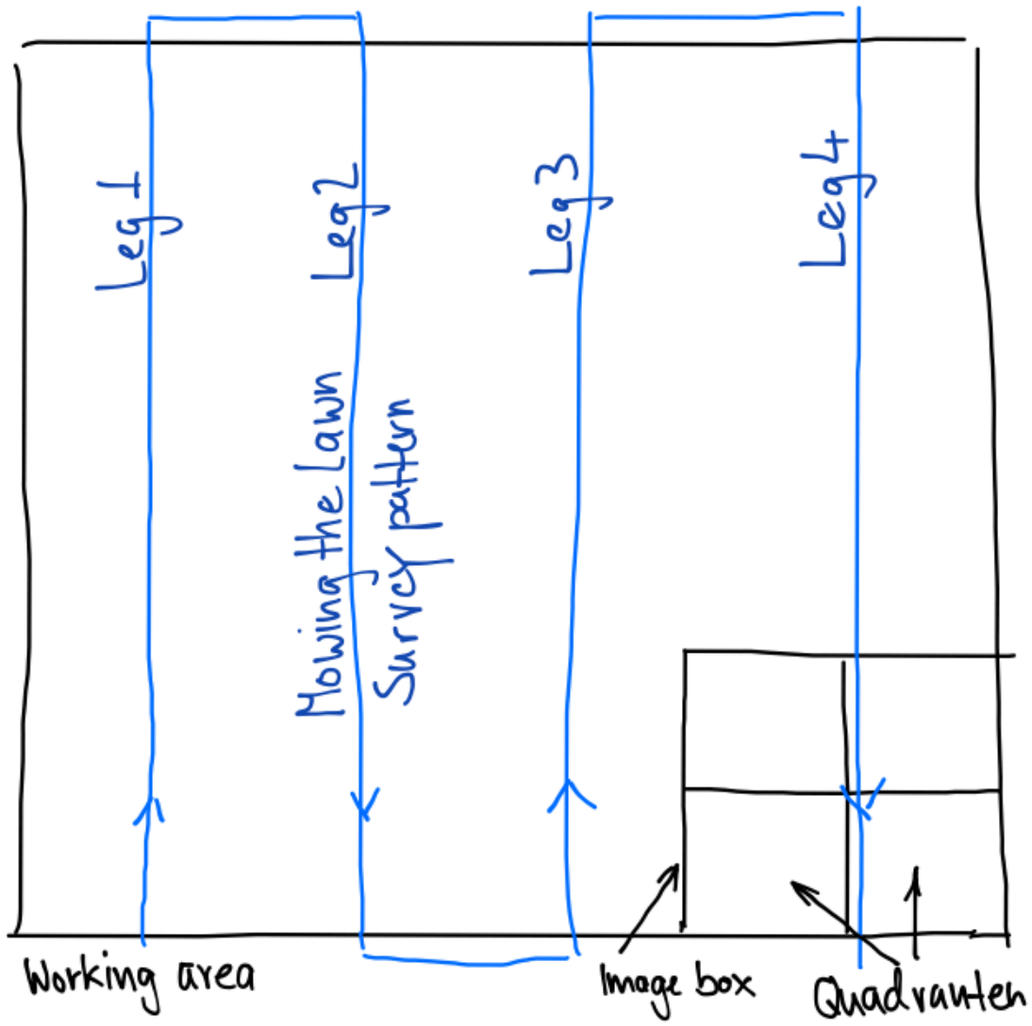
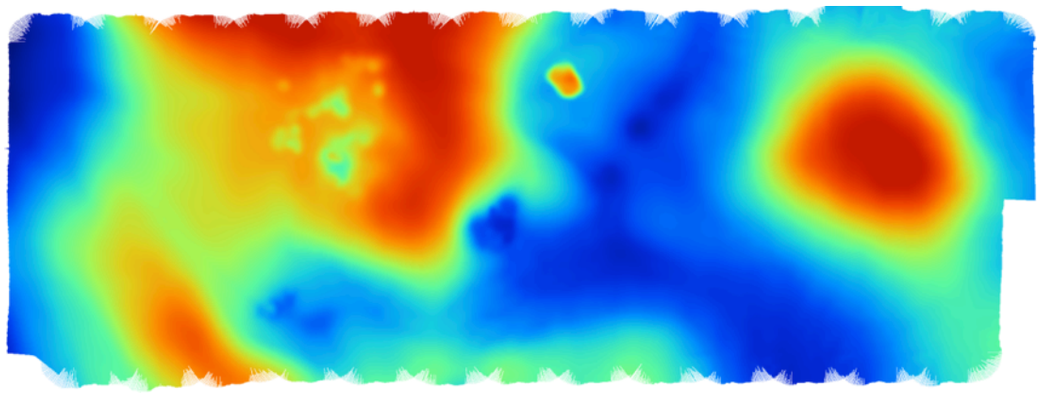
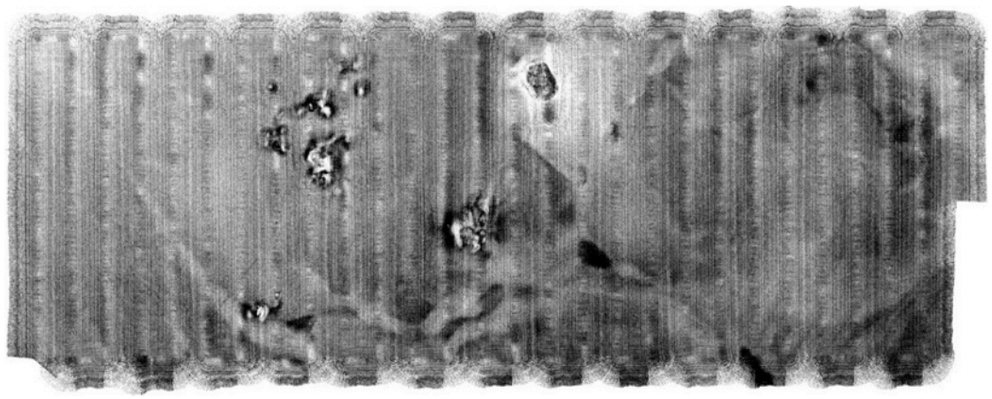
Computer Vision and Machine Learning

The Envisioned Mission



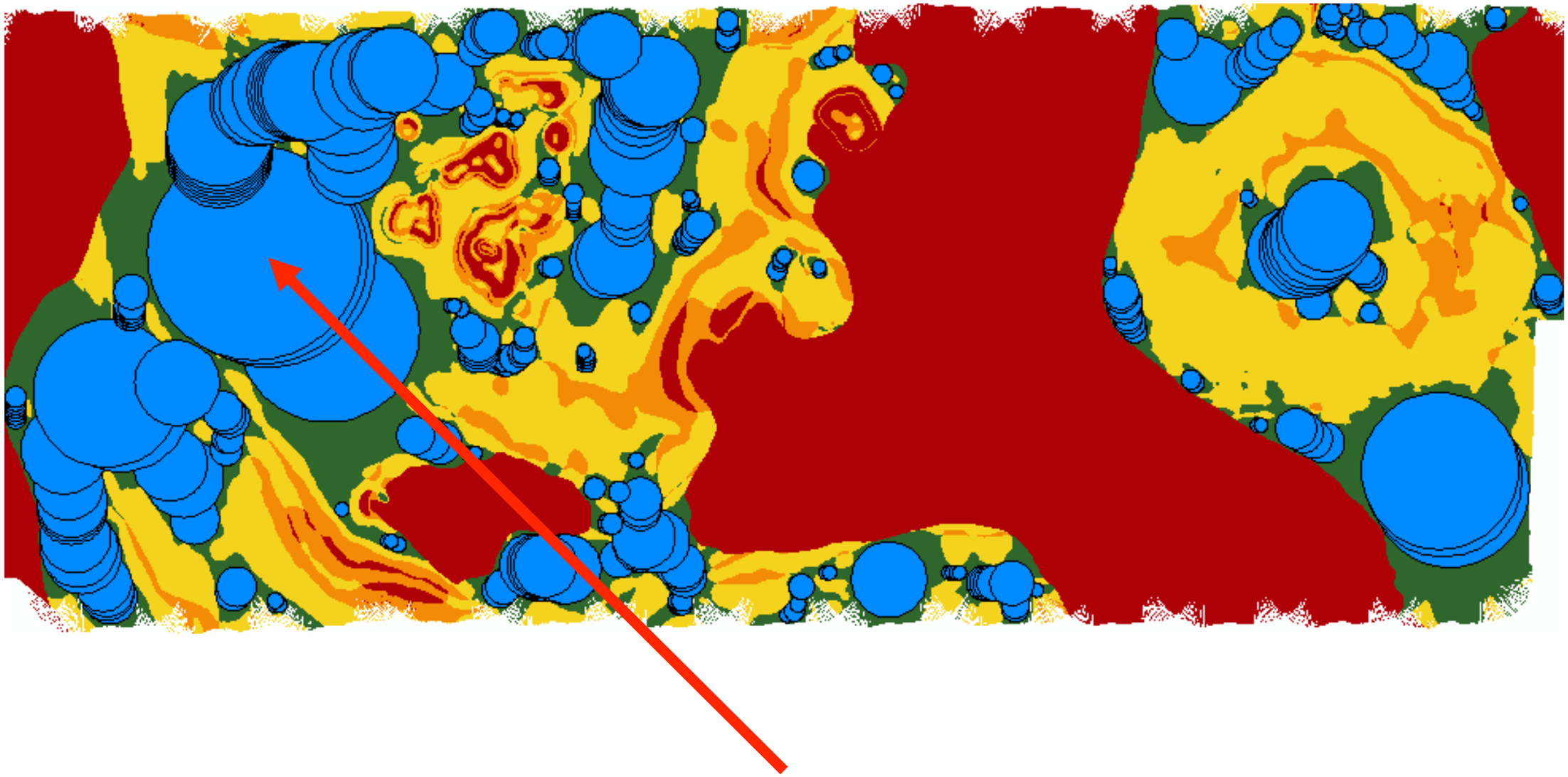
Mission to be executed





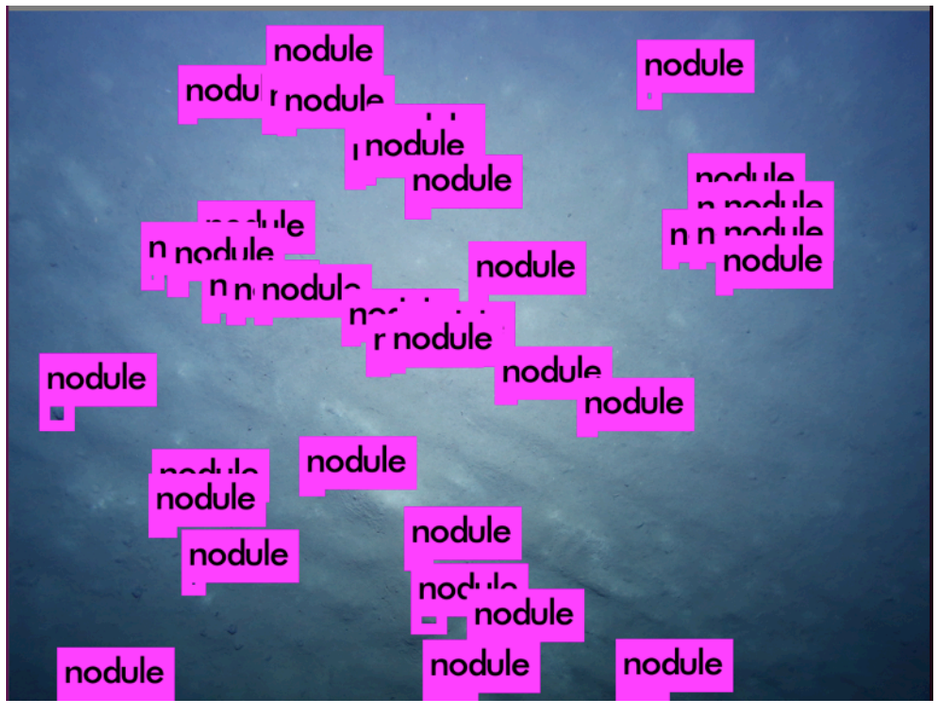
Reconstructed Bathymetry

The Envisioned Mission



Most promising zone to be scanned

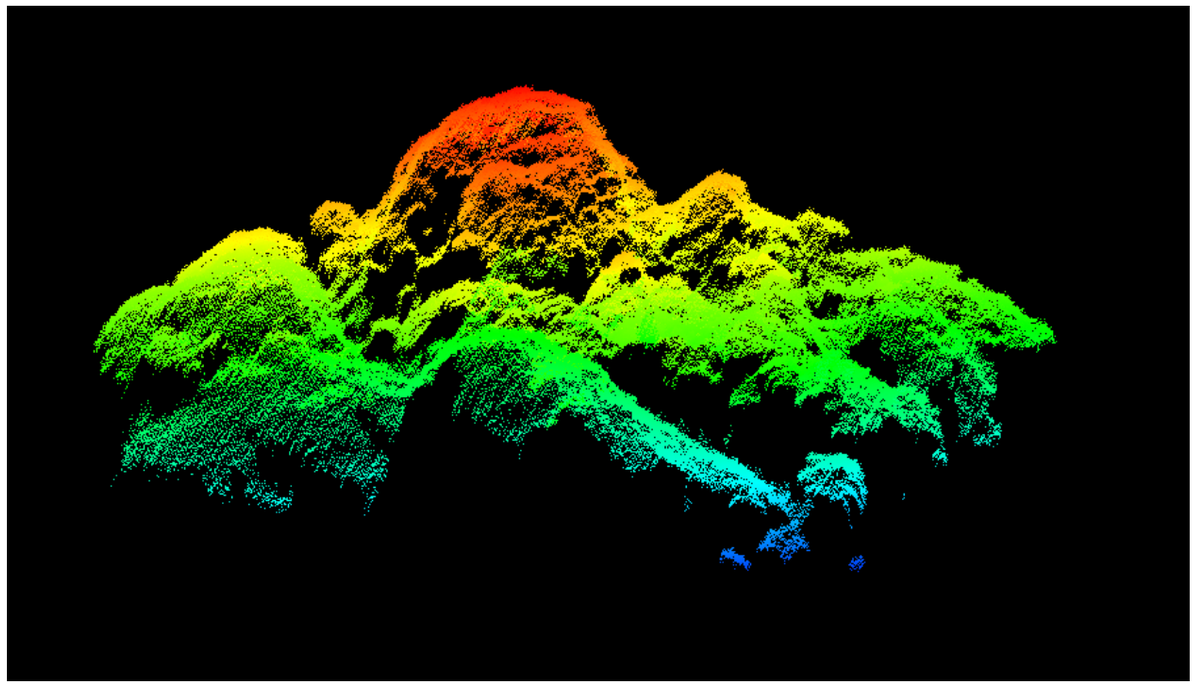
The Envisioned Mission



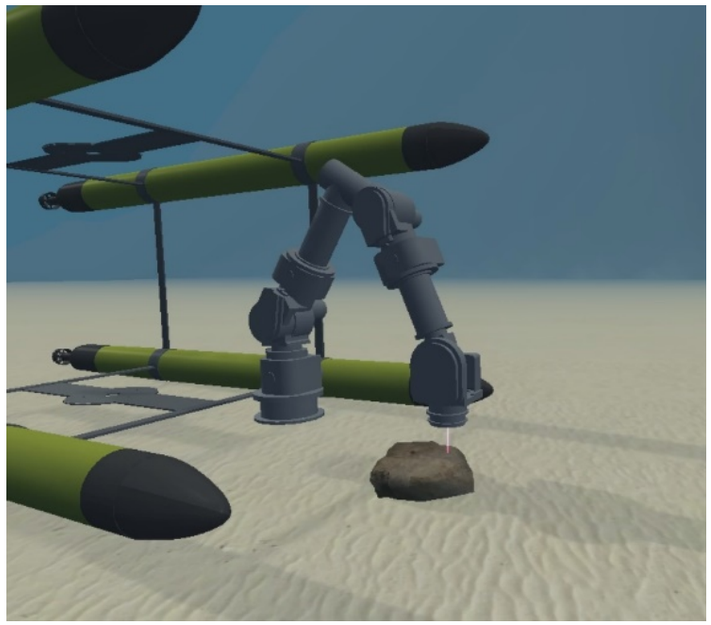
Vision based identification of potential nodules

Alignment to nodule

The Envisioned Mission

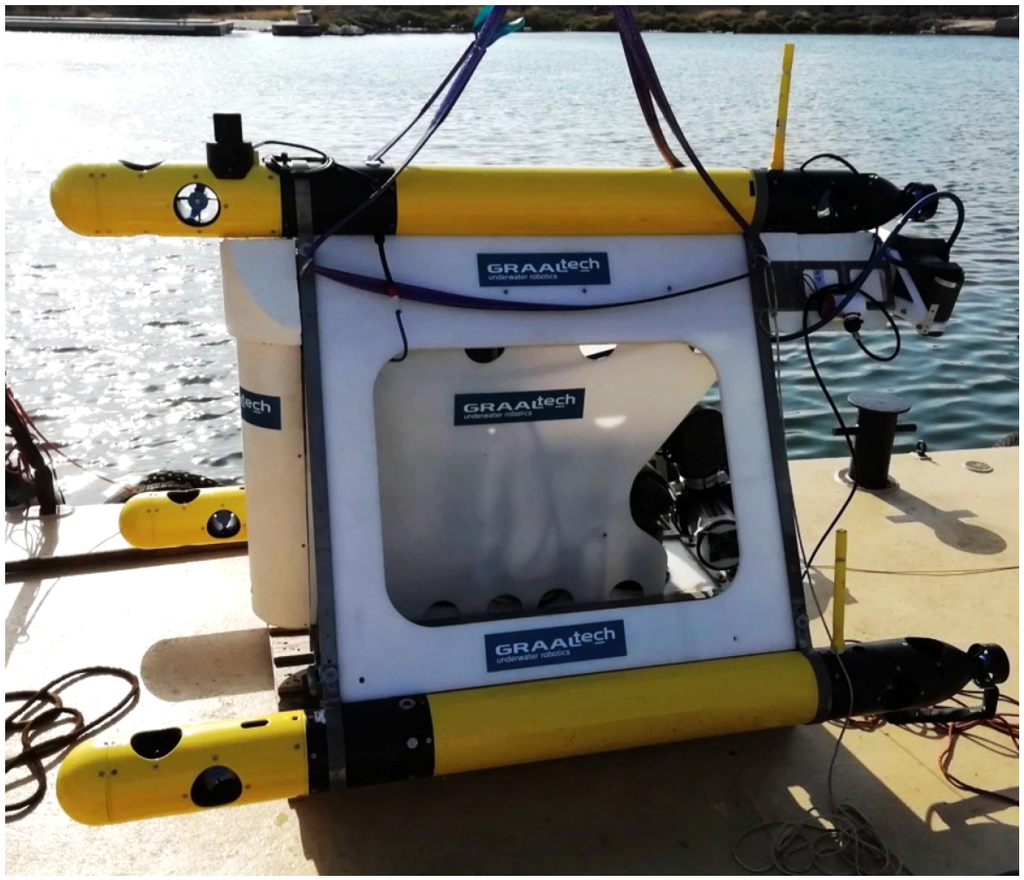


3D nodule reconstruction through Laser scanning



Landing and intervention

The ROBUST UVMS: Vehicle



Each AUV body has 2 vertical thrusters, 2 lateral thrusters and one main thruster

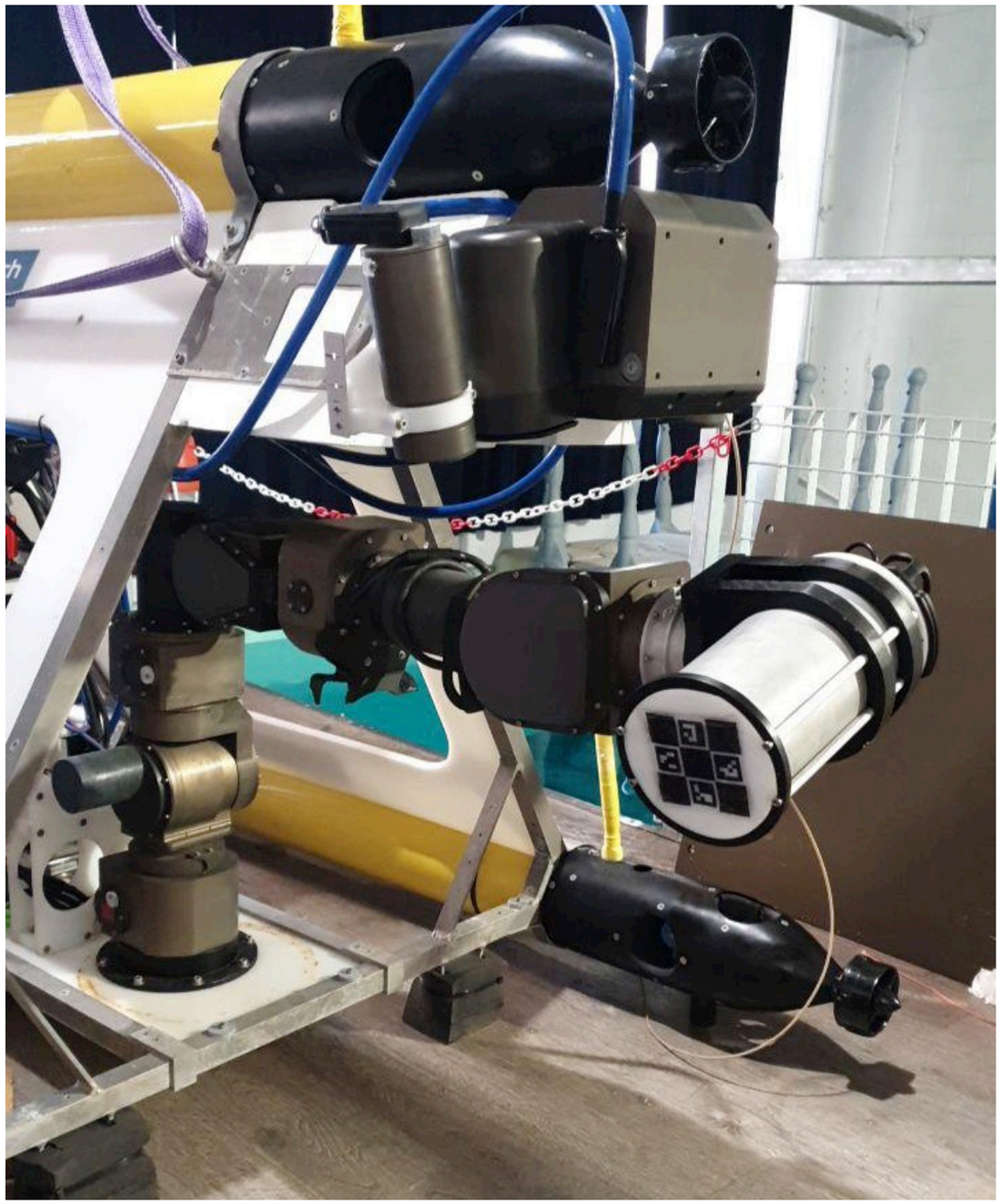
Nav sensors: DVL, AHRS, USBL

The ROBUST UVMS: Manipulator

7 DOF electrical arm

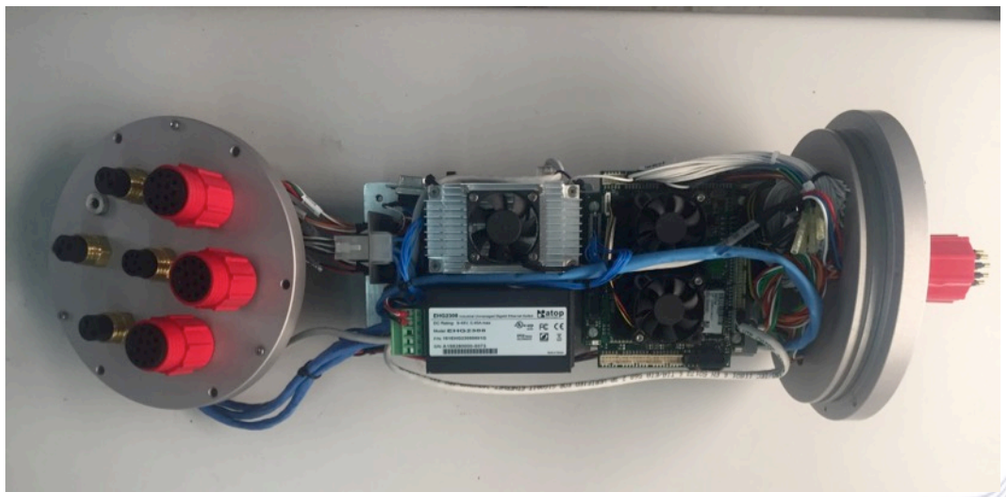
The end-effector carries the LIBS head

Marker on the end-effector for extrinsic camera calibration

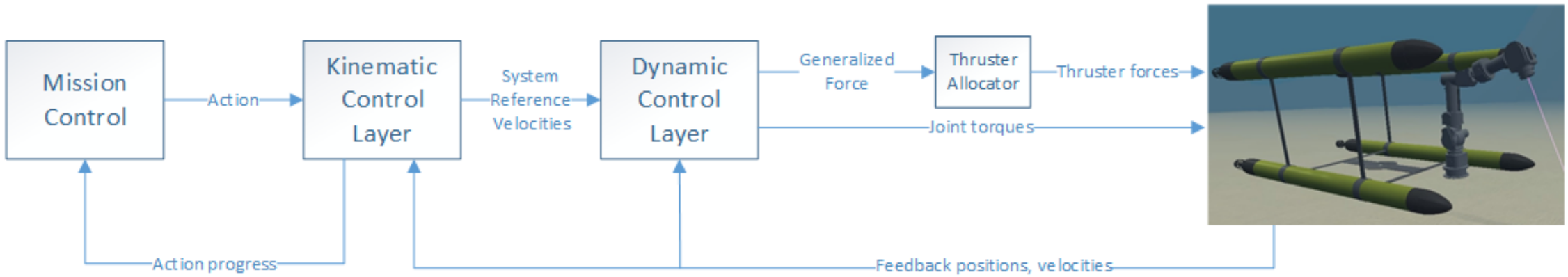


The ROBUST UVMS: Perception HW

Acquisition system:
- Nvidia Jetson TX2
- PC 104
- Stereo Visual System
  - 2x Prosilica GC1380
- Laser Scanner System
  - PhotonFocus 3D03
  - Laser + Motorized Mirror
  - PC 104



The Control Architecture



The KCL is in charge of executing an **action**

- Land in front of nodule
- Perform survey
- Move LIBS in position for measurement
- Etc.

It handles constraints:

- Minimum altitude from seafloor while doing survey
- Arm joints limits when moving the manipulator
- Etc.

The Control Architecture

The KCL is based on a task priority approach [1]

An **action** is a prioritized list of control objectives and associated tasks to be **concurrently** managed.
Control objectives in order of importance:

1. objectives related to physical constraints
2. objectives related to the safety of the system
3. objectives that are a prerequisite for the execution of the mission
4. action-defining objectives
5. optimization objectives

[1] Simetti, E., Casalino, G., Wanderlingh, F., & Aicardi, M. (2018). Task priority control of underwater intervention systems: Theory and applications. *Ocean Engineering*, *164*, 40-54.

Control Actions

Safe Waypoint Navigation

1. Vehicle minimum altitude;
2. Vehicle horizontal attitude;
3. Vehicle position (x, y and depth);
4. Vehicle heading aligned to velocity vector.

Landing Action

1. Vehicle horizontal attitude;
2. Nodule centered in the camera frame;
3. Vehicle altitude.

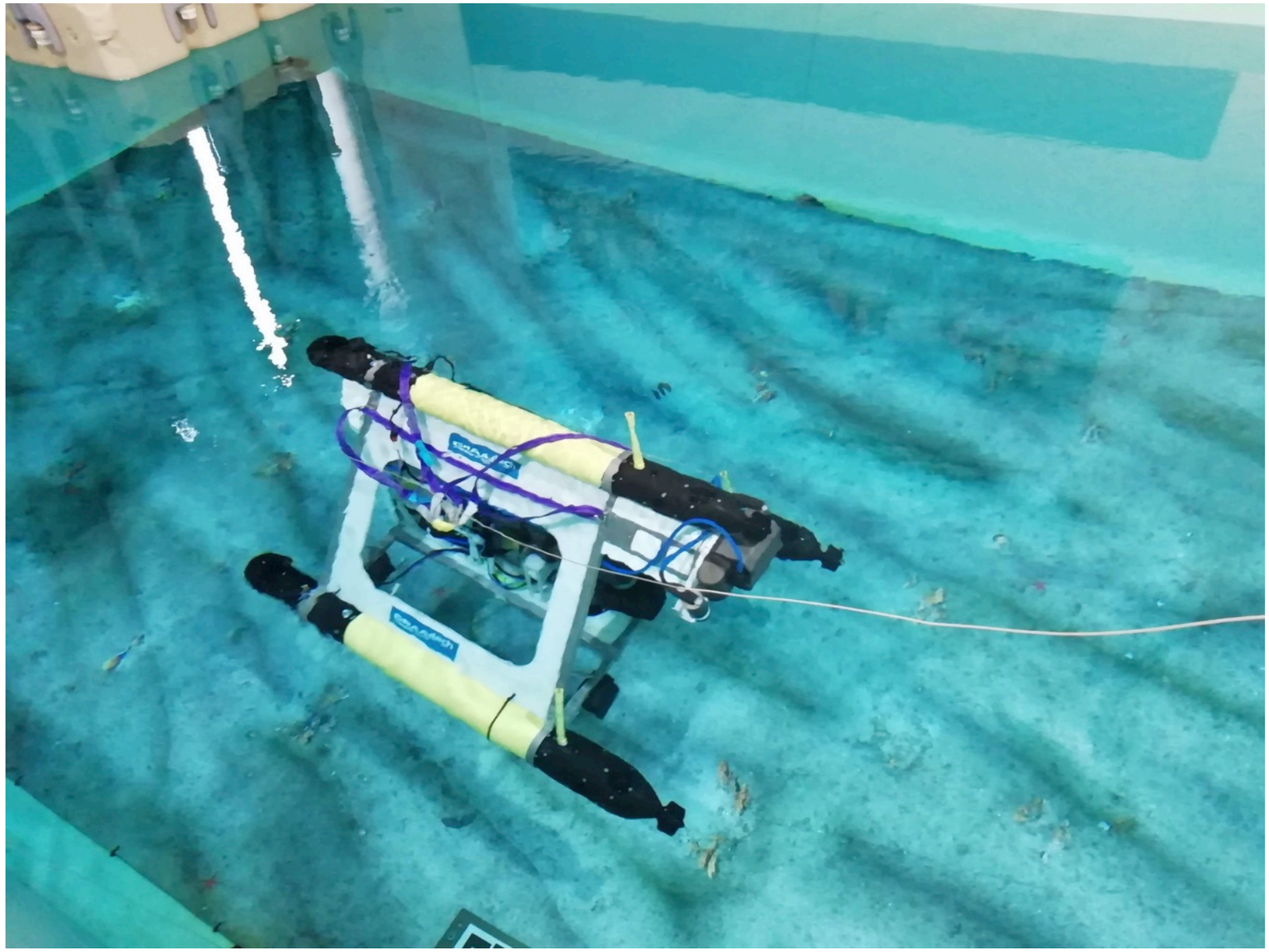
Path Following Action

1. Vehicle minimum altitude;
2. Vehicle horizontal attitude;
3. Path Following;
4. Vehicle heading aligned to velocity vector.

Fixed based manipulation Action

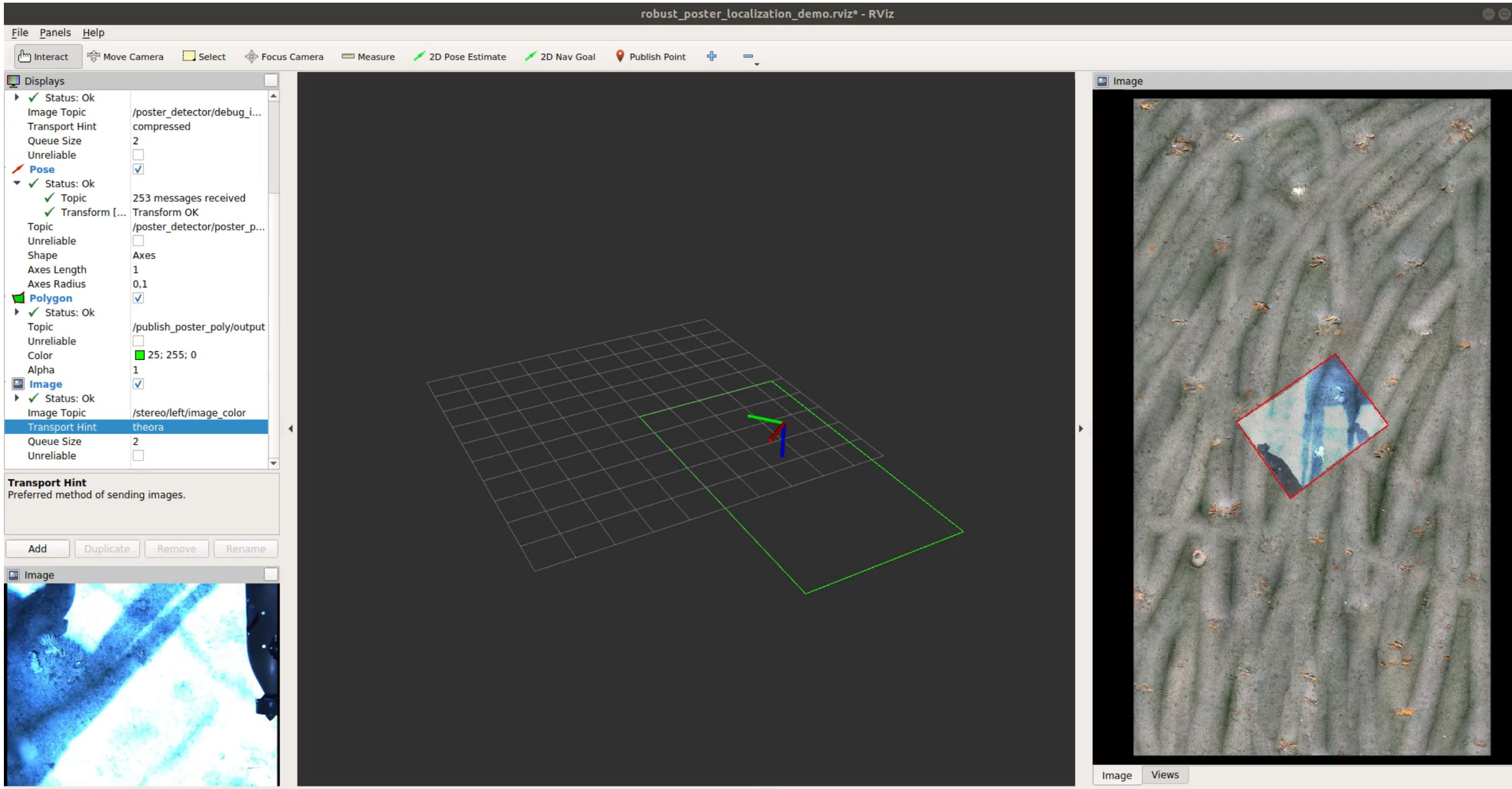
1. Vehicle constrained velocity;
2. Arm joint limits;
3. Arm obstacle avoidance (against the vehicle frame);
4. Arm manipulability;
5. End-effector position control;
6. End-effector orientation aligned to approach direction;
7. Arm preferred shape.

Preliminary Experiments @ Pool



Poster Localization

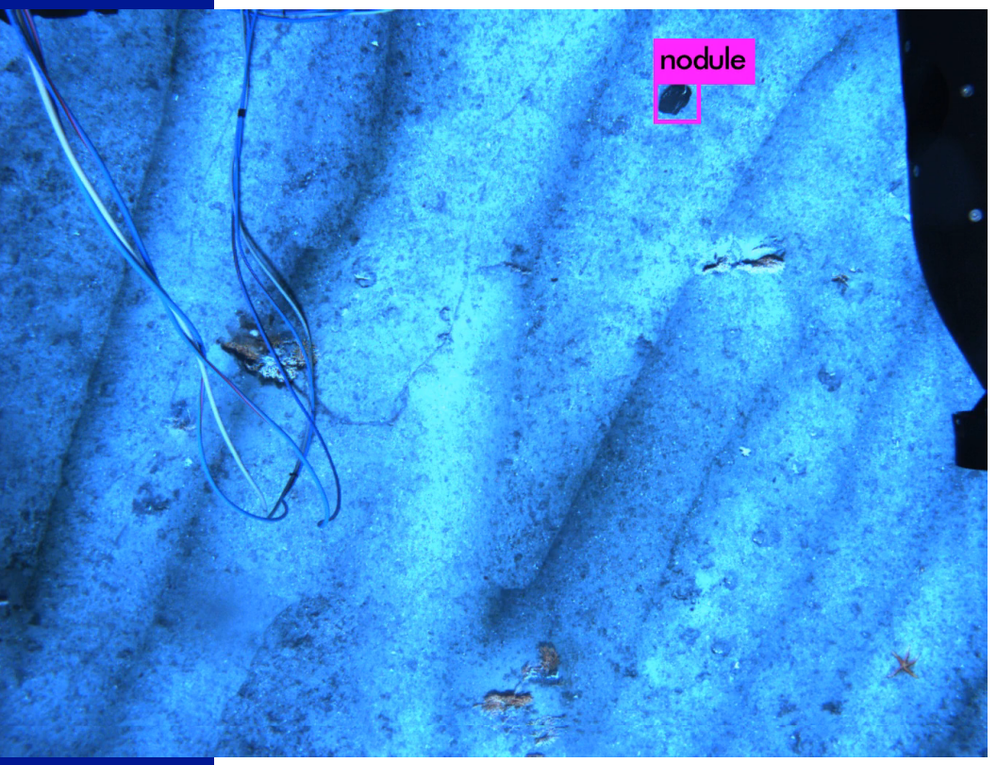
Registration on the poster provides absolute localization of the vehicle

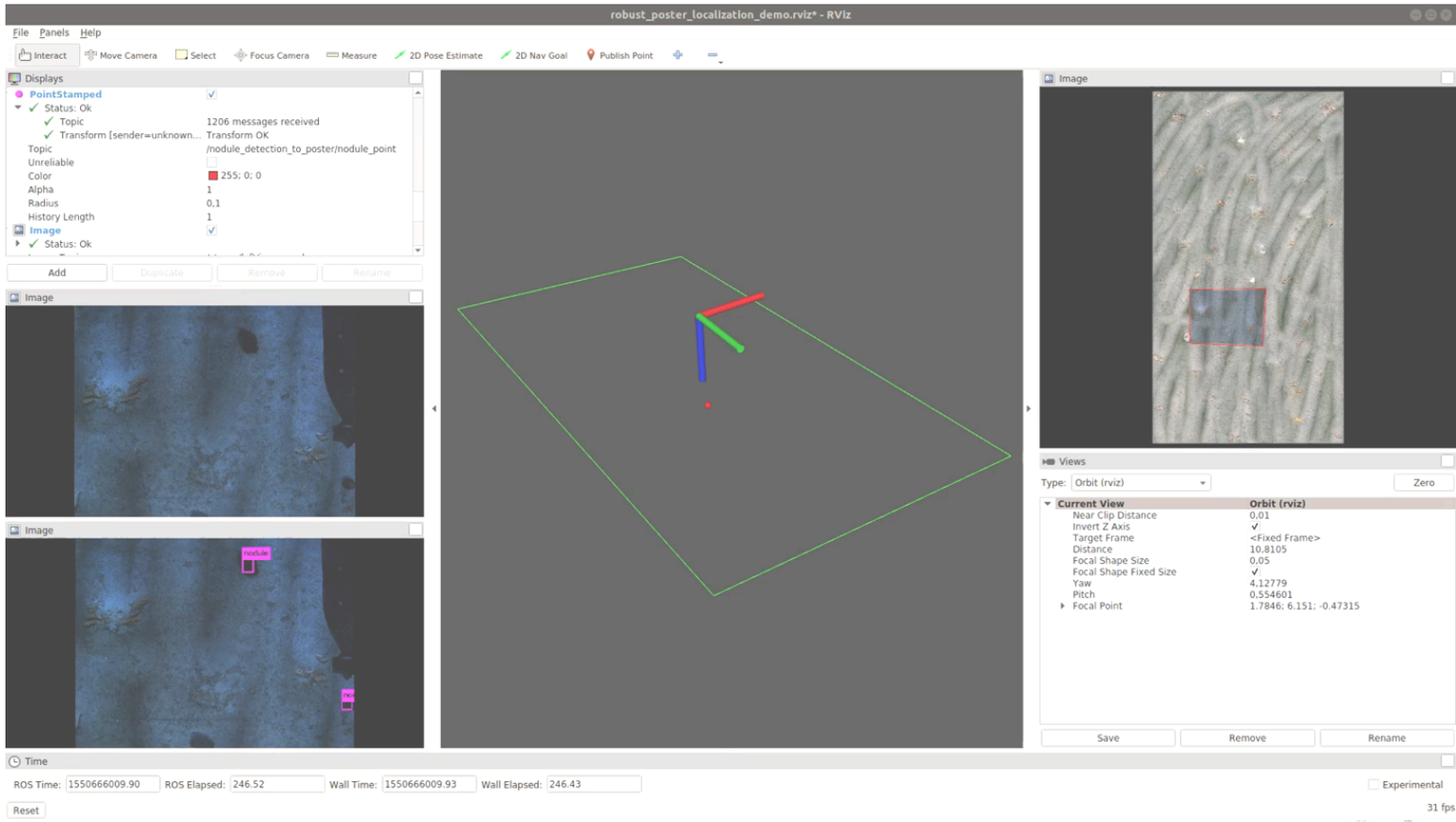


Yolo Based Nodule Detection

DarkNet YOLO network trained on a single class (nodule)

Obtained weights are used in a ROS module, and detections are performed at 4 fps on the Jetson TX2



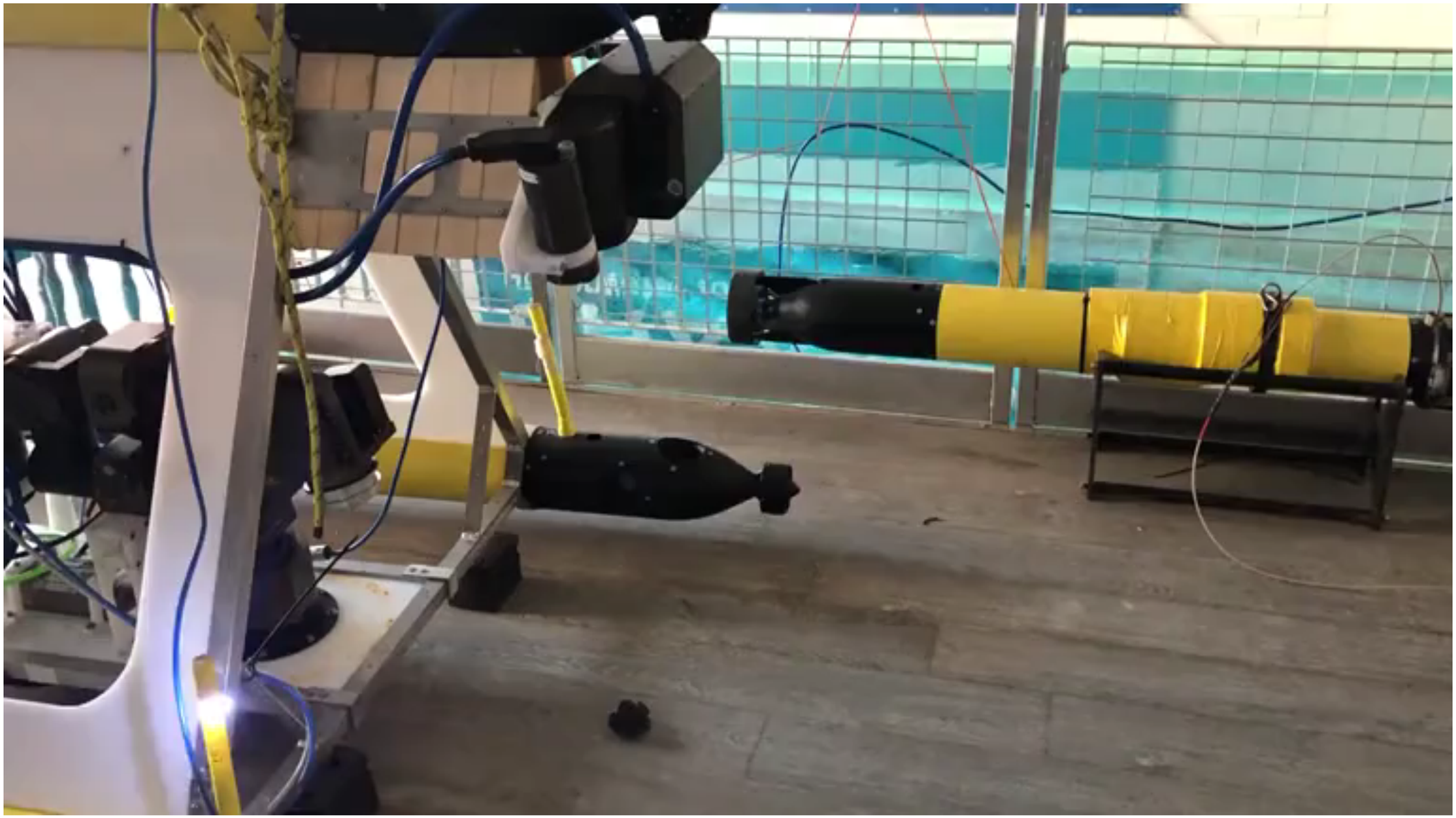


Landing and Sampling

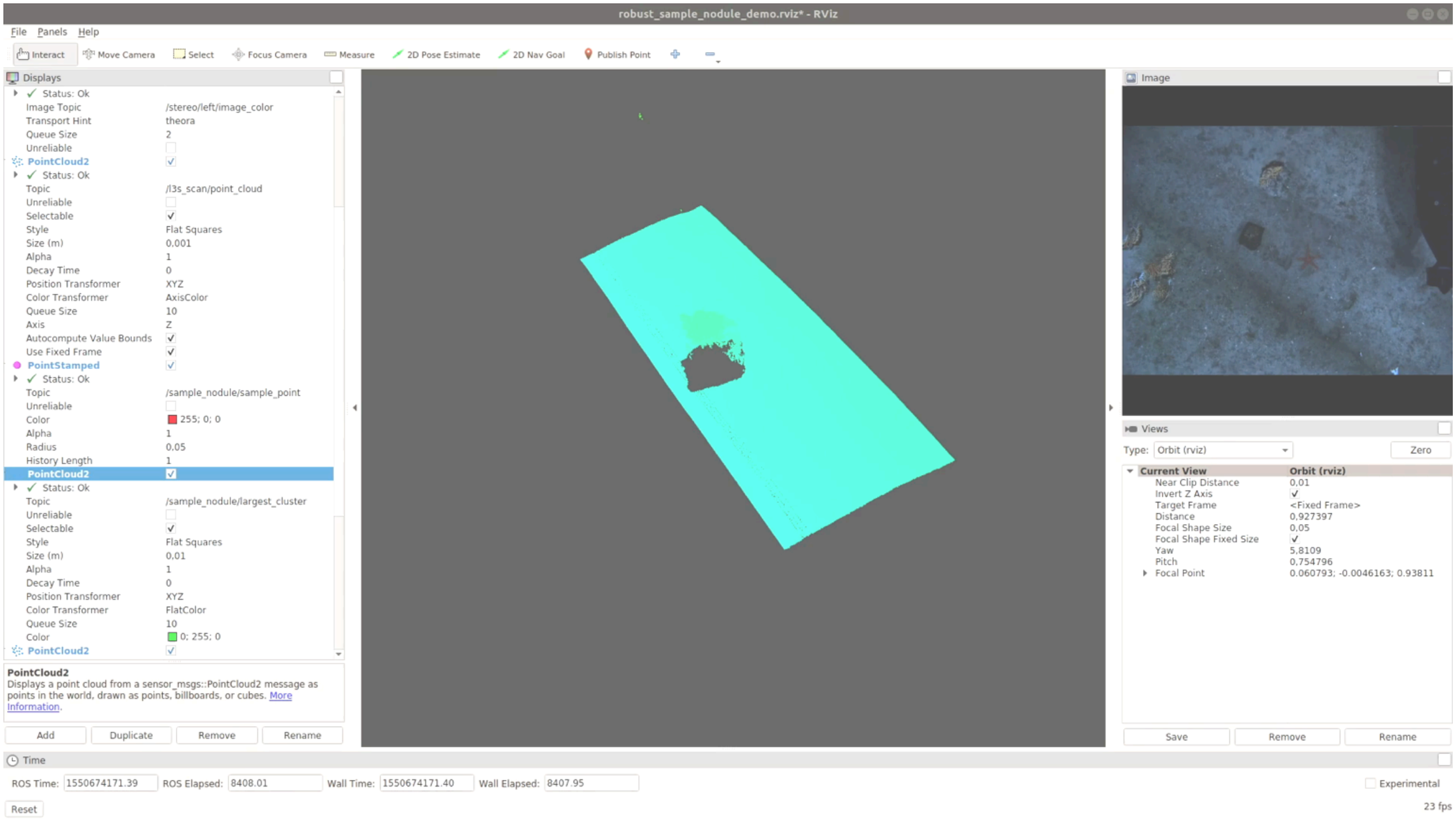
The sampling of the nodule is performed by:

- Once detected, nodule is tracked and the vehicle lands keeping it in the camera center
- A laser scanning on the nodule is performed creating a dense representation of the scene as a point cloud
- A point in the nodule is computed and an approaching position is provided to the arm

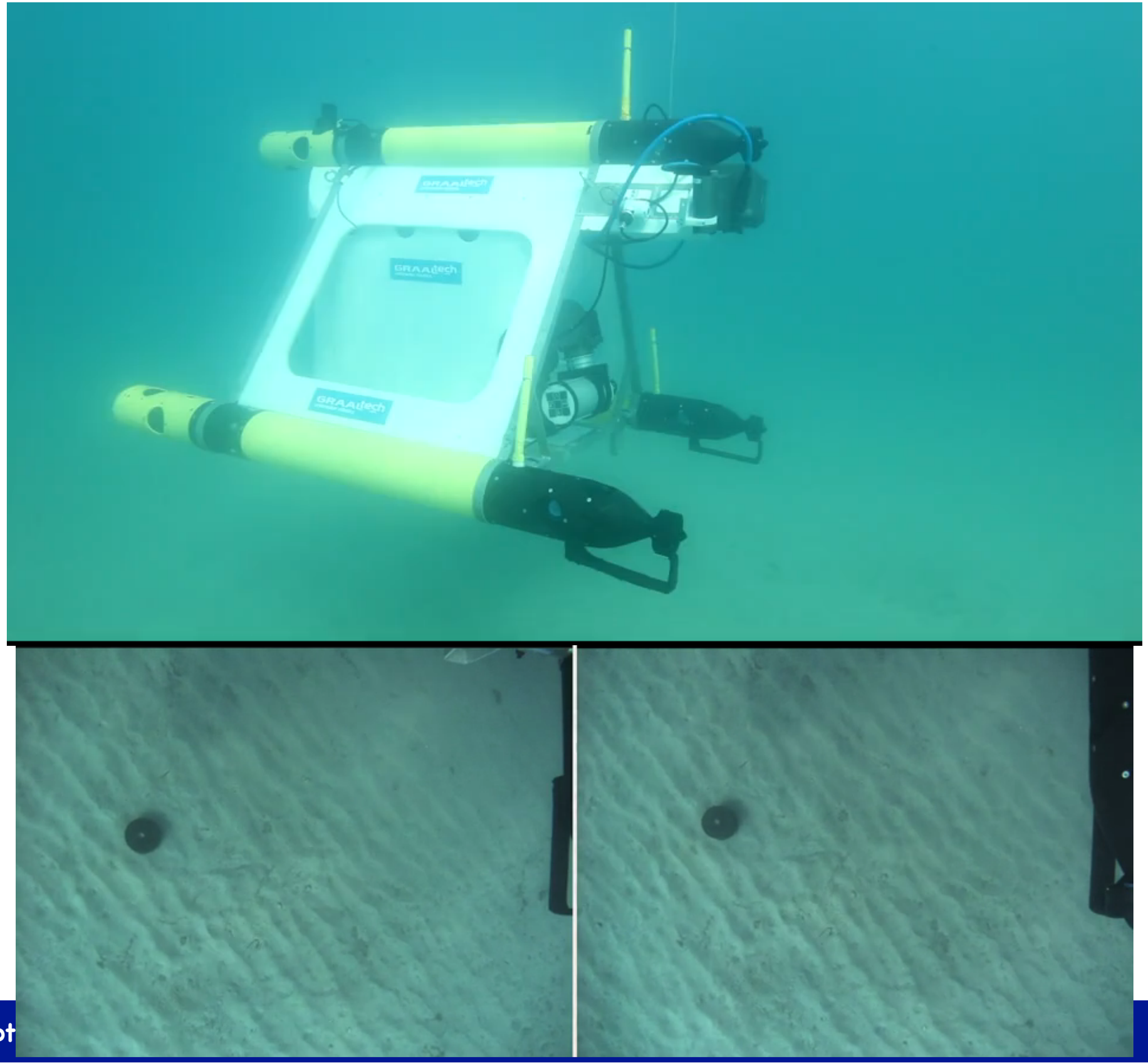
Scanning and Sampling Sequence



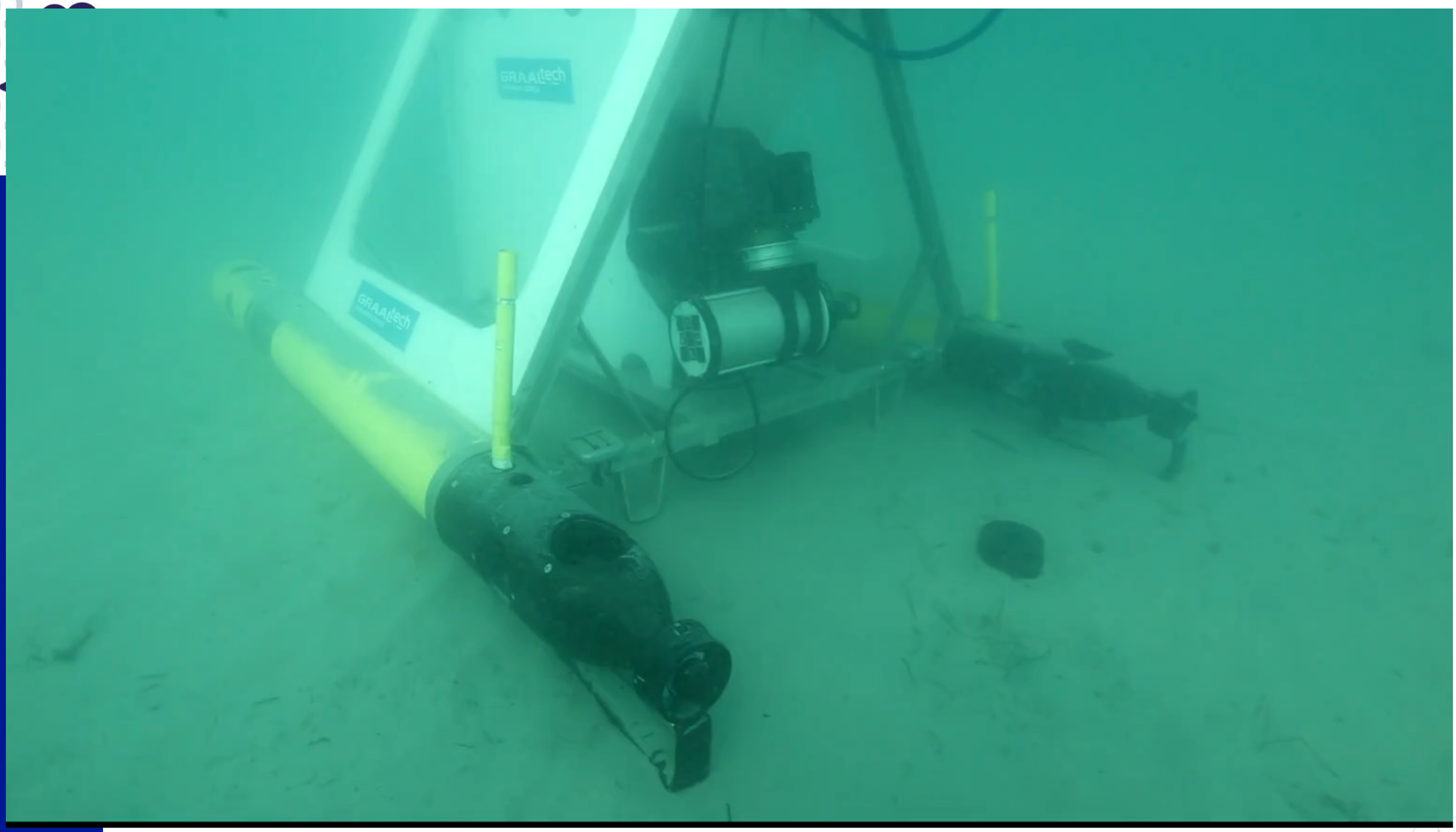
Scanning and Sampling Sequence



Sea Trials: Landing



Sea Trials: Inspection



Conclusions

Control framework based on a task priority approach

- Allows to easily create different complex behaviours
- Task implementation is quite generic and can be reused for different setup

Perception framework

- Allows identification of nodules based on DL (YOLO network) and subsequent tracking
- Runs in real time on the embedded CPU boards
- Both the laser reconstruction of the nodule or a simpler stereo camera computation can be used for driving the LIBS sensor over the nodule

THANKS FOR YOUR ATTENTION