UNMANNED UNDERWATER VEHICLE SIMULATOR

ENABLING THE SIMULATION OF MULTI-ROBOT UNDERWATER MISSIONS WITH GAZEBO

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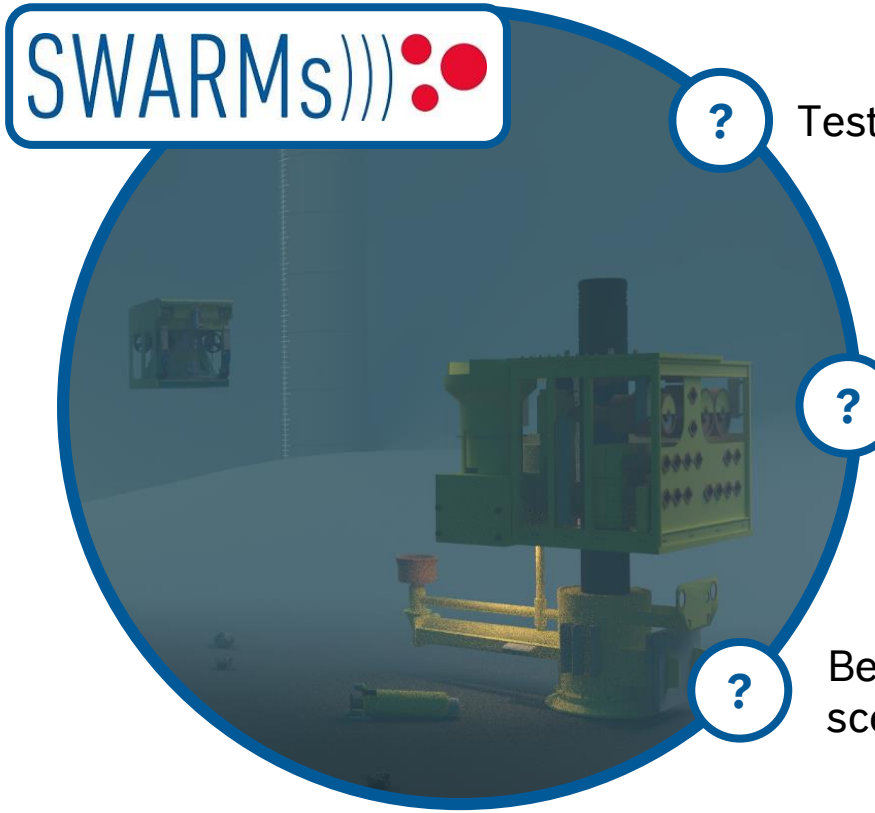
BOSCH

Motivation

EU-Project SWARMs (Smart and Networking Underwater Robots in Cooperation Meshes)



? Testing algorithms for underwater manipulation

? Planning missions strategies

? Behavior of the vehicles under different types of disturbances and failure scenarios

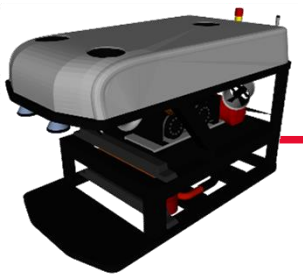
http://swarms.eu/

Motivation
Why use simulation?

- Mission with multiple underwater vehicles are expensive and time consuming
- Communication issue
  - Even in best case scenarios, acoustic communication with underwater vehicles is sparse
- Collision avoidance is still difficult, limited perception capabilities
- Difficult to repeat and/or reproduce certain missions in real life, such as plume tracking
- **Evaluation through simulation of the mission before deployment is crucial**

Vehicles from the 3rd SWARMs mission demonstration in Trondheim, Norway

Overview
UUV Simulator



Published on November 2016 on GitHub and still in development

Set of packages with Gazebo plugins and ROS modules to enable simulation of underwater vehicles

Simulation packages (Gazebo and ROS):
- `uuv_simulator`
- `uuv_plume_simulator`
- `uuv_manipulators`

Underwater vehicle packages:
- `eca_a9`
- `desistek_saga`
- `rexrov2`
- `lauv_gazebo`

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Overview

Some examples of plugins

Gazebo plugins

- Thruster plugin
- Fin plugin
- Underwater object plugin

Command and control

- Thruster manager
- Trajectory control

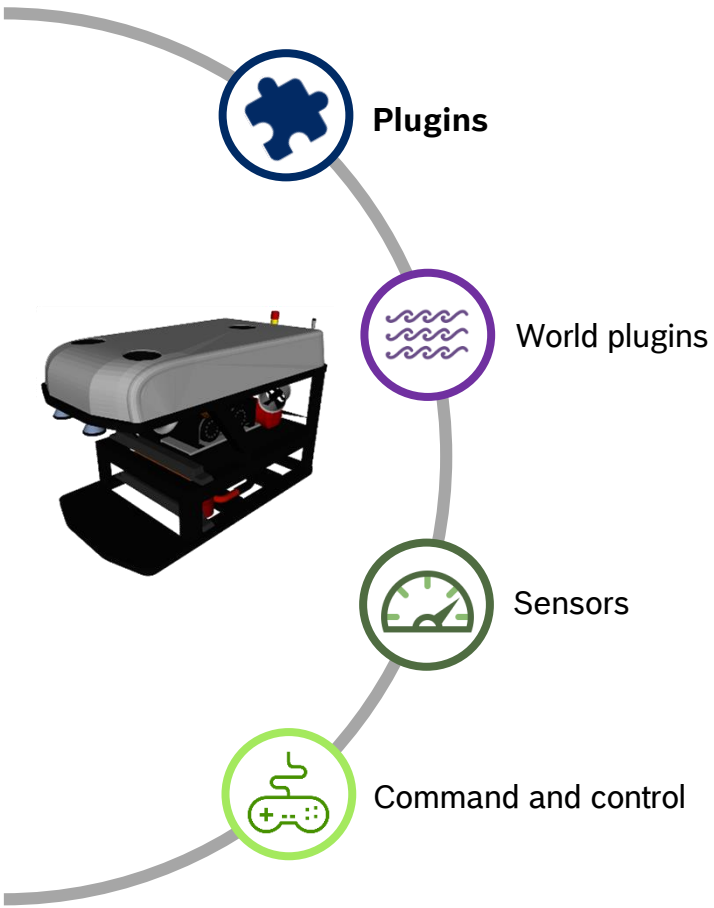
Gazebo sensor plugins

- Particle concentration sensor

World plugins

- Current velocity plugin
- Plume simulation

UUV Simulator



Underwater object plugin

$$(M_{RB} + M_A)\dot{\nu}_r + (C_{RB}(\nu_r) + C_A(\nu_r))\nu_r + D(\nu_r)\nu_r + g(\eta) + g_0 = \tau$$

Fossen's equation of motion for marine crafts [1]

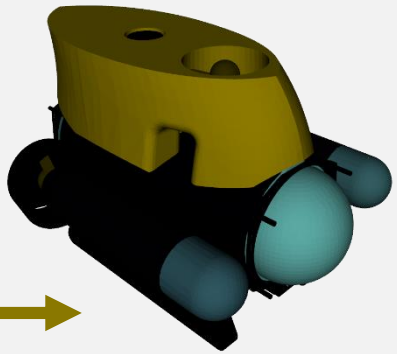
Provided by Gazebo's physics engine

$$M_{RB}\dot{\nu} + C_{RB}(\nu)\nu + g_0 = \tau_g + \tau_{contacts}$$

$$\tau_g = -M_A\dot{\nu}_r - C_A(\nu_r)\nu_r - D(\nu_r)\nu_r - g(\eta)$$

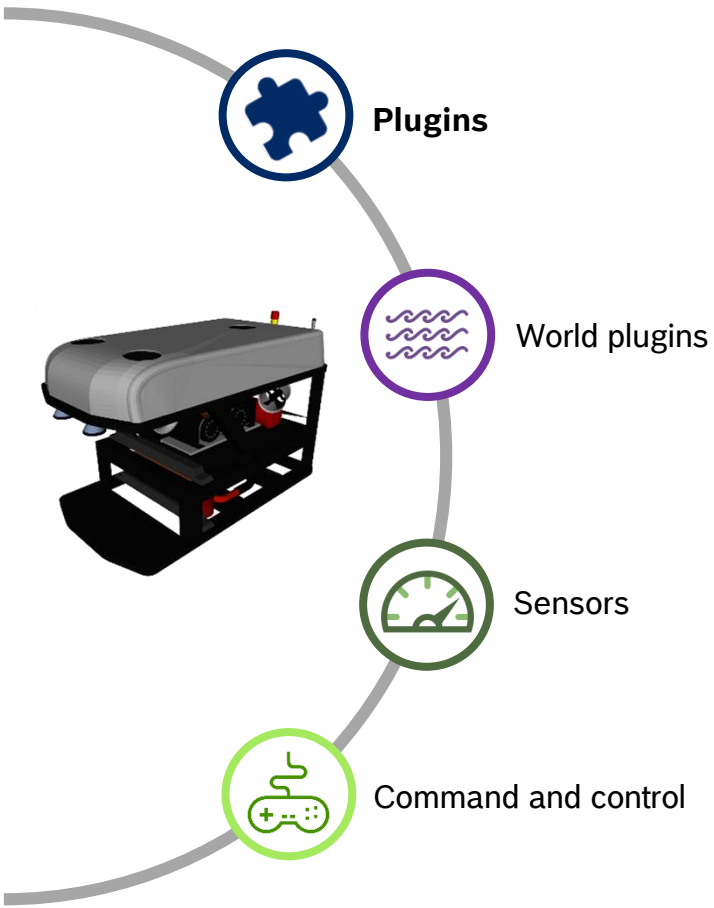
URDF

- Added-mass coefficients
- Linear and quadratic damping coefficients
- Volume
- Fluid density
- Center of buoyancy

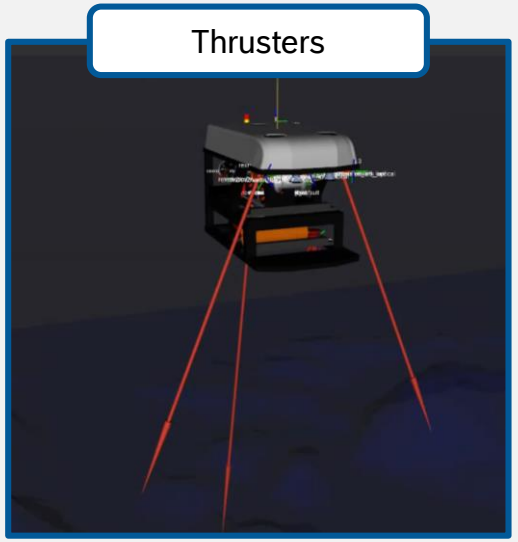


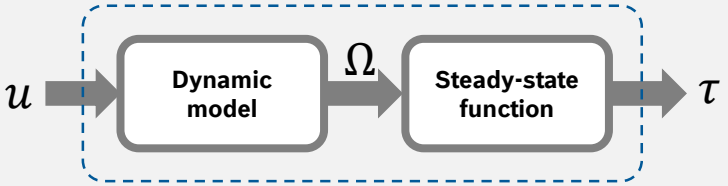
[1] Fossen, Thor I. *Handbook of marine craft hydrodynamics and motion control*. John Wiley & Sons, 2011.

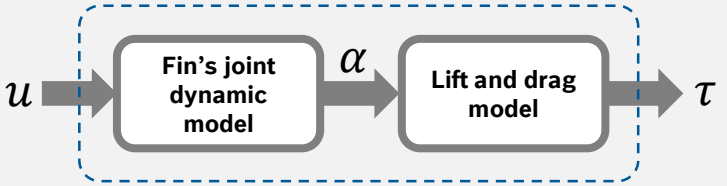
UUV Simulator



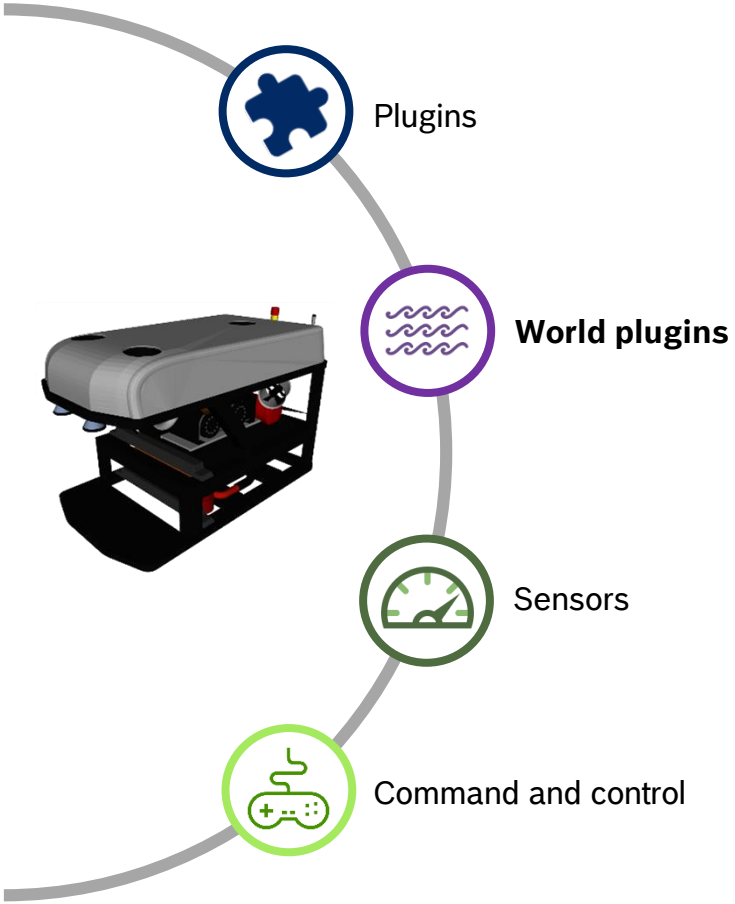
Thruster and fin plugins



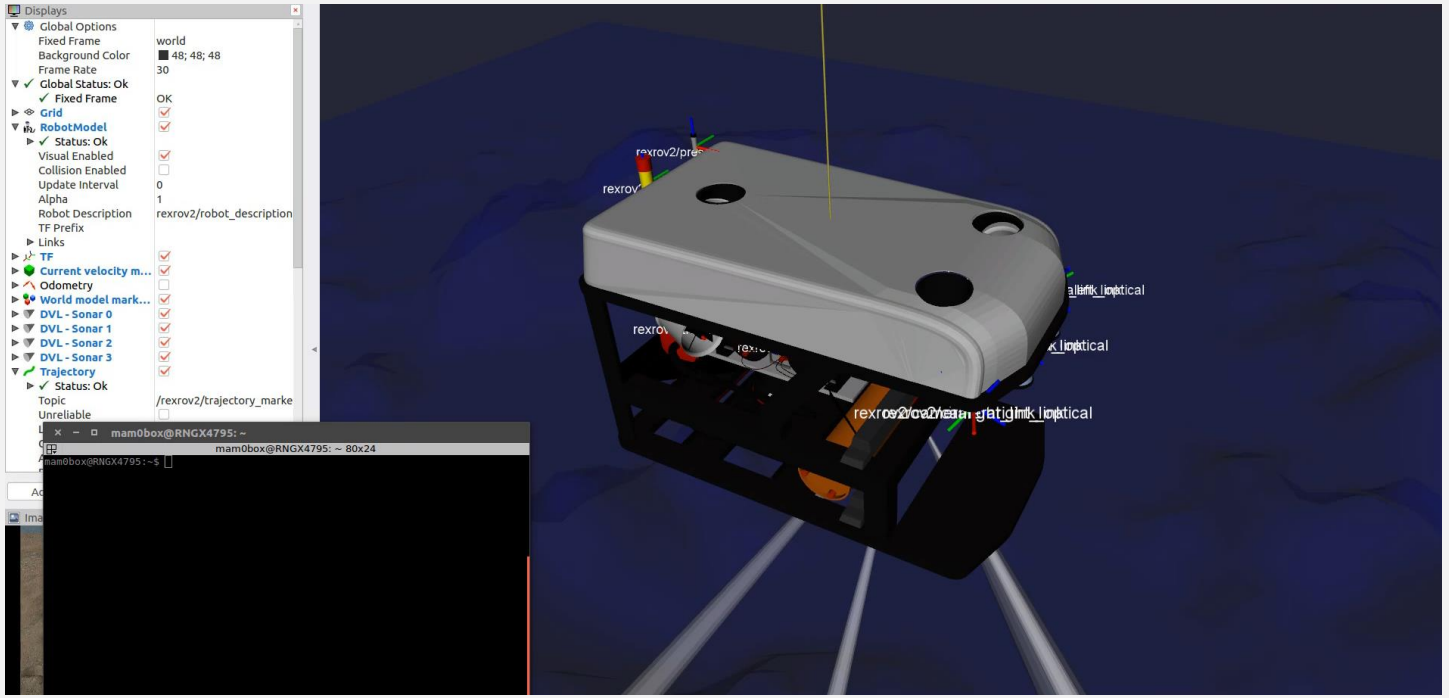




UUV Simulator



Current velocity



- Gazebo world plugin for generation of current velocity topics
- 3D current velocity
- Constant currents or based on Gauss-Markov processes
- Configurable through ROS services

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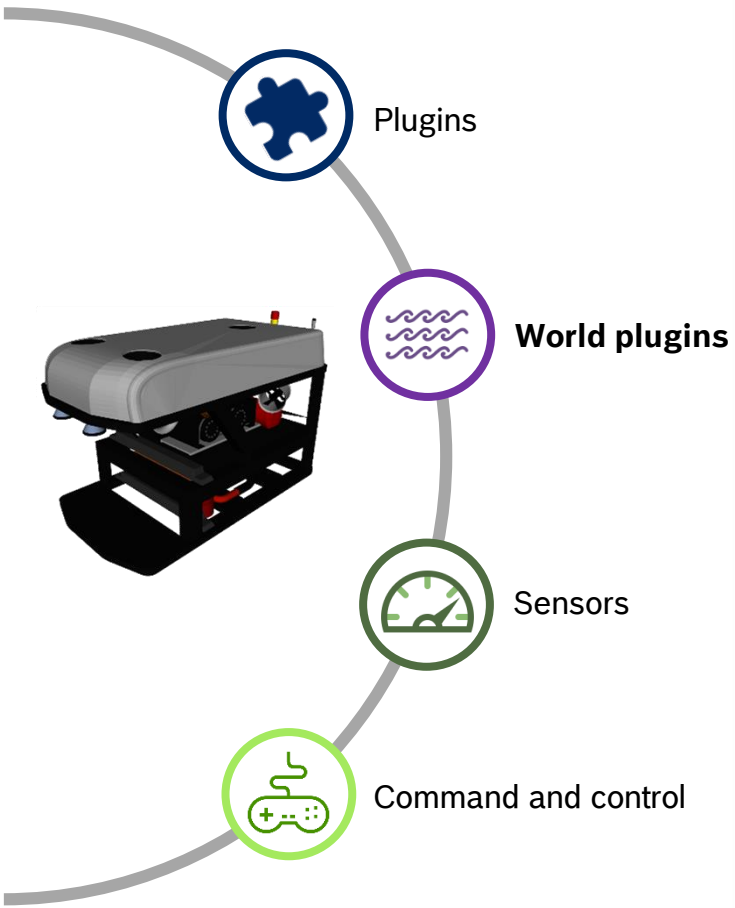
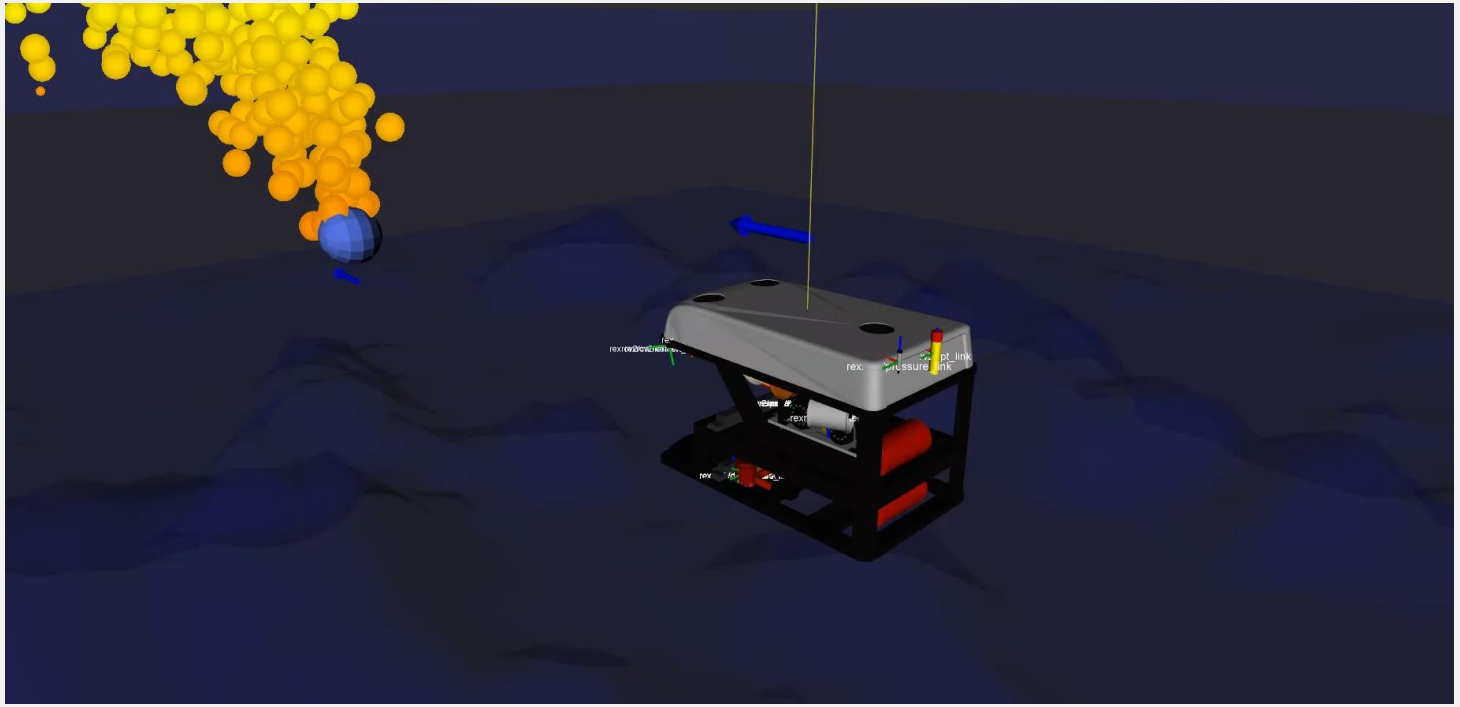
UUV Simulator



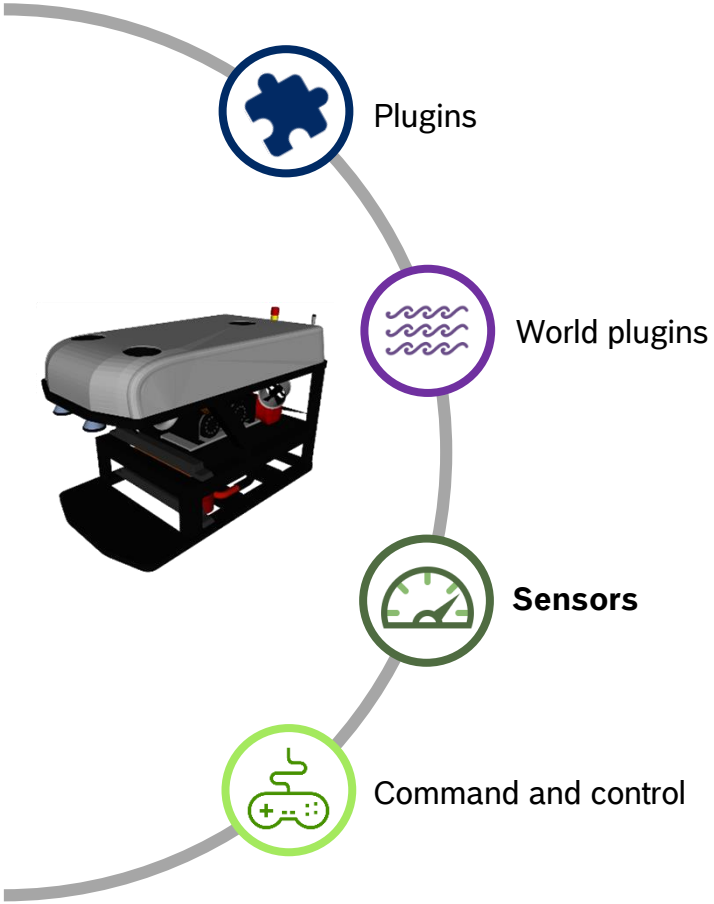
Plume simulator



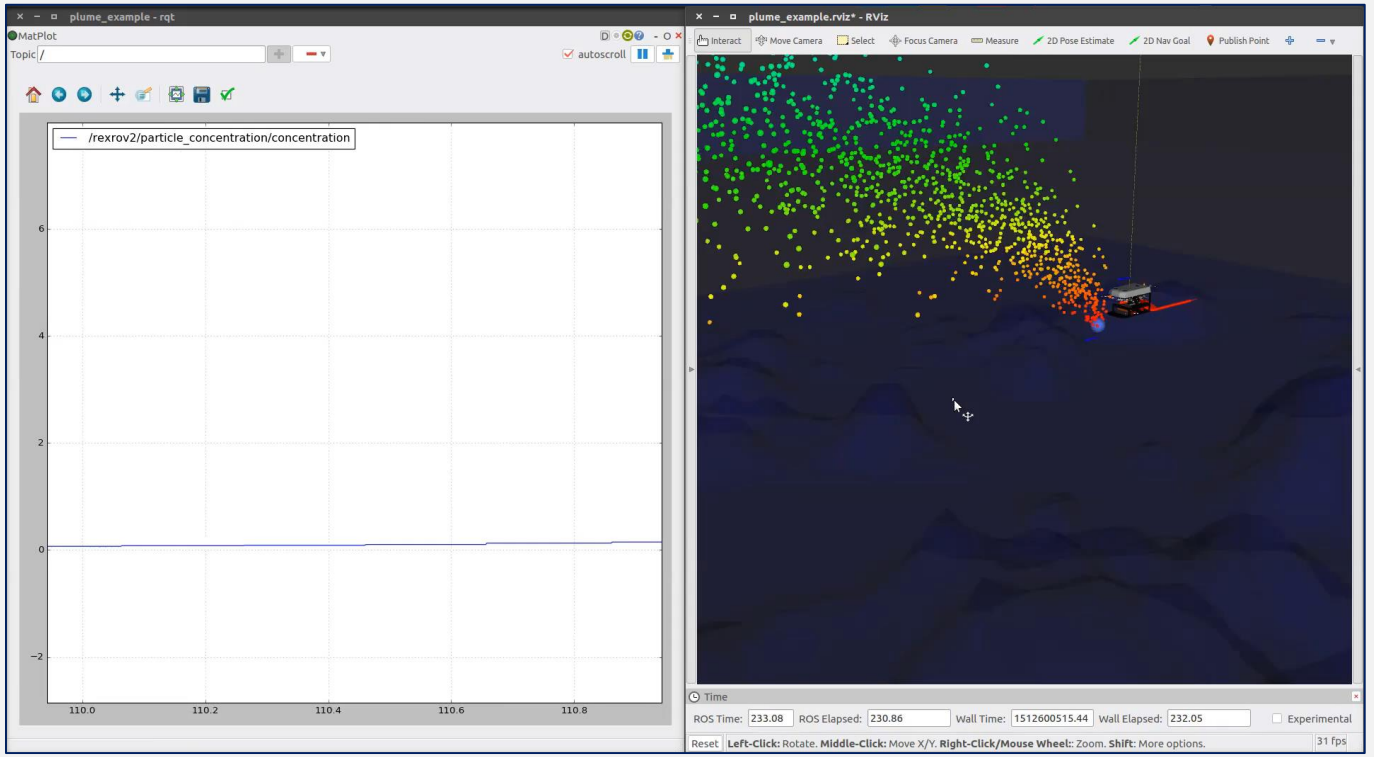
- Simulation of plume particles subject to current fields and buoyancy, and a particle concentration sensor based on [1]
- Implementation of a plume particle concentration sensor
- ROS package published in https://github.com/uuvsimulator/uuv_plume_simulator
- Used as a software in the loop component for the tests on motion planning for plume tracking algorithms on the real vehicle mission of the SWARMs project in Norway, June 2018

[1] Yu Tian and Aiqun Zhang, “Simulation environment and guidance system for AUV tracing chemical plume in 3-dimensions,” 2010 2nd International Asia Conference on Informatics in Control, Automation and Robotics (CAR 2010), Mar. 2010.

UUV Simulator
Sensors

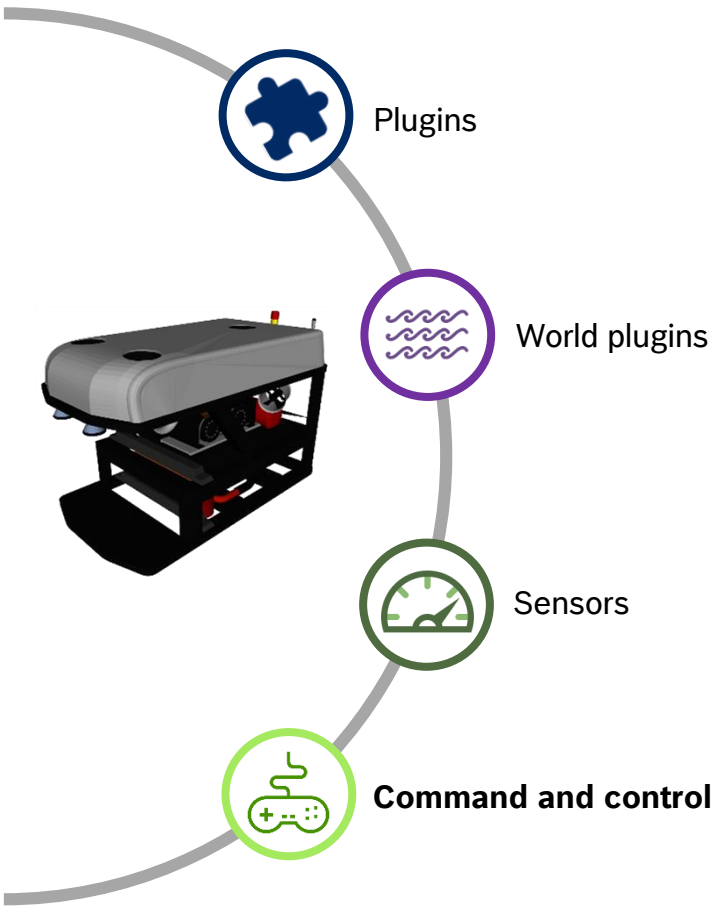


Particle concentration sensor

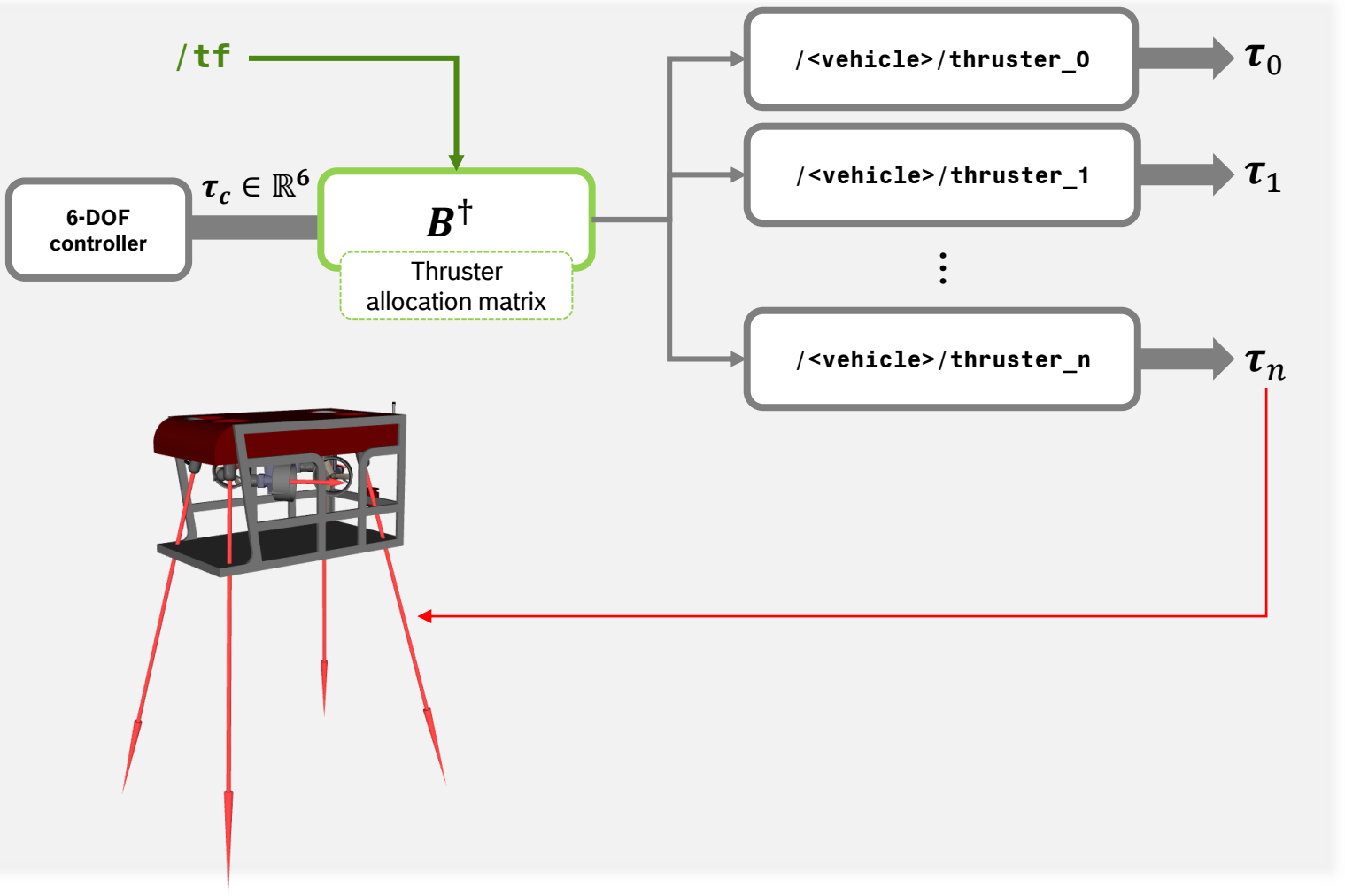


[1] Yu Tian and Aiqun Zhang, "Simulation environment and guidance system for AUV tracing chemical plume in 3-dimensions," 2010 2nd International Asia Conference on Informatics in Control, Automation and Robotics (CAR 2010), Mar. 2010.

UUV Simulator



Thruster manager



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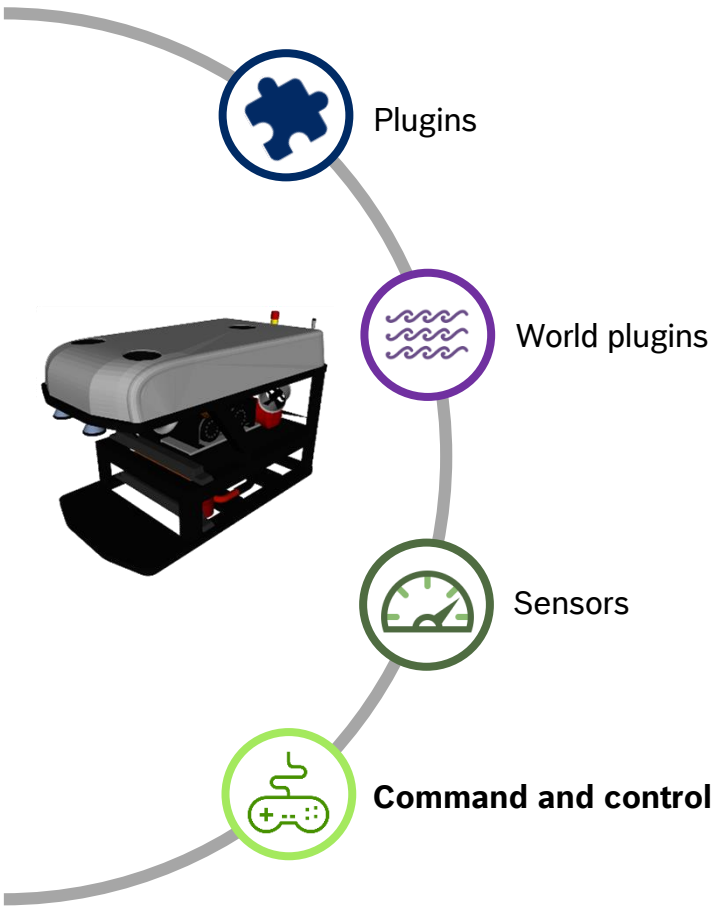
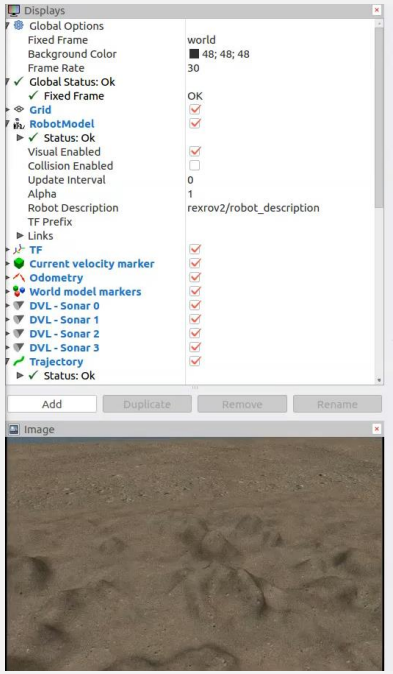
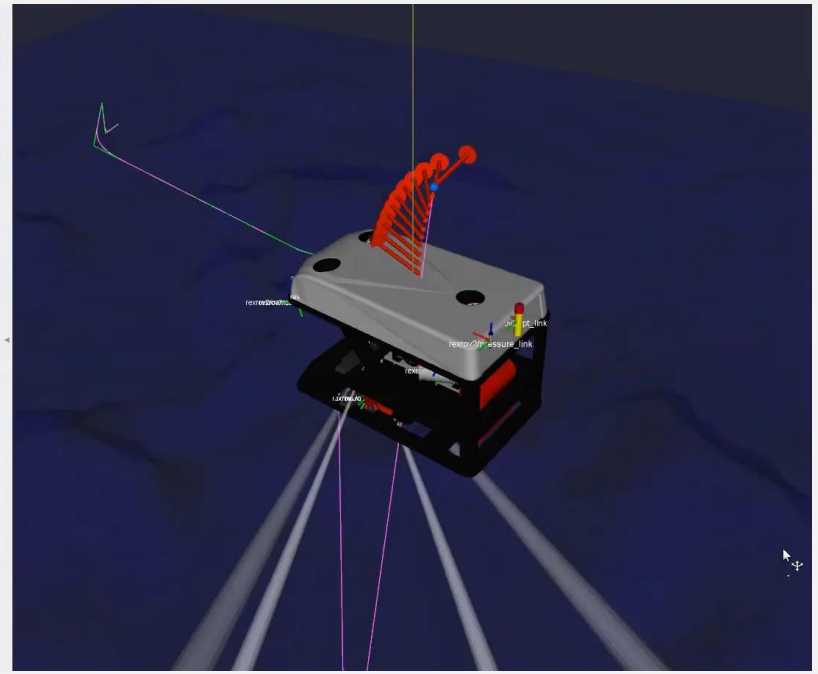
UUV Simulator



Trajectory control



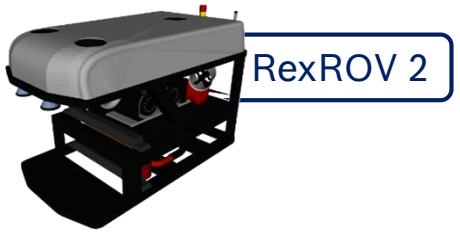


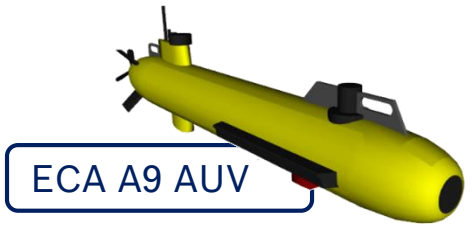
1. Trajectory tracking controllers for thruster actuated vehicles
   - Model-free sliding mode [1]
   - PID
   - PD with restoring forces compensation
   - Singularity-free trajectory controller [2]
2. For AUVs with control surfaces, a geometric PD-based controller is available
3. Python API for fast and easy development of new custom controllers
4. Waypoint interpolators for path generation, including
   - splines
   - linear interpolation with polynomial blends
   - Dubins path algorithm

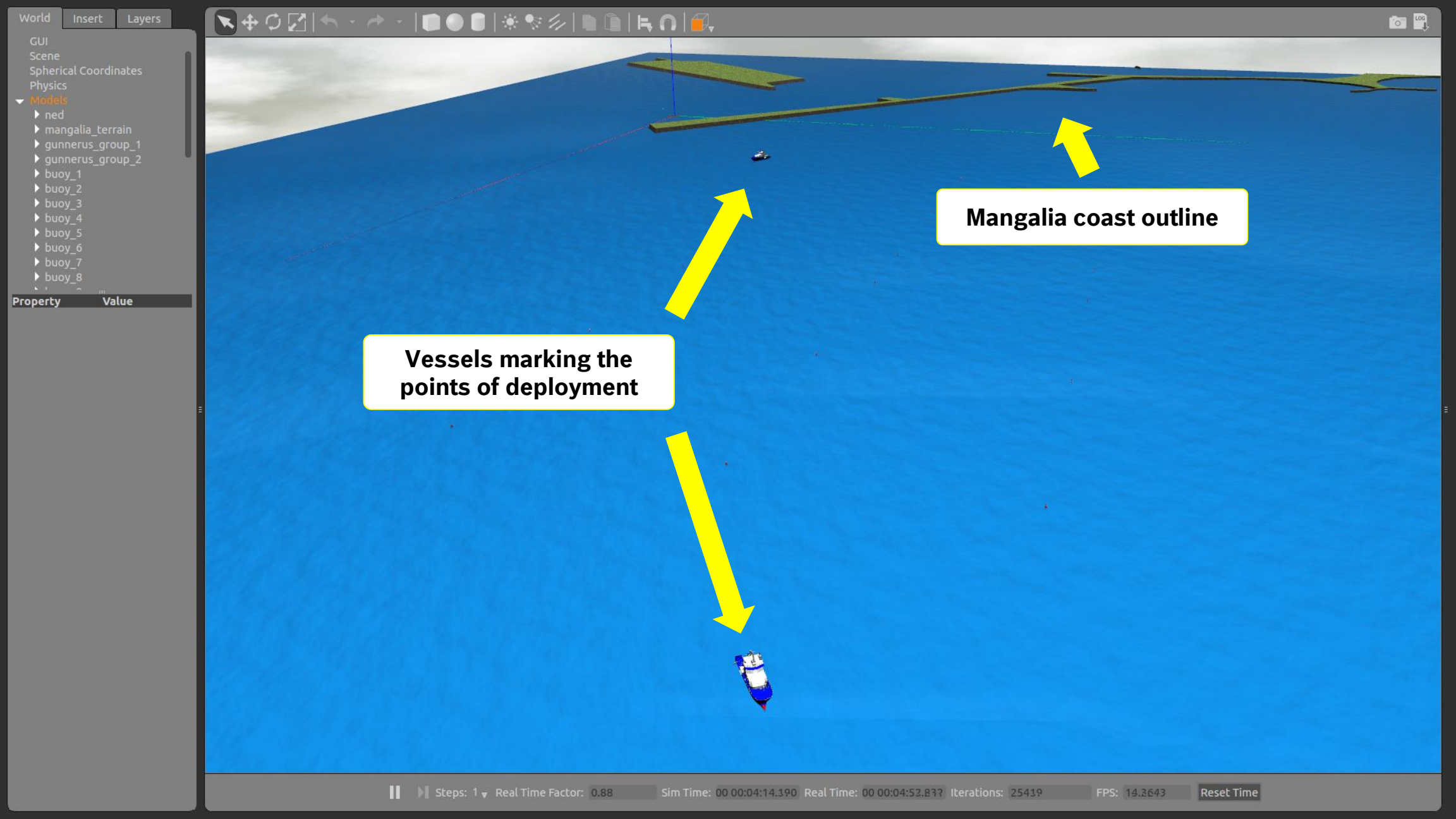
[1] L. G. García-Valdovinos et al., “Modelling, Design and Robust Control of a Remotely Operated Underwater Vehicle,” International Journal of Advanced Robotic Systems, vol. 11, no. 1, p. 1, Jan. 2014.
[2] O.-E. Fjellstad and T. I. Fossen, “Singularity-free tracking of unmanned underwater vehicles in 6 DOF,” Proceedings of 1994 33rd IEEE Conference on Decision and Control.

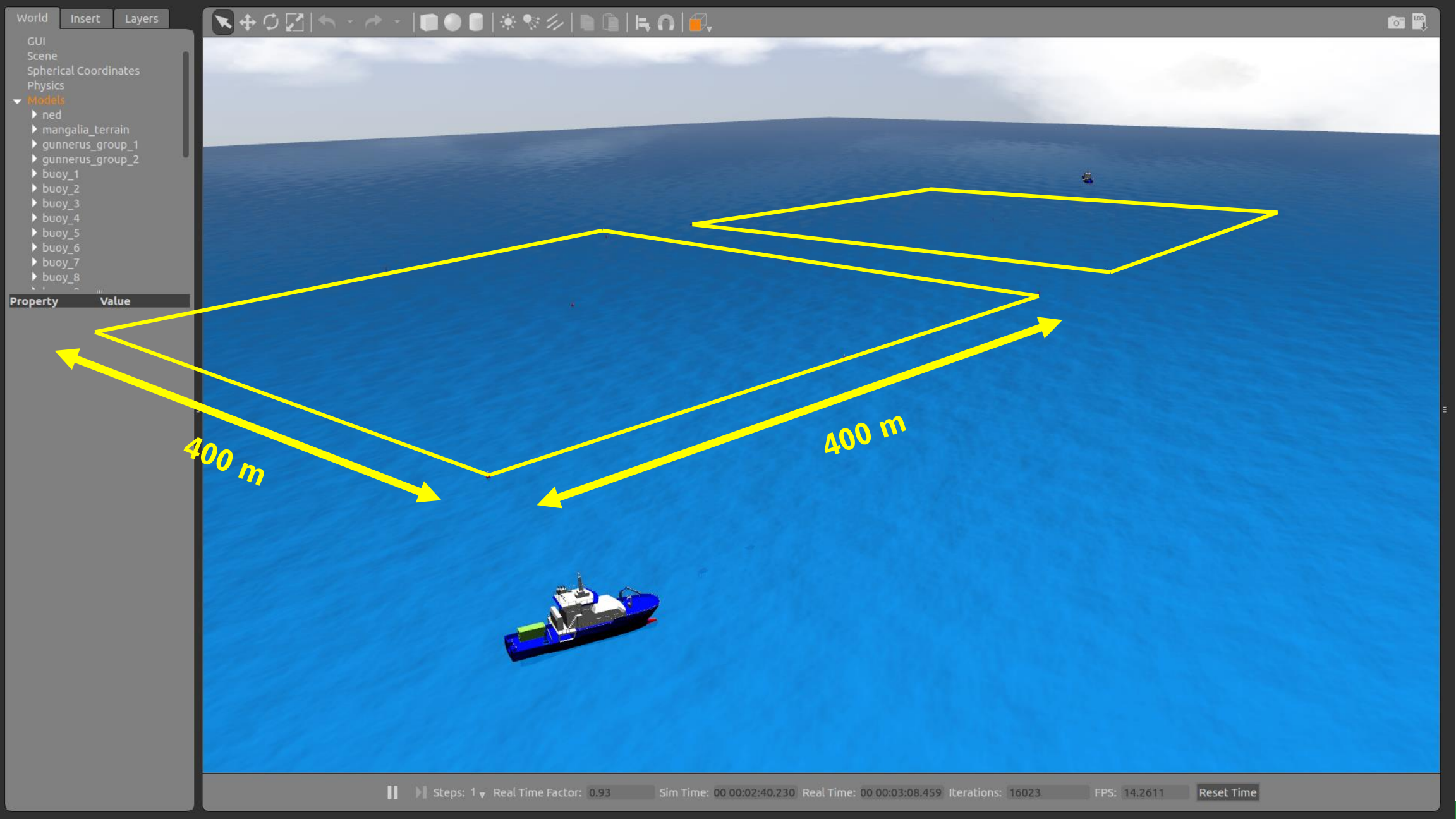
Use-cases
Cooperative seabed mapping

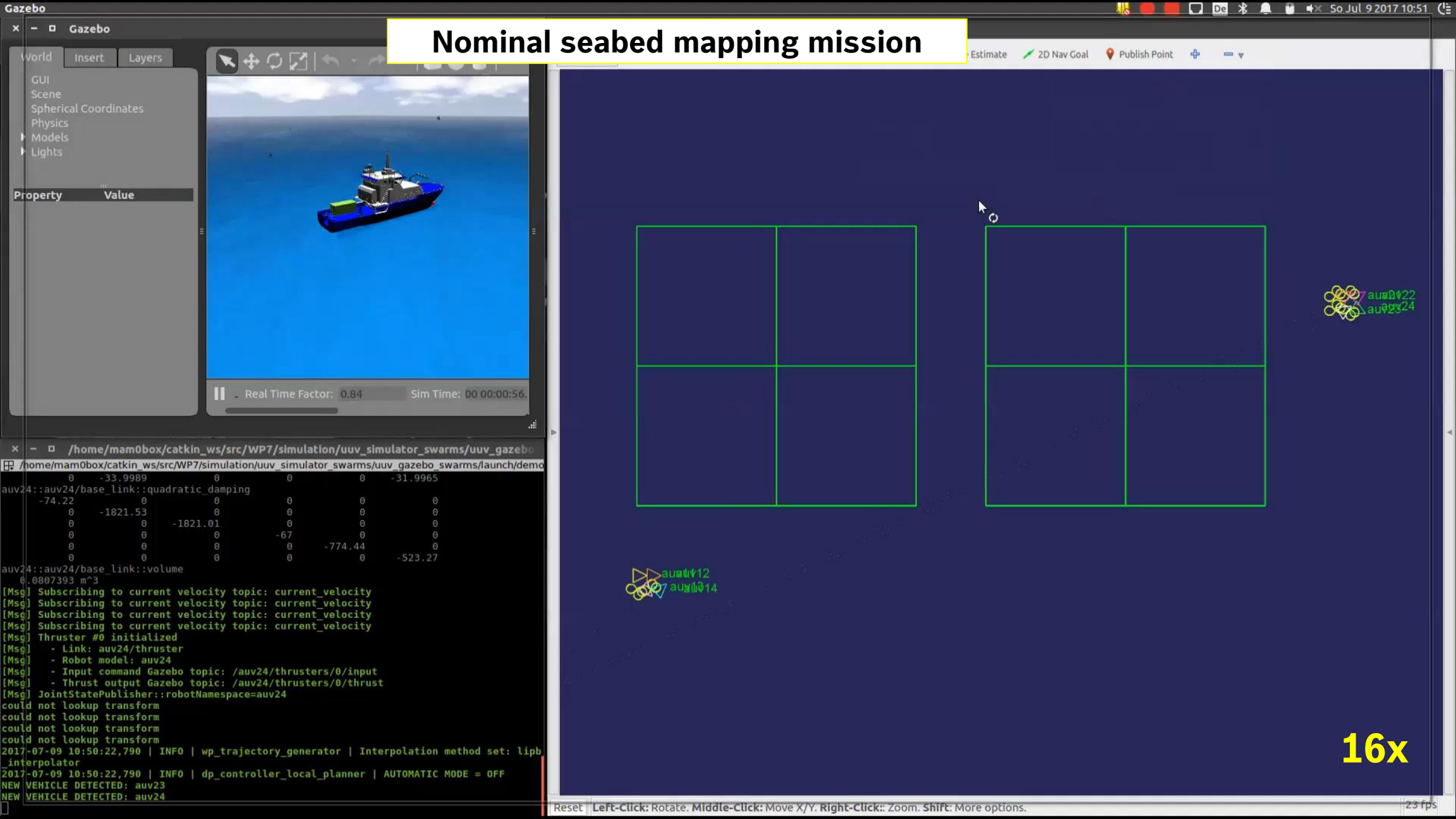
- 2nd SWARMs demonstration mission in Mangalia, Romania (2017)
- Description
  - Deployment of 8 underwater vehicles (6 AUVs and 2 ROVs) by the coast of Mangalia, Romania, for seabed mapping of a large area
- Objectives
  - Test the nominal mission for extraction of a seabed bathymetry map
  - Test the functionalities of the RSOA (Robot System Onboard Architecture, developed by ONERA) installed on each vehicle designed to detected abnormal situations and re-plan the mission accordingly, such as
    - Loss of power for thruster output
    - Sonar failure during the mission
- Vehicles:


RexROV 2

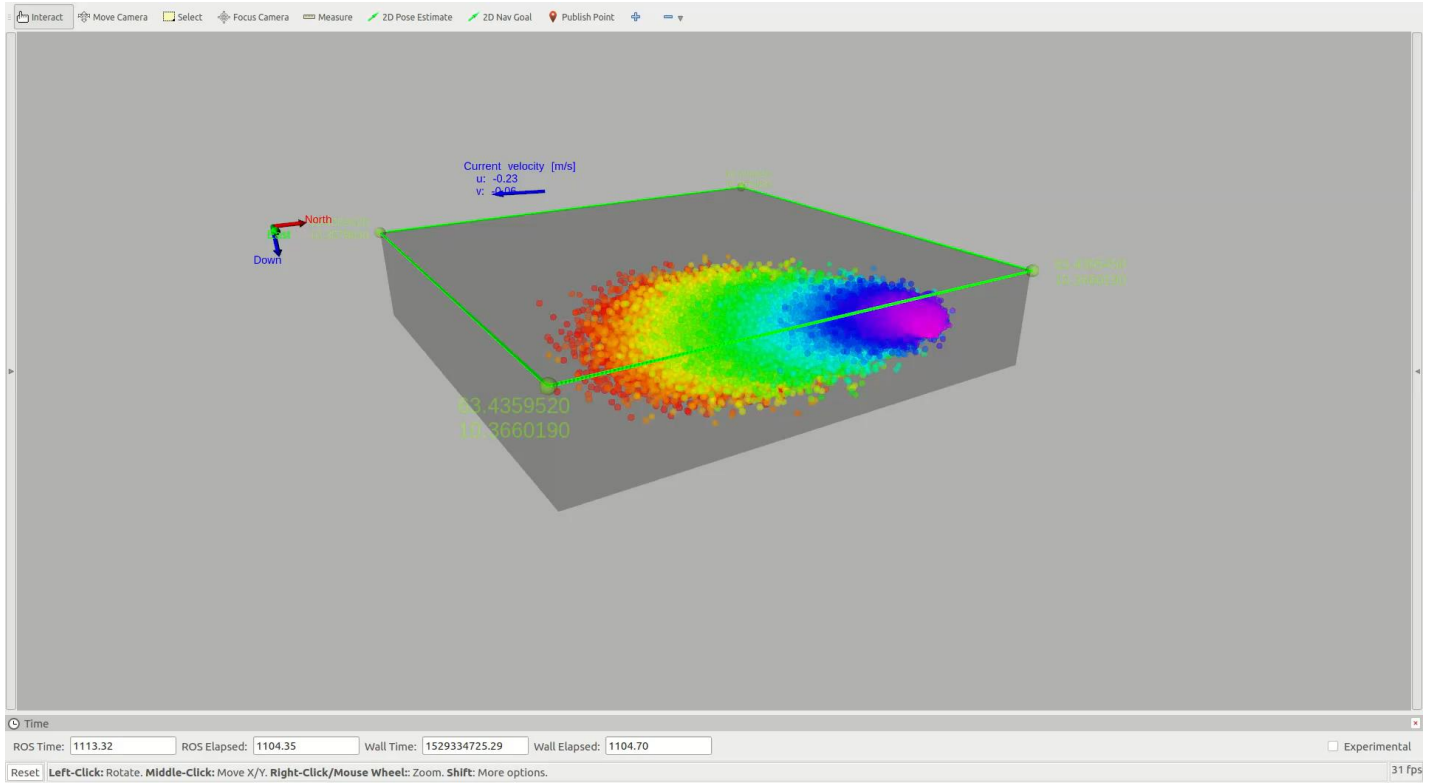

ECA A9 AUV


World
Insert
Layers
GUI
Scene
Spherical Coordinates
Physics
Models
ned
mangalia_terrain
gunnerus_group_1
gunnerus_group_2
buoy_1
buoy_2
buoy_3
buoy_4
buoy_5
buoy_6
buoy_7
buoy_8
Property
Value
Mangalia coast outline
Vessels marking the points of deployment
Steps: 1
Real Time Factor: 0.88
Sim Time: 00 00:04:14.190
Real Time: 00 00:04:52.833
Iterations: 25419
FPS: 14.3643
Reset Time

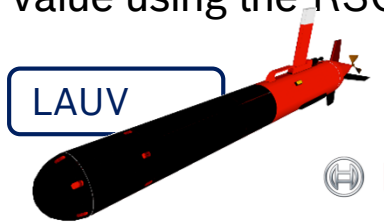

World
Insert
Layers
GUI
Scene
Spherical Coordinates
Physics
Models
ned
mangalia_terrain
gunnerus_group_1
gunnerus_group_2
buoy_1
buoy_2
buoy_3
buoy_4
buoy_5
buoy_6
buoy_7
buoy_8
Property
Value
400 m
400 m
Steps: 1
Real Time Factor: 0.93
Sim Time: 00 00:02:40.230
Real Time: 00 00:03:08.459
Iterations: 16023
FPS: 14.2611
Reset Time

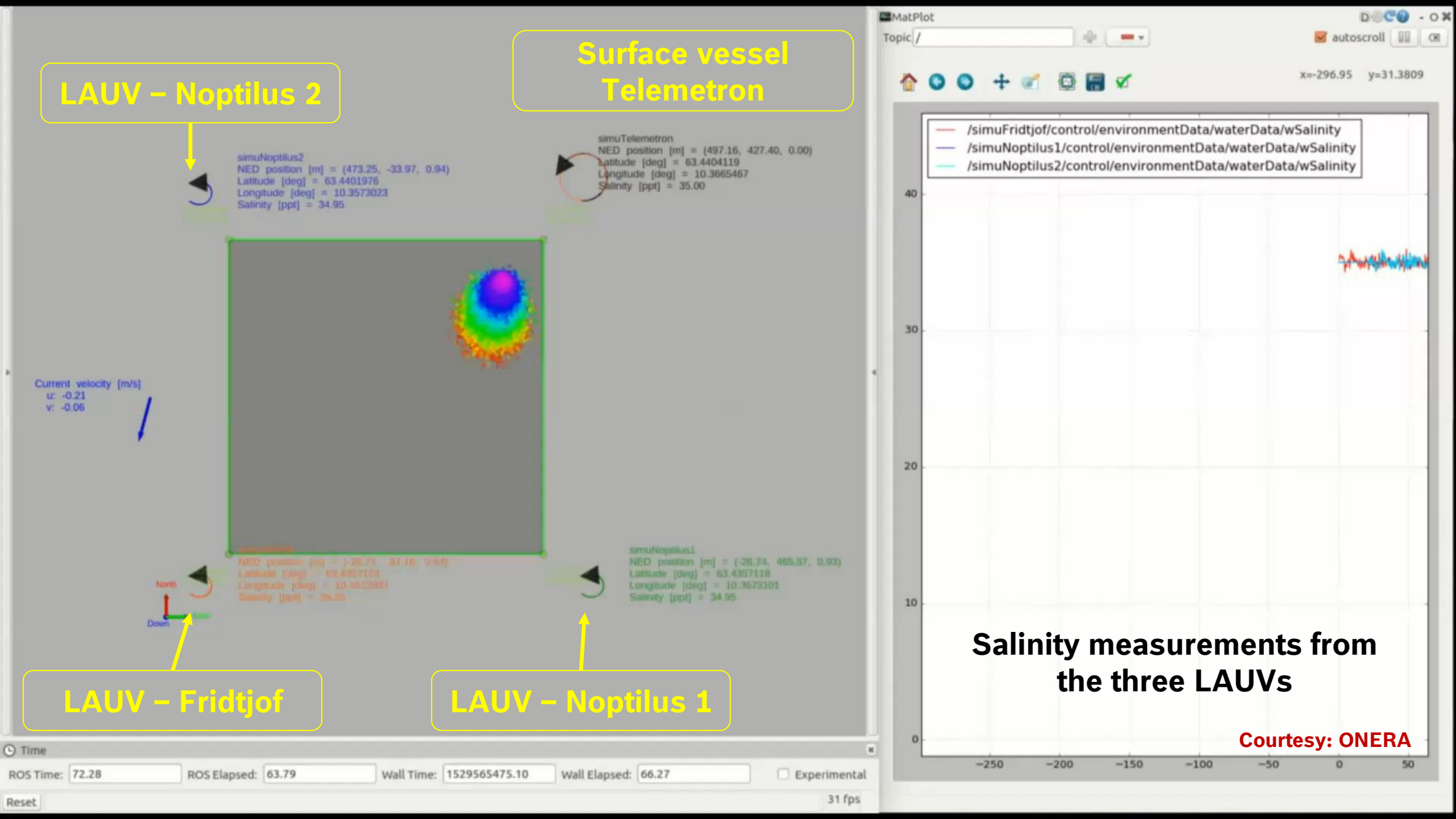

Gazebo
So Jul 9 2017 10:51
Gazebo
Nominal seabed mapping mission
World
Insert
Layers
GUI
Scene
Spherical Coordinates
Physics
Models
Lights
Property
Value
Real Time Factor: 0.84
Sim Time: 00 00:00:56.
Estimate
2D Nav Goal
Publish Point
/home/mam0box/catkin_ws/src/WP7/simulation/uuv_simulator_swarms/uuv_gazebo
/home/mam0box/catkin_ws/src/WP7/simulation/uuv_simulator_swarms/uuv_gazebo_swarms/launch/demo
0 -33.9989 0 0 0 -31.9965
auv24::auv24/base_link::quadratic_damping
-74.22 0 0 0 0 0
0 -1821.53 0 0 0 0
0 0 -1821.01 0 0 0
0 0 0 -67 0 0
0 0 0 0 -774.44 0
0 0 0 0 0 -523.27
auv24::auv24/base_link::volume
0.0807393 m^3
[Msg] Subscribing to current velocity topic: current_velocity
[Msg] Subscribing to current velocity topic: current_velocity
[Msg] Subscribing to current velocity topic: current_velocity
[Msg] Subscribing to current velocity topic: current_velocity
[Msg] Thruster #0 initialized
[Msg] - Link: auv24/thruster
[Msg] - Robot model: auv24
[Msg] - Input command Gazebo topic: /auv24/thrusters/0/input
[Msg] - Thrust output Gazebo topic: /auv24/thrusters/0/thrust
[Msg] JointStatePublisher::robotNamespace=auv24
could not lookup transform
could not lookup transform
could not lookup transform
could not lookup transform
2017-07-09 10:50:22,790 | INFO | wp_trajectory_generator | Interpolation method set: lipb
_interpolator
2017-07-09 10:50:22,790 | INFO | dp_controller_local_planner | AUTOMATIC MODE = OFF
NEW VEHICLE DETECTED: auv23
NEW VEHICLE DETECTED: auv24
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click:: Zoom. Shift: More options.
23 fps
16x

Use-cases
Fresh water plume tracking



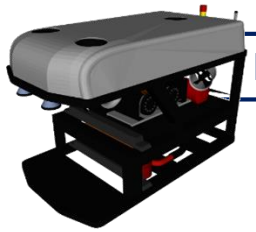
- 3rd SWARMs demonstration mission in Trondheim, Norway (2018)
- Description
  - Deploy multiple AUVs in different depths to find and track a fresh water plume at the Trondheim Fjord in Trondheim, Norway
- Objectives
  - Test maneuver strategies to track the plume as efficiently as possible using the variations of salinity value using the RSOA
- Vehicle:



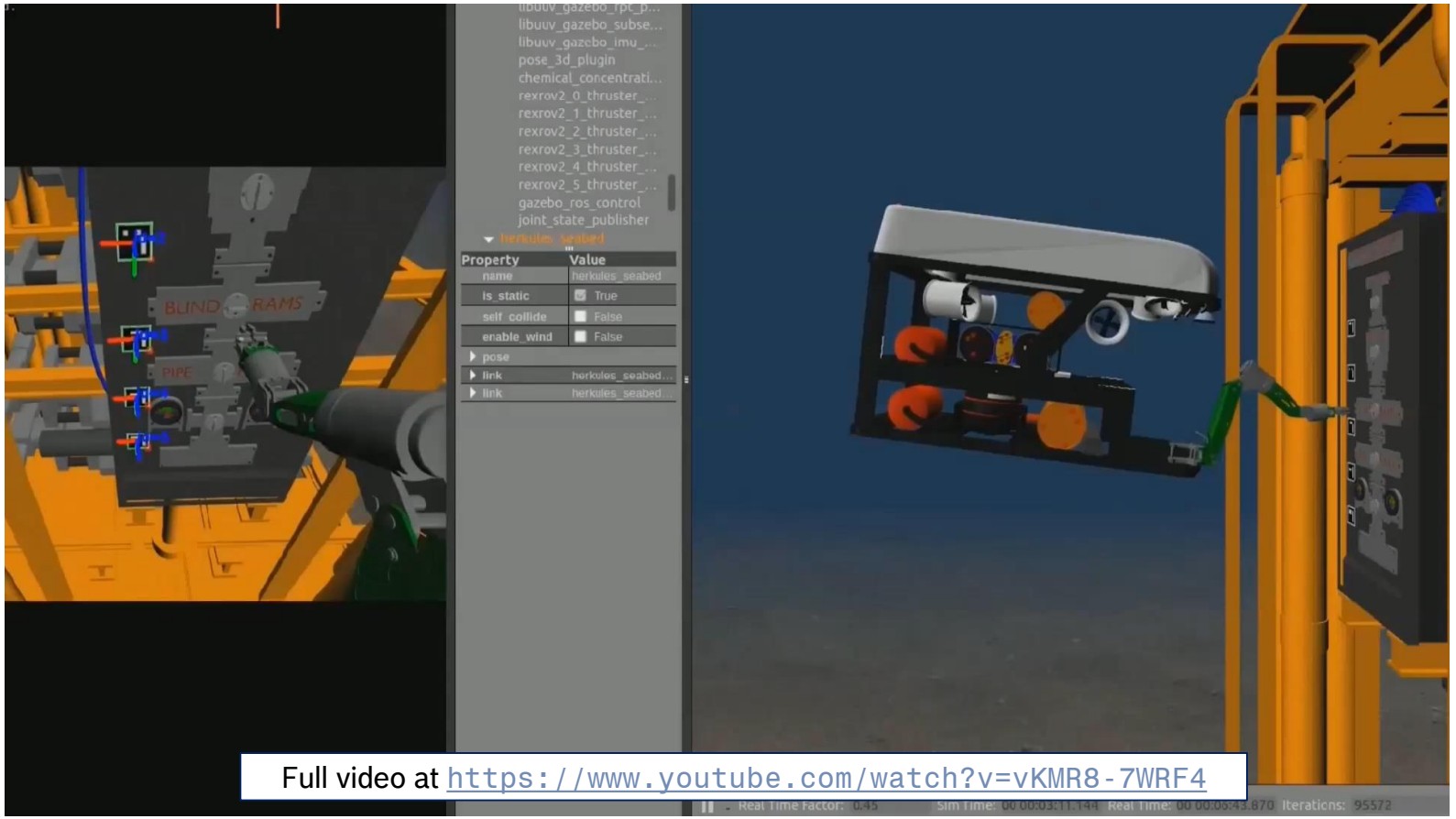

LAUV – Noptilus 2
Surface vessel
Telemetron
simuNoptilus2
NED position [m] = (473.25, -33.97, 0.94)
Latitude [deg] = 63.4401976
Longitude [deg] = 10.3573023
Salinity [ppt] = 34.95
simuTelemetron
NED position [m] = (497.16, 427.40, 0.00)
Latitude [deg] = 63.4404119
Longitude [deg] = 10.3665467
Salinity [ppt] = 35.00
Current velocity [m/s]
u: -0.21
v: -0.06
simuNoptilus1
NED position [m] = (-26.74, 465.57, 0.93)
Latitude [deg] = 63.4357118
Longitude [deg] = 10.3673101
Salinity [ppt] = 34.95
North
Down
LAUV – Fridtjof
LAUV – Noptilus 1
Time
ROS Time: 72.28
ROS Elapsed: 63.79
Wall Time: 1529565475.10
Wall Elapsed: 66.27
Experimental
Reset
31 fps
MatPlot
Topic /
autoscroll
x=-296.95 y=31.3809
/simuFridtjof/control/environmentData/waterData/wSalinity
/simuNoptilus1/control/environmentData/waterData/wSalinity
/simuNoptilus2/control/environmentData/waterData/wSalinity
40
30
20
10
0
−250
−200
−150
−100
−50
0
50
Salinity measurements from the three LAUVs
Courtesy: ONERA

Use-cases
Camera-assisted underwater manipulation

- 3rd SWARMs demonstration mission in Trondheim, Norway (2018)
- Description:
  - Showcase the possibility of using visual markers to assist the on the control of position and orientation of the end-effector to turn valves on a panel
- Vehicle:



RexROV 2



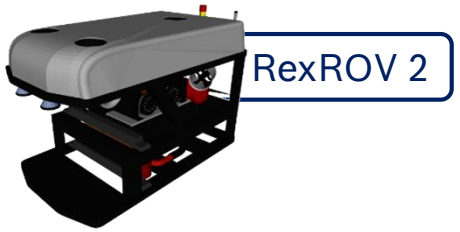
Full video at https://www.youtube.com/watch?v=vKMR8-7WRF4

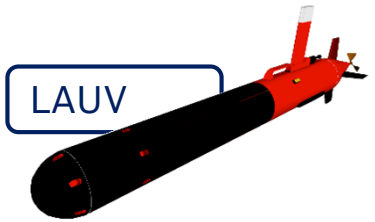
Future steps

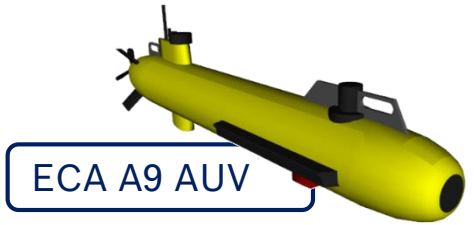
- The UUV simulator project will be continued still as an open-source project after the SWARMs project is over
- Improvement of sensor plugins, specially acoustic-based
- Improve the scenarios (underwater visual effects)
- Improve the underwater manipulation packages

Important links

- UUV Simulator's documentation: https://uuvsimulator.github.io/
- UUV Simulator: https://github.com/uuvsimulator/uuv_simulator
- Underwater vehicle packages:
  - Desistek SAGA ROV: https://github.com/uuvsimulator/desistek_saga
  - ECA A9 AUV: https://github.com/uuvsimulator/eca_a9
  - RexROV 2: https://github.com/uuvsimulator/rexrov2
  - LAUV: https://github.com/uuvsimulator/lauv_gazebo
- Plume simulator: https://github.com/uuvsimulator/uuv_plume_simulator







Acknowledgments

- Robert Bosch GmbH
  - Sebastian Scherer
  - Luiz Ricardo Douat
  - Thomas Winkler

- SWARMs project partners
  - Vehicle parameters, meshes (ECA A9 AUV and Desistek SAGA ROV)
  - Feedback
  - Pull requests
  - Bug reports

- Contributors on GitHub

THANK YOU

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