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Scalable full-cycle marine litter remediation in the Mediterranean: Robotic and participatory solutions

SeaClear2.0

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D3.6
Integrated System Hardware Trials Report
WP3 – *Hardware Upgrade*

Grant Agreement no. 101093822

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Deliverable description	This report describes the trials of the integrated hardware, conducted at Subsea Tech seaside facilities in Marseille, Fraunhofer CML facilities in Hamburg and UNIDU facilities in Dubrovnik. The objective was to verify that all hardware interactions (mechanical, electronic, communication) were operational. A real piece of litter (car tire) pick-up was undertaken, in teleoperated mode, to validate this integration.

1 R = Document, report, DEM = Demonstrator, OTHER = Software, technical diagram, etc., DMP = Data Management Plan

2 PU = Public, C-UE/EU-C = EU Confidential under Decision 2015/444, SEN = Sensitive

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Nico ZANTOPP	20/12/2024	V0.3	Addition of CML contribution
Yves CHARDARD	21/12/2024	V1.0	Contributions integration and final draft
Stefan SOSNOWSKI, Yves CHARDARD	24/12/2024	V1.1	Final version after last review

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Definitions

- **Beneficiary:** A legal entity that is signatory of the EC Grant Agreement no. 101093822.
- **Consortium:** The SeaClear2.0 Consortium, comprising the list of beneficiaries below.
- **Consortium Agreement:** Agreement concluded amongst the SeaClear2.0 beneficiaries for the implementation of the Grant Agreement.
- **Grant Agreement:** The agreement signed between the beneficiaries and the EC for the undertaking of the SeaClear2.0 project (Grant Agreement no. 101093822).

Beneficiaries of the SeaClear2.0 Consortium are referred to herein according to the following abbreviations:

- **TU Delft**: TECHNISCHE UNIVERSITEIT DELFT
- **DUNEA**: REGIONALNA AGENCIJA DUNEA
- **Fraunhofer**: FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
- **HPA**: HAMBURG PORT AUTHORITY
- **ISOTECH**: ISOTECH LTD
- **MDanchor**: M. DANCHOR LTD
- **Subsea Tech**: SUBSEA TECH SAS
- **TECNOSUB**: TÉCNICAS Y OBRAS SUBACUÁTICAS, SLU
- **TUM**: TECHNISCHE UNIVERSITAET MUENCHEN
- **UNIDU**: SVEUCILISTE U DUBROVNIKU
- **UTC**: UNIVERSITATEA TEHNICA CLUJ-NAPOCA
- **VEO**: VEOLIA PROPRETE
- **VLPF**: VENICE LAGOON PLASTIC FREE

Abbreviations

- **CAD:** Computer-aided Design
- **EC**: European Commission
- **WP**: Work Package
- **UAV:** Uncrewed Aerial Vehicle
- **ROV:** Remotely Operated underwater Vehicle
- **USV:** Uncrewed Surface Vehicle
- **LARS** : Launch And Recovery System
- **USBL** : Ultra Short BaseLine

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Executive summary

This deliverable reports on the tests undertaken by the project team to validate the proper integration of the hardware components of the SeaClear2.0 system.

To minimize transportation time and costs, tests were conducted at 3 different sites: Marseille for the SeaCAT USV + the Mini Tortuga ROV, the DJI drone and the grapple, Hamburg for the Sea Dragon USV and Dubrovnik for the surface litter collection USVs. This was possible because there is no physical link between the main system and the latter two. The core functionality of the systems could be validated independently and the interaction of the systems does not depend on specific interfaces. The exception was the docking operation of the SeaDragon on the SeaCAT, but a mock-up of the SeaCAT stern was built for the Hamburg tests.

The whole system will be brought together for May 25, 2025 trials in Hamburg and extra time will be provided ahead of the demo to validate the global system operation.

The trials were conducted very efficiently at all 3 sites, with only minor issues being quickly resolved on site, and the final day in Marseille saw the rapid recovery of a car tire, demonstrating that the system hardware was operational.

The trials were conducted with some delay due to the late delivery of the SeaCAT USV following the shipyard bankruptcy, but ultimately the trials were completed in week 50 and WP3 was generally completed on time, in line with the SeaClear2.0 Description of Activities (DoA).

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1. Introduction

1.1 SeaClear2.0 at a glance

SeaClear2.0 is the next step to the H2020-funded SeaClear (https://seaclear-project.eu), where several of the SeaClear2.0 partners have been developing the first autonomous robotic system for seafloor litter collection. An uncrewed surface vehicle (USV) called SeaCAT acts as a hub for an uncrewed aerial vehicle (UAV) that searches for litter from the air and contributes to situational awareness, an observation uncrewed underwater vehicle (ROV) called Mini-Tortuga that searches for litter underwater, and a collection ROV called Tortuga that collects the litter with a custom gripper-plus-suction device and deposits it in a basket lowered from the USV. The very nature of SeaClear (labelled SeaClear 1.0 in this document) as the first project to design such a solution means it must focus almost exclusively on technological developments in robotics hardware and algorithms, with a single system.

Moreover, the system is limited to only seafloor litter of up to tens of cm in size and at depths of up to tens of meters; it cannot collect surface litter or larger objects like fishing equipment, bikes, e-scooters, tires, shipping equipment, etc. The aim of SeaClear2.0 is to upscale and upgrade the system initially made for SeaClear 1.0. This means collecting bigger and heavier litter with a modified SeaCAT and a smart grapple, storing and shipping it to shore with a dedicated USV Tender, as well as collecting surface litter with a USV and a team of highly manoeuvrable surface robots. In the end, SeaClear 1.0 and SeaClear2.0 will be working together, exploiting their shared and complementary litter detection and collection capabilities.

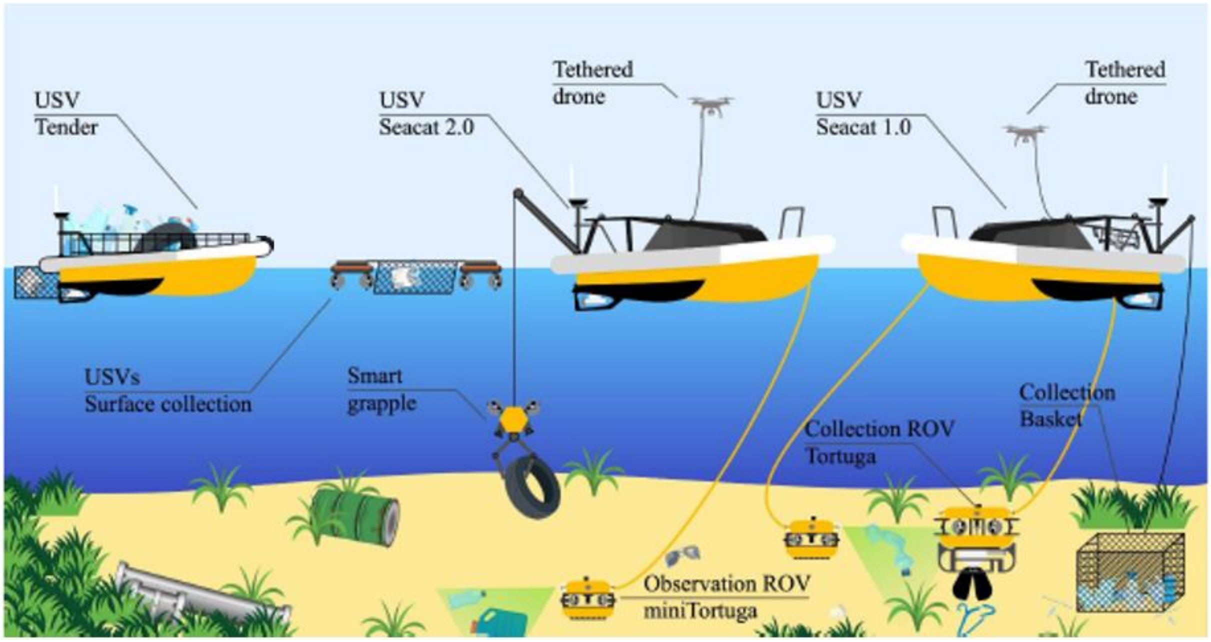

Figure 1: Concept of SeaClea 2.0 robotic system (left/middle) and SeaClear 1.0 (right)

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1.2 Deliverable objective

The primary objective of this deliverable is to report on the trials undertaken after the hardware integration of the following components:

- Grapple/SeaCat USV
- Obs ROV mini Tortuga/SeaCat USV
- UAV DJI /SeaCat USV
- + 2 stand-alone systems: USV SeaDragon for litter transfer to shore and micro-USVs for surface litter collection.

1.3 System overview

The SeaClear2.0 system includes one main USV, SeaCAT, which supports an observation ROV mini-Tortuga and its LARS at the bow, a captive DJI Matrice 210 UAV and its winch on top of the ROV LARS and a lifting frame with a 300 m cable and a 250 kg lifting capacity grapple at the stern.

Figure 2: Overview of the SeaClear2.0 hardware system tested in Marseille.

The system also includes the SeaDragon USV which transfer the litter to the shore and two micro-USVs with a collecting net for the surface litter, see pictures below.

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Figure 3: Shuttle tender SeaDragon USV tested in Hamburg

Figure 4: Surface litter collection system tested in Dubrovnik.

Detailed hardware design of each robotic component is available through the dedicated deliverables:

- D3.1 USV hardware design report
- D3.2 Smart grapple design report
- D3.3 Shuttle tender USV hardware design report

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- D3.4 Floating litter collection systems design report

TECHNICAL SPECIFICATIONS

VESSEL

MAIN FEATURES

Type	Twin hull catamaran, aluminium
Dimensions	L 6.83 m x B 3.1 m x H 2.15 m
Weight	1200 kg without payload
Payload capacity	250 kg
Max. speed	6 knots
Draught	0.73 m (empty), 0.90m with max payload
Max. sea state	3 (operation), 5 (transit)
Communication	Wifi / 2.4GHz radio / LTE
Endurance	Up to 10 days at 2 knots

GRAPPLE

MAIN FEATURES

Dimensions	L 0.7 m x B 0.7 m x H 1.2 m
Weight	78 kg (in air), neutrally buoyant in water
Lift capacity	250 kg
Max. operating depth	300 m
Max. object width	1.25 m x 1.25 m
Grabbing force	250N - 1920N (configuration dependent)
Maximum speed	0.8s open to close

TENDER

MAIN FEATURES

Type	Twin hull catamaran, fiberglass
Dimensions	L 5.5 m x W 2 m x H 2.5 m
Weight	280 kg
Propulsion	2 electric azimuth thrusters, 6kW
Payload capacity	350 kg
Communication	Wifi / 2.4GHz radio / LTE
Draught	0.3 m
Endurance	10 h at 2 kts, 2h at 9 kts
Operational sea state	4 Beaufort

Figure 5: SeaClear2.0 main components specifications as presented in the product data sheet

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2. Hardware sea trials

2.1 Marseille trials

The SeaCAT USV, the mini ROV Tortuga and its LARS, the captive drone DJI Matrice 210 RTK, and the motorised grapple with its lifting frame were integrated and tested during weeks 49 and 50 at Subsea Tech facilities in the harbour of Marseille.

Figure 6: Subsea Tech facilities in Marseille Harbour

In week 48, on its arrival from the painting shop, the SeaCAT USV was equipped with its lateral floatation tubes and then brought inside the workshop to complete the electronics integration and the mounting of the propulsion system.

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Figure 7: Installing the floatation tubes each side of the hull on Friday 13th

Monday 16th and Tuesday 17th were used to complete SeaCAT electronic integration and to allow TUM and UNIDU teams to unpack, tune and test their respective equipment, i.e. the UAV and the grapple.

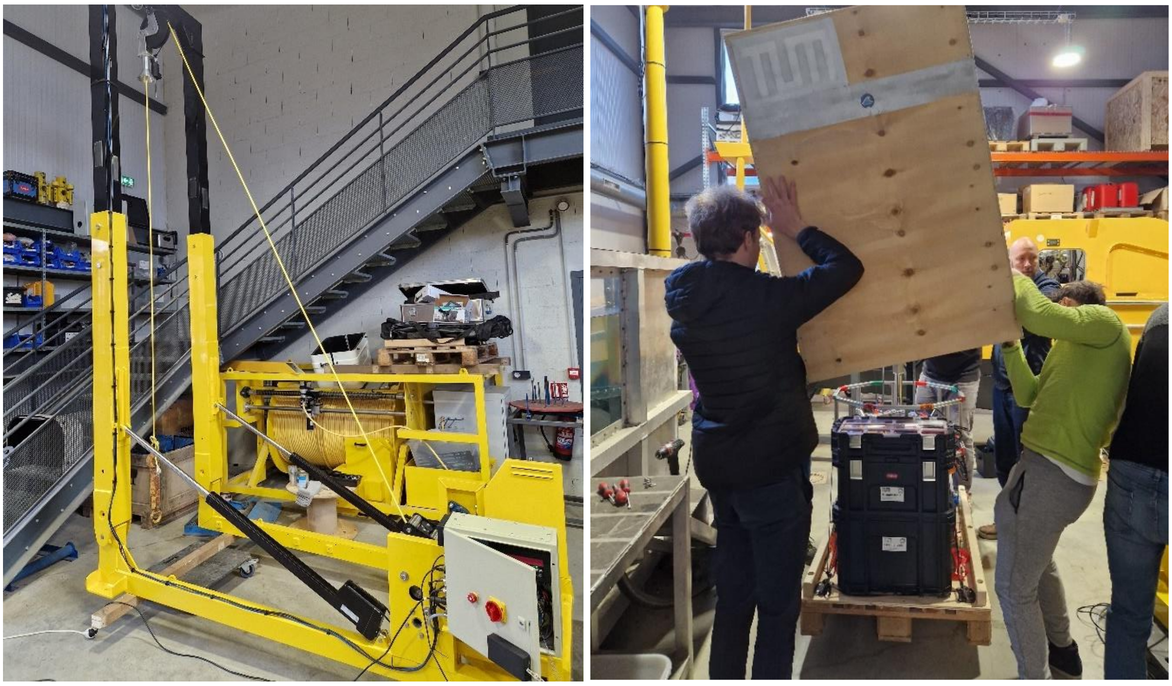

Figure 8: Grapple LARS testing and grapple unpacking on Monday 16th

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Figure 9: UAV preparation in workshop and testing on car park by UNIDU team on Monday 16th

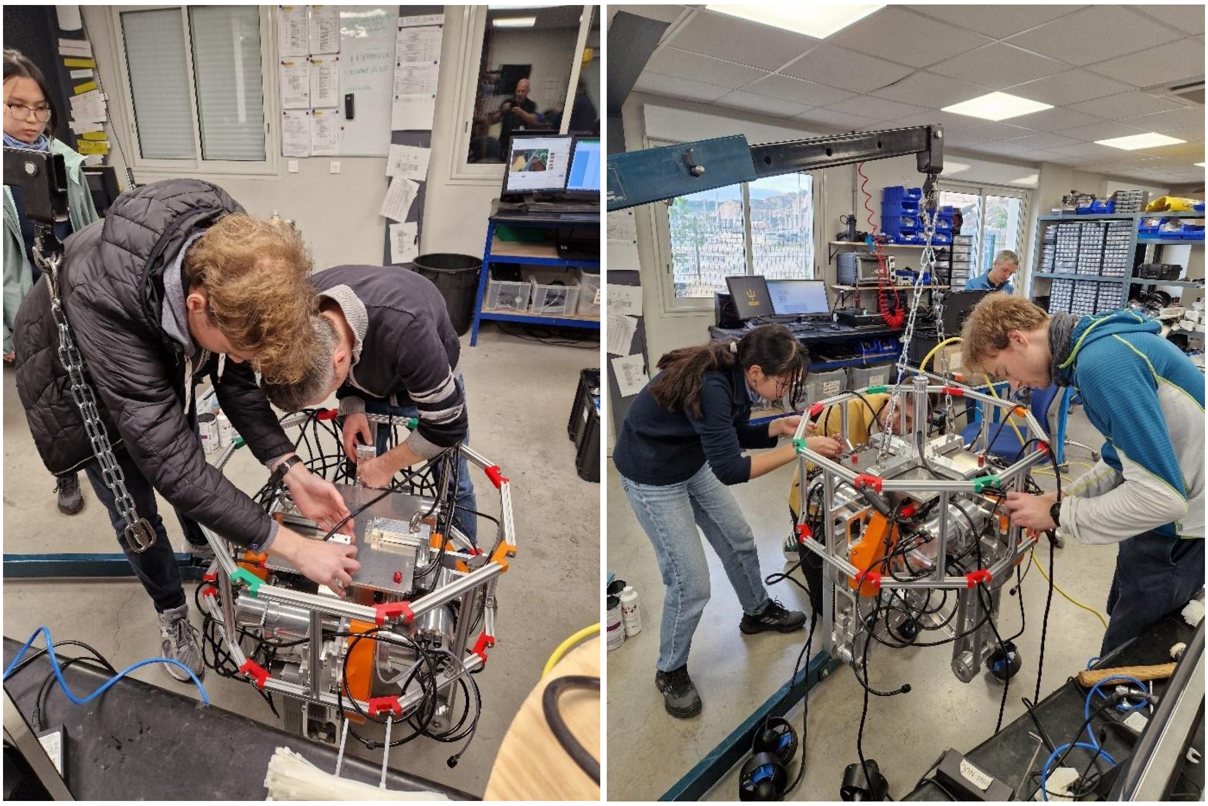

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Figure 10: Final calibration and tuning of grapple for TUM team on Tuesday 17th

Figure 11: UAV platform & winch mounted on ROV LARS and grapple frame mounted on SeaCAT on Wednesday 18th

On Wednesday late afternoon, the SeaCAT was driven to the nearby Corbières marina to lift in water. SeaCAT stayed there overnight, ready for early morning operations.

On Thursday 19th, the control station was set-up directly on the quay side, enjoying a sunny and warm day.

Figure 12: Control station set-up on the quay side and preparation of grapple installation

UAV automated take-off and landing were successfully undertaken along quay and the grapple was attached to its umbilical and lifted onboard SeaCAT. Functional tests with tilting frame and grapple opening/closing were conducted to check system operation before submersion.

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Figure 13: UAV tests above water and grapple connection to lifting frame.

The USV was then positioned over a car tire spotted by the ROV and the grapple was lowered manually to reach the target. After adjusting the position thanks to its embedded propulsions system, the grapple grabbed the tire in a few seconds, although the tire was half buried in thick sediments.

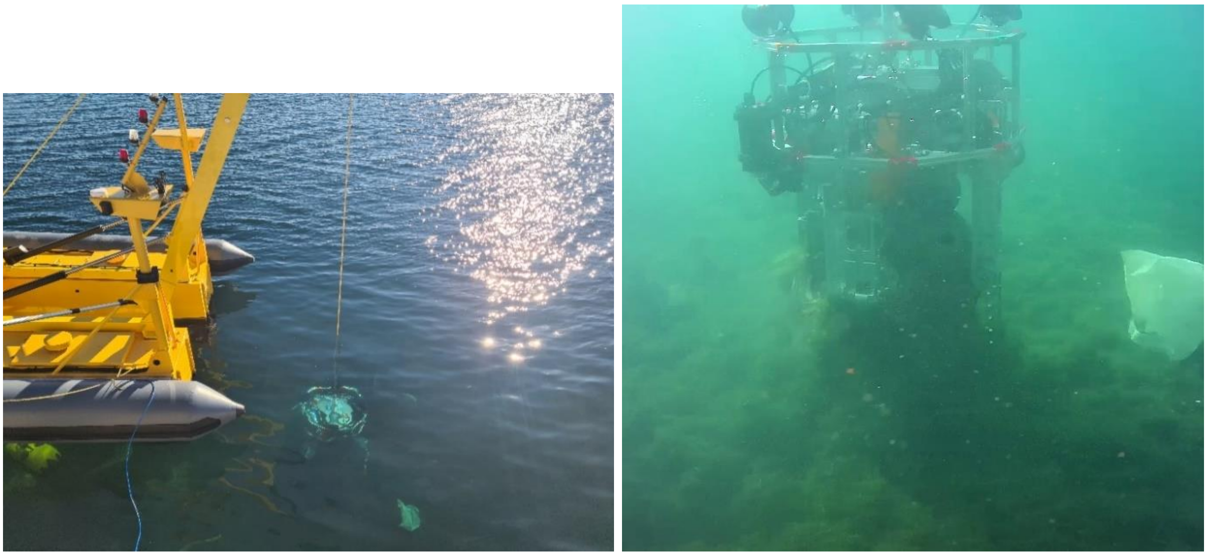

Figure 14: SeaCAT positioned over the target and tire grabbing filmed by the ROV

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Figure 15: Tire lifted out of the water and last UAV flight from the SeaCAT in the channel

All equipment was then demobilised on Thursday evening, SeaCAT brought back to Subsea Tech facilities, and grapple, ROV and UAV secured inside Subsea Tech premises.

Both UNIDU and TUM teams left Marseille on Friday morning after having packed their respective equipment.

A debrief meeting was held on Friday and following outstanding issues were highlighted:

- UAV and winch: no outstanding issue, the system has been working as per its nominal performances during the whole trials.
- ROV and LARS: no major issue, the system has been working fine during the whole trials. However, we need to lengthen the LARS cable harness to accommodate the new electronic compartment hatch design.
- SeaCAT: few minor hardware remaining works, planned to be completed before mid-January 2025:
    - Install hatch pneumatic jacks
    - Change the battery 125A breaker for a ON/OFF switch
    - Complete the air-cooling unit cabling and duct routing

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    - Complete the fuel transfer pump cable routing and modify software to accommodate both ways pumping (starboard to portside tank and vice-versa)
    - Complete bow thrusters low level control software adjustments
    - Reconfigure grapple pulley force sensor to avoid inconsistent values and check proximity sensor (broke down during trials)
    - Optimise grapple winch motor controller programming for low-speed mode
    - Check fuel gauges cabling (inconsistent values)
- Grapple: few minor hardware remaining works, planned to be completed until end of February 2025:
    - Detected a ground connection in the electronics box, which could lead to accelerated corrosion. Minor isolation works in the box will solve this.
    - Minor leaks were detected in the pre-checks on Tuesday before submersion and fixed immediately. Check and rework some of the sealing surfaces on the electronics box to prevent additional potential leaks.
    - Modify the electrical startup sequence for thruster speed controllers to prevent voltage fluctuations if more than four thrusters are installed
    - Install buoyancy foam
    - Install final cage rings instead of the interim solution
    - Check belt tensioning and maximum load transfer again (slippage during high load situation when grabbing the tire, in-situ fixed with automatic recalibration)
    - Add some more protective covers on belts and other grapple parts to ensure functionality under adverse conditions

2.2 Hamburg trials

The integration trials of SeaDragon into the overall system has occurred at multiple levels. Initially, the systems were integrated into a CAD model. After verification, the system was transferred to a simulation environment. Subsequently, a demonstrator of SeaCAT was built, which will be used for further testing.

<u>CAD Integration</u>

The first phase of the integration process focused on incorporating both SeaDragon and SeaCAT into a comprehensive CAD model using Autodesk Inventor. By adding both ships into the CAD environment, we were able to analyze the physical interface between the two vessels. This integration was crucial to ensure that all mechanical aspects of the docking procedure were accurately represented. One of the significant adjustments made during this phase was modifying the width of SeaDragon, as the initial dimensions of SeaDragon did not align with the docking interface of SeaCat. This adjustment ensured compatibility during docking operations, allowing for a seamless connection between the two ships.

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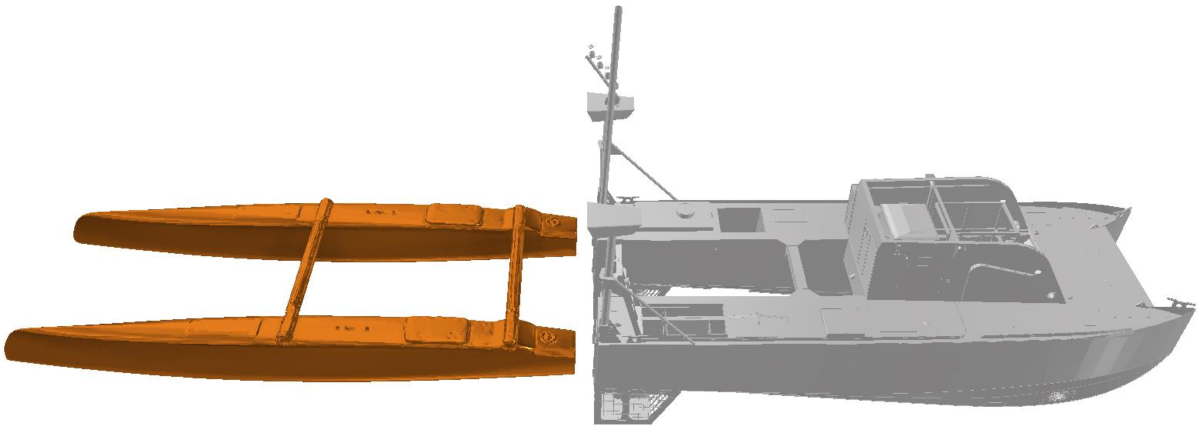

Figure 16: CAD Model of the two USVs

Simulation Trials

To safely conduct docking procedures without causing damage to either system, a simulation environment was established where both systems are present and can be tested simultaneously. This is particularly advantageous for validating the algorithms for docking. The simulation tool used was Gazebo Garden. Gazebo is a powerful open-source software for physical simulation of robotic systems and virtual environments. It is frequently used in robotics research and development to simulate realistic scenarios before testing them in the physical world.

The developed simulation builds upon the existing plugins of the VRX Simulator. VRX, highlighted as a top repository on Gazebo's official site under maritime simulations, is optimized for USVs and widely used in both research and competitions focused on marine robotics. VRX includes custom plugins tailored for maritime simulations, such as ocean waves and buoyancy physics, which enable realistic, dynamic marine environment modelling. Since the simulator is challenging to adapt to the specific vehicles of the SeaClear 2 project, only a portion of the developed plugins were used.

Figure 17:SeaCat and SeaDragon in the Simulation Environment

In the simulation environment, the following components were modelled:

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- Buoyancy of SeaCat and SeaDragon: Buoyancy models were used to simulate how each vessel interacts with water, which is essential for realistic movement and stability analysis.
- SeaDragon's Dynamics: Detailed dynamic models for SeaDragon were created to simulate its motion, accounting for forces such as thrust, drag, and environmental influences.
- Simplified Dynamics of SeaCat: A simplified dynamic model of SeaCat was implemented, with parameters that need to be optimized to match real-world performance.
- Full Sensor Setup for SeaDragon: SeaDragon's sensor suite, including LiDAR, INS, cameras, and IMU, was modelled to test perception algorithms and data integration.
- Basic Sensor Setup for SeaCat: SeaCat was equipped with essential sensors like IMU and GNSS to provide fundamental navigation data within the simulation.
- Collision Detection Based on Meshes: The collision models were based on the detailed meshes of both vessels to accurately detect and respond to physical interactions.
- Wave Interface for Both Ships: A wave simulation interface was included to mimic sea conditions, affecting the motion and interaction of the ships.
- Thrusters for SeaDragon: The propulsion system of SeaDragon was modelled to simulate thrust generation and manoeuvrability.
- ROS2 Interface for Both Ships: A ROS2 communication interface was established to facilitate data exchange between the vessels.

Capabilities of the Simulation Environment:

- Testing communication between the two ships using the ROS2 interface (sharing position and orientation).
- Testing autonomous docking procedures, allowing for iterative development and refinement of control algorithms in a risk-free environment.
- Testing autonomous navigation form shore to SeaCat.

<u>Real-World Testing</u>

SeaDragon was extensively tested throughout the year to evaluate its performance and reliability in real maritime conditions. Most of the tests were carried out in the harbour basin in front of the Fraunhofer CML in Hamburg (see figure 18)

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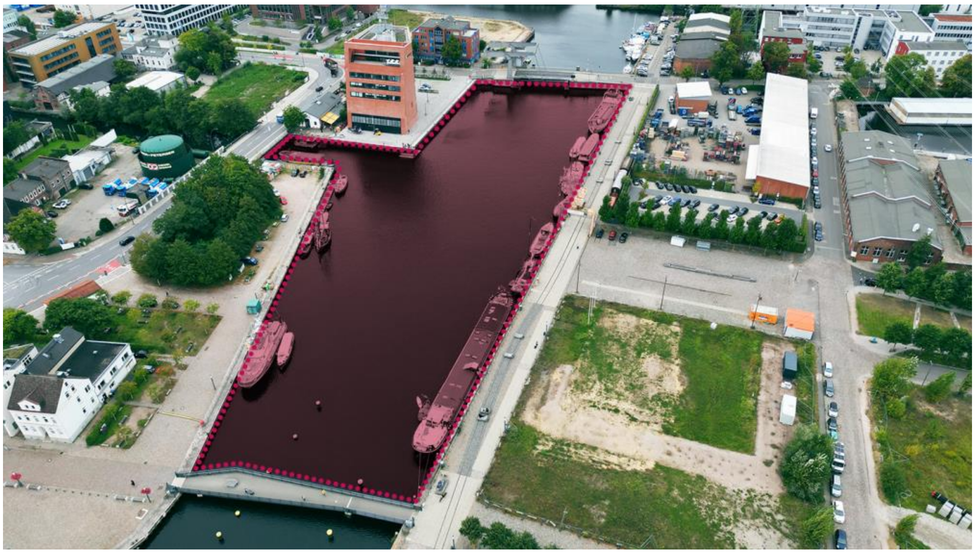

Figure 18: Test area in front of the Fraunhofer CML

The testing focused on various aspects of the vessel, including its payload capacity, maneuverability. To confirm the payload capacity, experiments were conducted where weight was strategically distributed across the hulls of SeaDragon. These tests ensured that the vessel could handle the required loads during operation without compromising stability or performance.

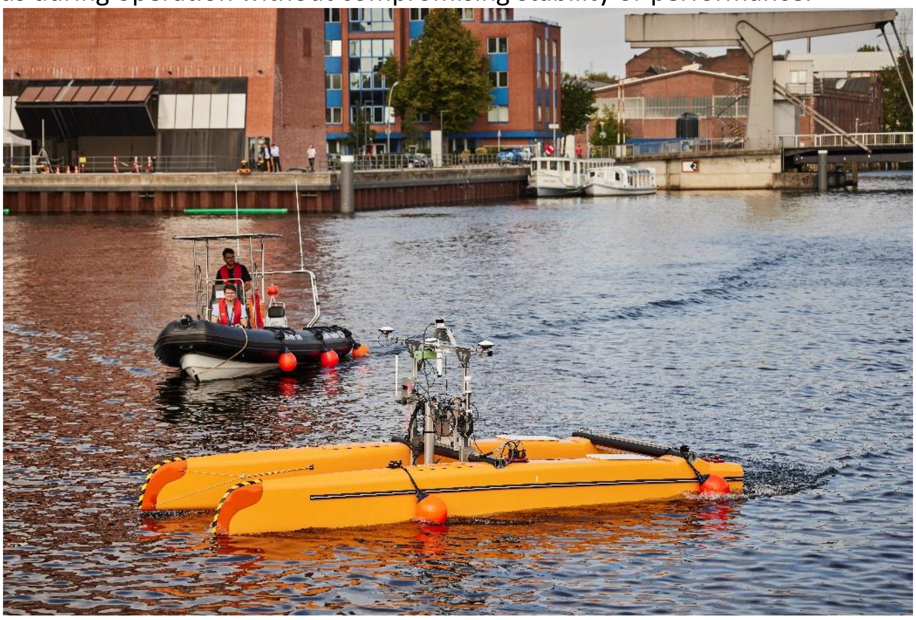

Figure 19: SeaDragon during the trials in the Hamburg Port

In order to simulate realistic docking scenarios, a wooden structure matching the original size of SeaCAT was fabricated (see Figure 20). This mock-up allowed for comprehensive testing of the docking mechanisms and procedures under real environmental conditions, even when the actual SeaCAT ship was not available. The use of the replica enabled the team to identify and address potential issues in the docking process, improving the overall integration of the two systems.

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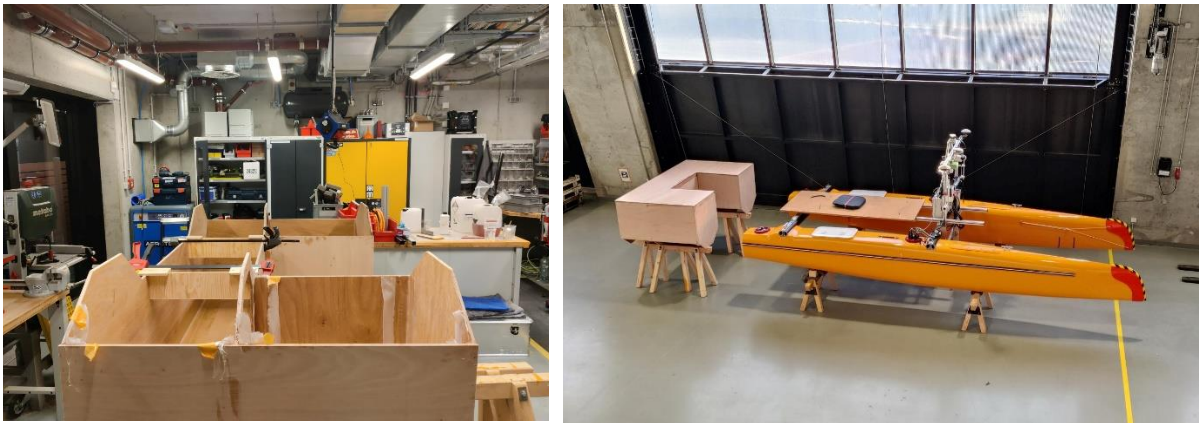

Figure 20: SeaCat Mock-up build and integration

The debriefing at the end of the test season revealed a few minor open points. SeaDragon: few minor hardware remaining works, planned to be completed in Q1 2025:

- Further protection to prevent damage to the ships
- If the tests reveal problems in maintaining the position of the two ships when docked, an additional holding mechanism
- Final integration of cameras and radar sensors for the detection of SeaCat
- Enhanced testing of the servo motors for turning the thrusters
- Integration of the container for collecting the trash

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2.3 Dubrovnik trials

The surface litter collection systems consisting of two USVs with the collection net were integrated and tested during week 40 next to UNIDU facilities in Dubrovnik. The sea trials took place on Friday close to Dubrovnik port, Fig 21.

Figure 21: Deployment of the surface collection system

The litter prepared for the trials consisted of plastic bottles, cans, Styrofoam and plastic bags, Fig 22. The litter was partially afloat and partially submerged as to test the collection capabilities of the collection net.

Figure 22: Surface and submerged litter used for the trials

The surface collection system was able to fulfil the task. The upgraded net was able to contain the above the sea litter and the submerged net was able to collect the underwater litter, see Fig 23 and 24. Also the new propulsion system was tested for improved thrust for each of the USVs.

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Figure 23: Testing of the upgraded collection net and the upgraded propulsion

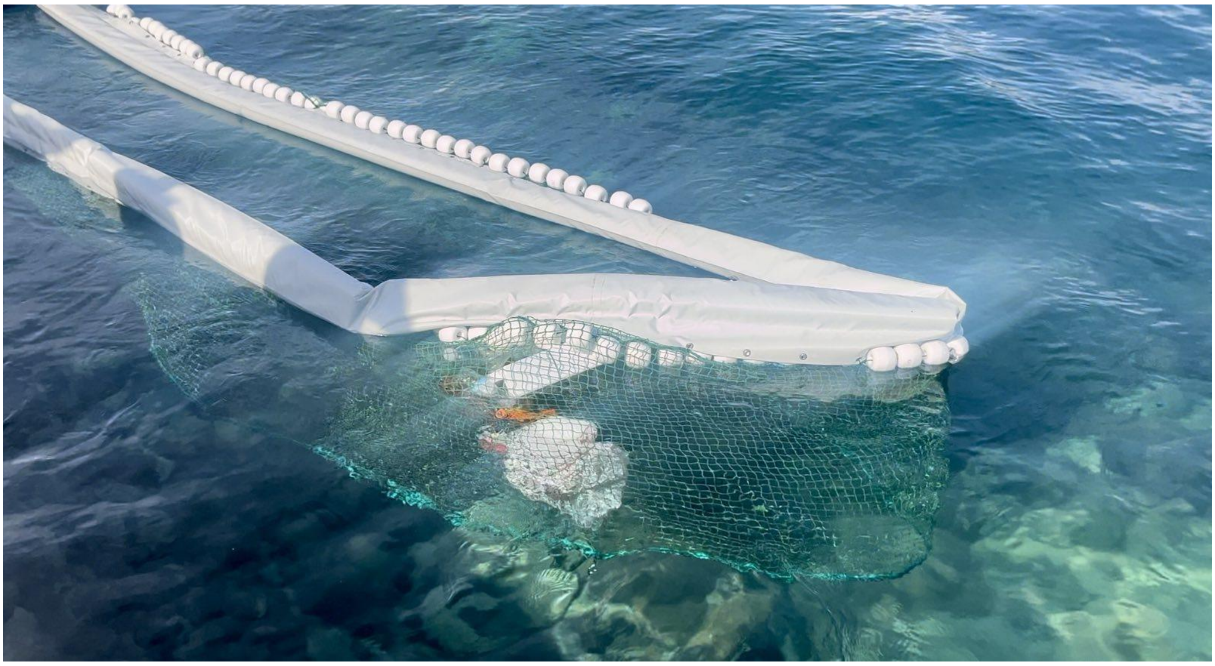

Figure 24: Successful collection of the litter in the water column

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3. Conclusions

Despite an extremely tight schedule remaining for trials, mainly due to the late delivery of the SeaCAT after bankruptcy of the first shipyard, the integrated hardware trials were conducted on time to allow completion of WP3 works by the end of 2024, as planned in the SeaClear2.0 Description of Activities (DoA).

A very good preparation, an active collaboration between partners and clement weather conditions in all sites allowed to carry out the whole trials in just few days and with successful results.

Few minor outstanding issues have been spotted, most of them not predictable before system full assembly but they should be all fixed by end of March 2025.

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