Fraunhofer CML

Fraunhofer-Center für Maritime Logistik und Dienstleistungen CML

ICMASS 2024

Lidar-Based Obstacle Detection and Path Prediction for Unmanned Surface Vehicles

Nico Zantopp, Akif Budak, Cosmin Delea, Herberto Werner, Ching Nok Au, Johannes Oeffner

Lidar-Based Obstacle Detection

for Unmanned Surface Vehicles

  Public information

Fraunhofer CML

Introduction

Digital test field Elbe

1. Integration of inland vessels in digital logistics chains
   Digitization of ship and land systems for the transmission of logistics-relevant data.

2. Improving the river Elbe's navigability
   Recording and provision of fairway and navigation channel information based on highly precise digital data.

3. Reduction of downtimes and energy requirements
   AI-based analysis and assistance systems for inland vessels.

This project was funded by the Federal Ministry of Digital and Transport under the funding code 45DTW2V09A.

Maritime Infrastructure

Backbone of Global Trade economy

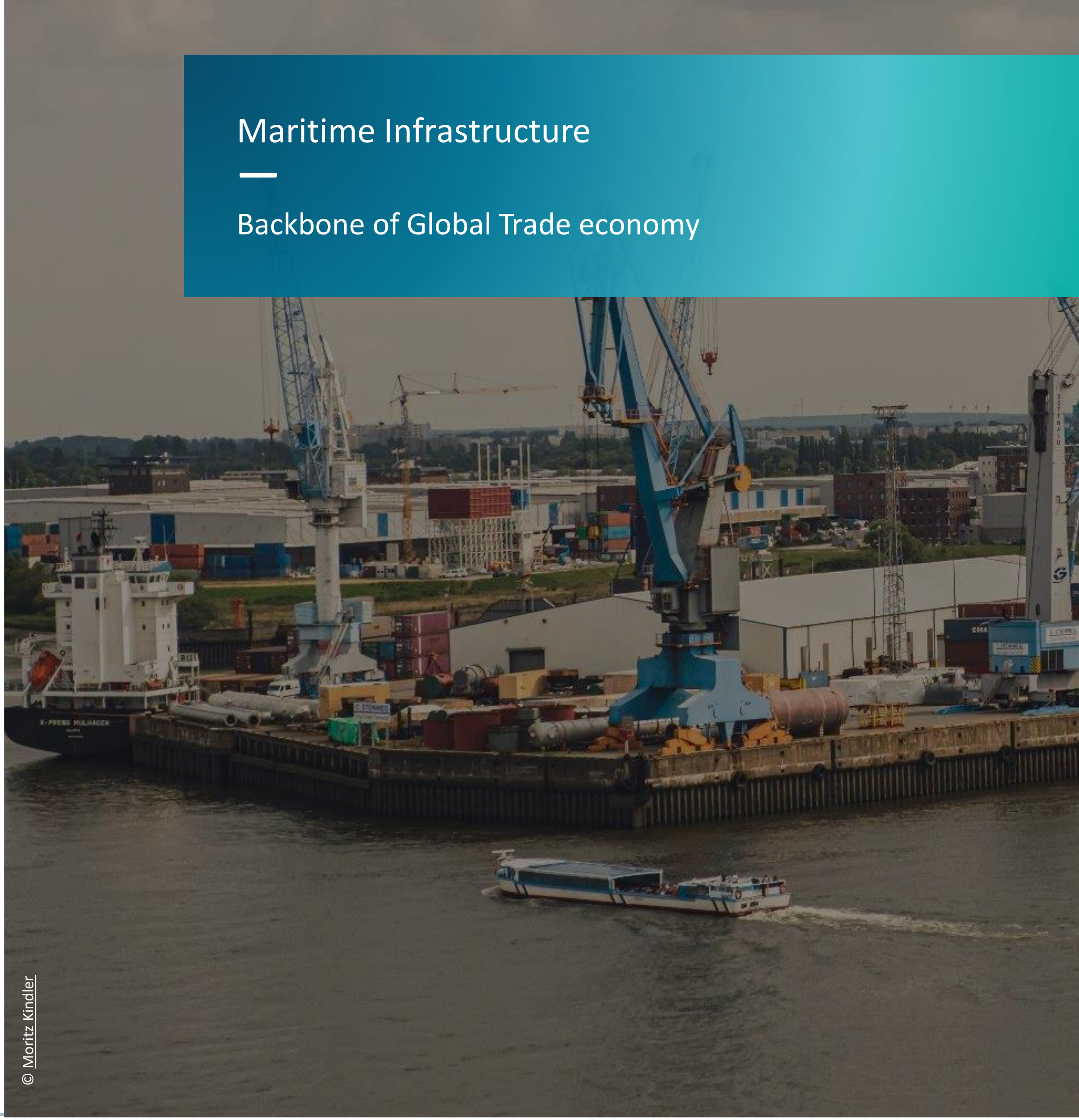


Image: https://unsplash.com/de/fotos/schiff-in-der-nahe-von-seehafen-shdC9zPtPKU

Why USVs?

Beneftits

Efficiency

- Operate 24/7 without fatigue.
- Cover vast areas swiftly.

Safety

- Reduce human exposure to maritime hazards.
- Reliable in unpredictable sea conditions.

Cost-Effective

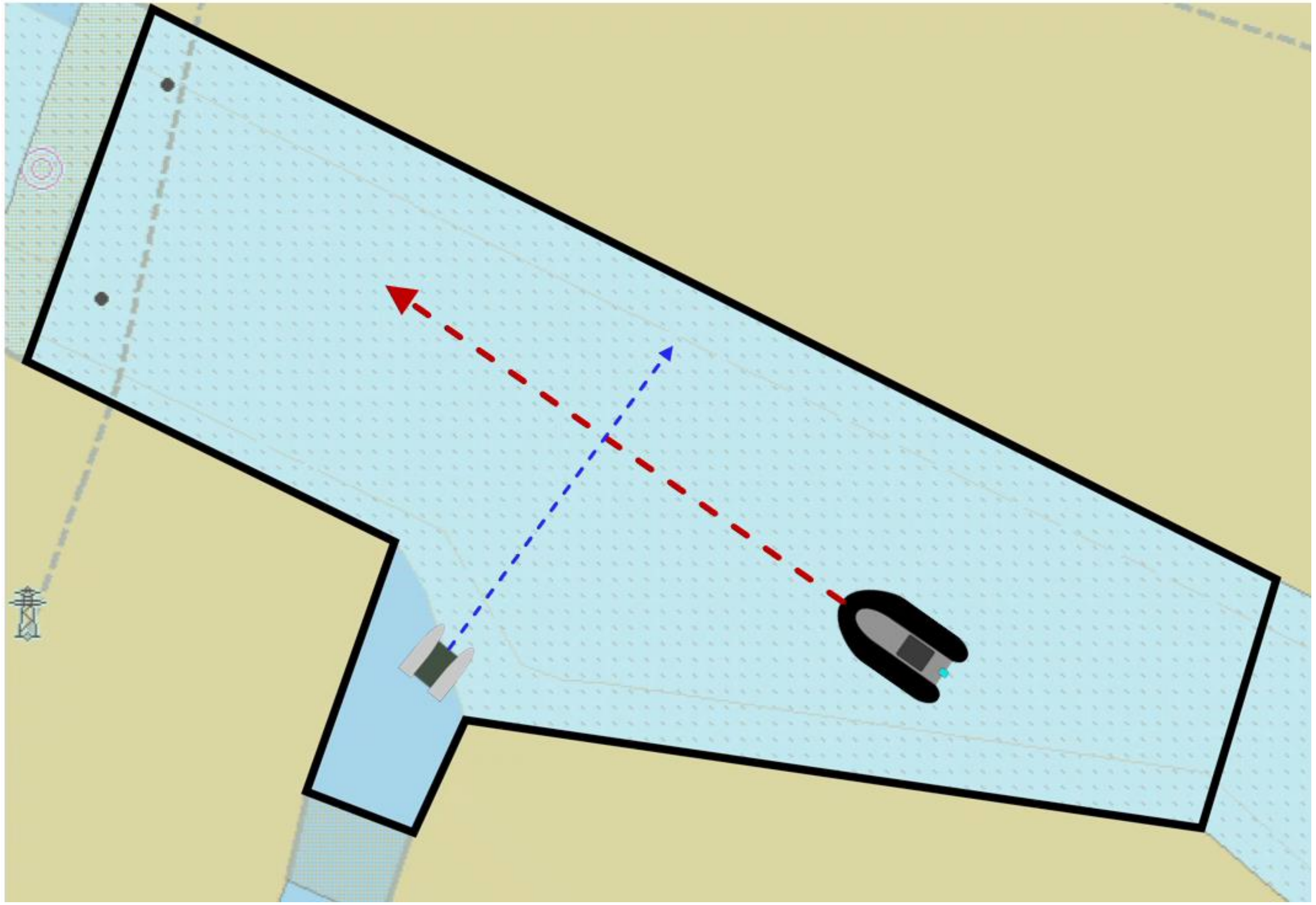
- Minimize long-term human operational costs.
- Efficient maintenance and operation.

Advanced Technology

- AI-powered surveillance and monitoring.
- Real-time data collection and analysis.

Motivation

Why do we need tracking of dynamic objects?



With Tracking

Developed Pipeline

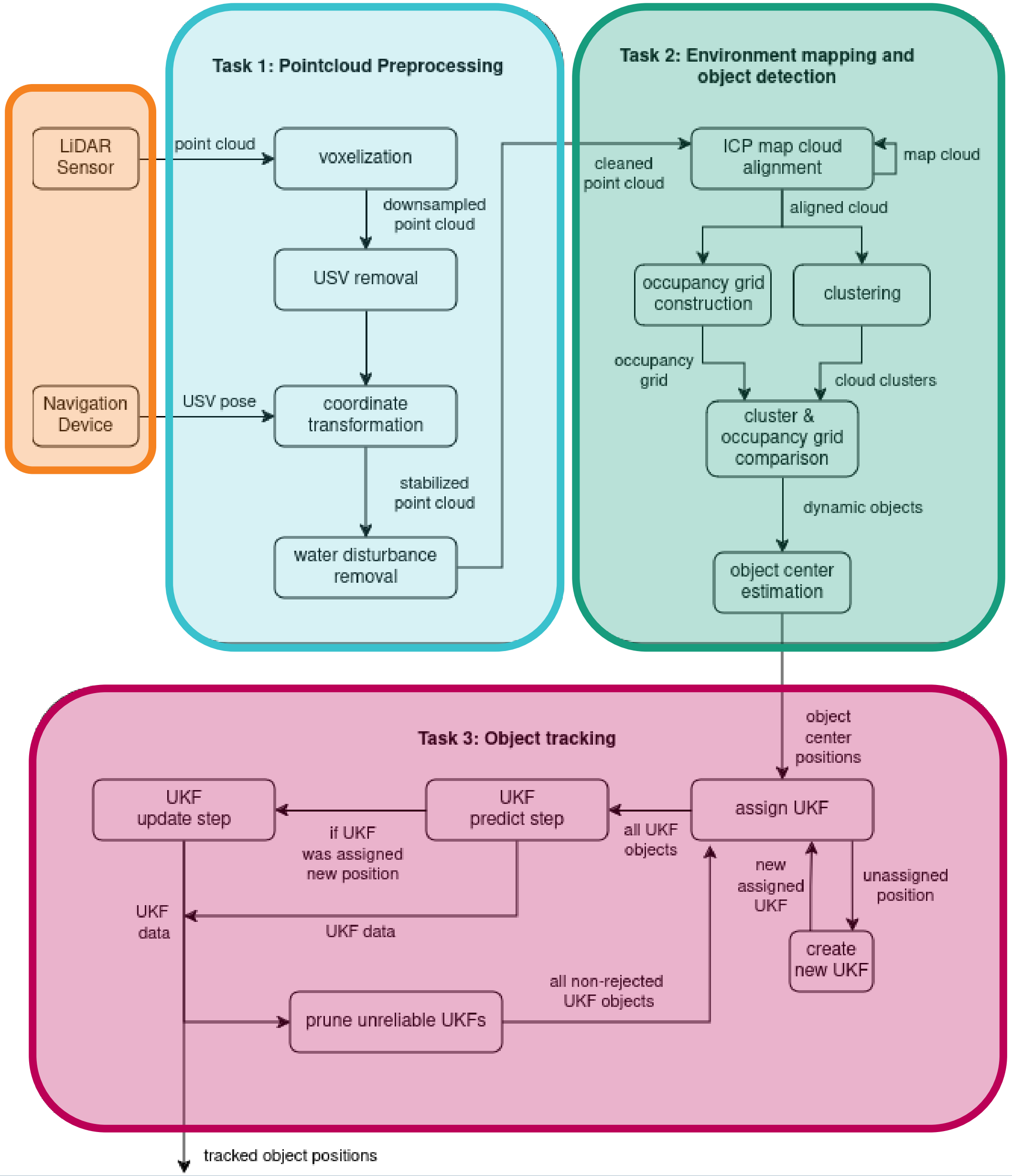
Overview

Data Sources

Task 1: Pointcloud Preprocessing

Task 2: Environment Mapping and Object Detection

Task 3: Object Tracking

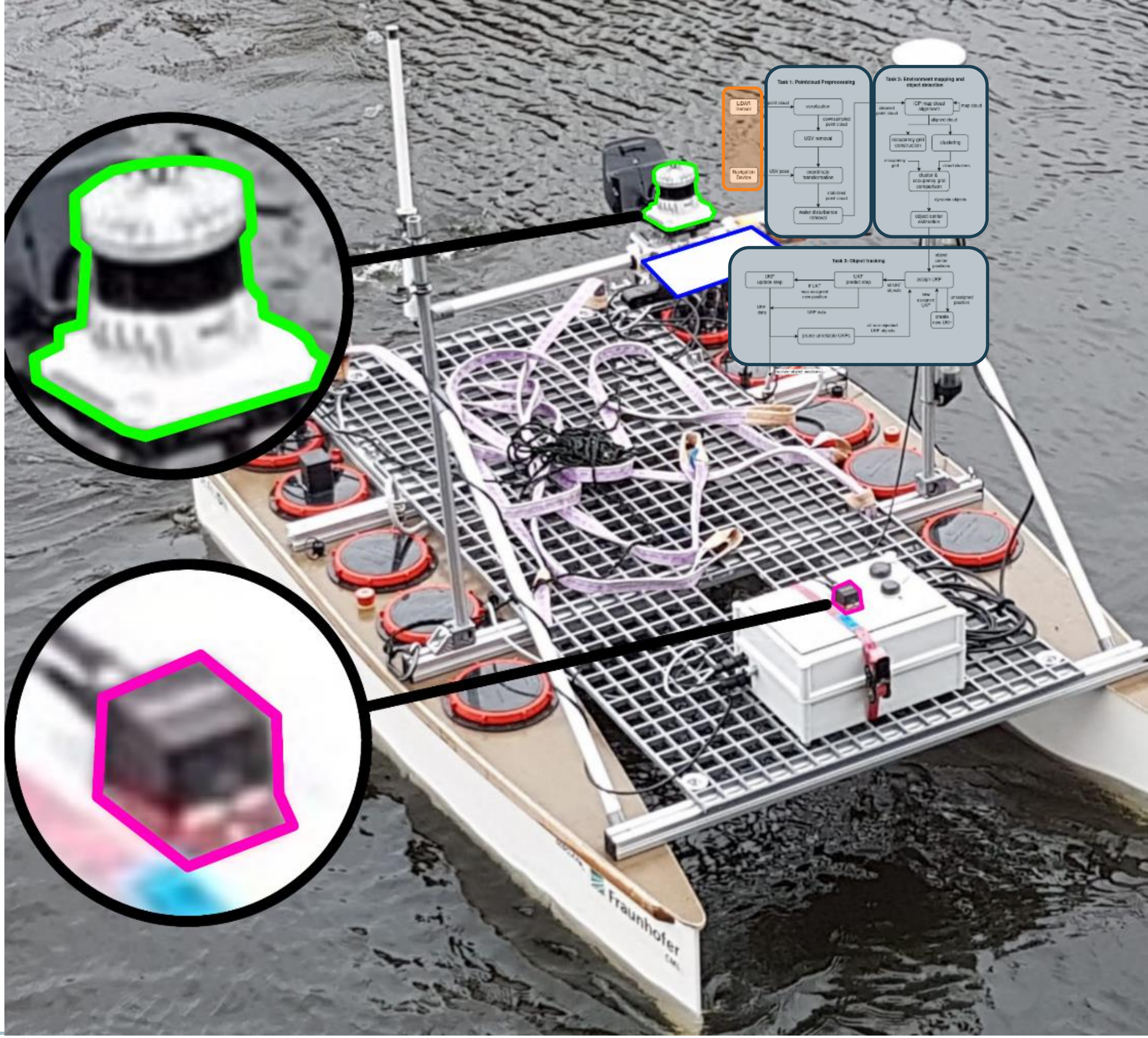


SeaML:SeaLion

Data sources

Vehicle Facts

- Catamaran Design
- Construction dimensions - 2.2m x 1.5m
- Interface for different sensors and payloads
  - Payload up to 100kg
- 2 x 3HP electric outboard motors
- 2 x 48V batterys (50 Ah 2.3 kWh each)
- Modular power grid (5/12/24/48V Output power)
- Sensors



Fraunhofer CML

Developed Pipeline

Task 1

Pointcloud Preprocessing

Down-sampling for Computational Efficiency**:**

- Reduces point-cloud size for lower computational load.

Pass-through Filtering:

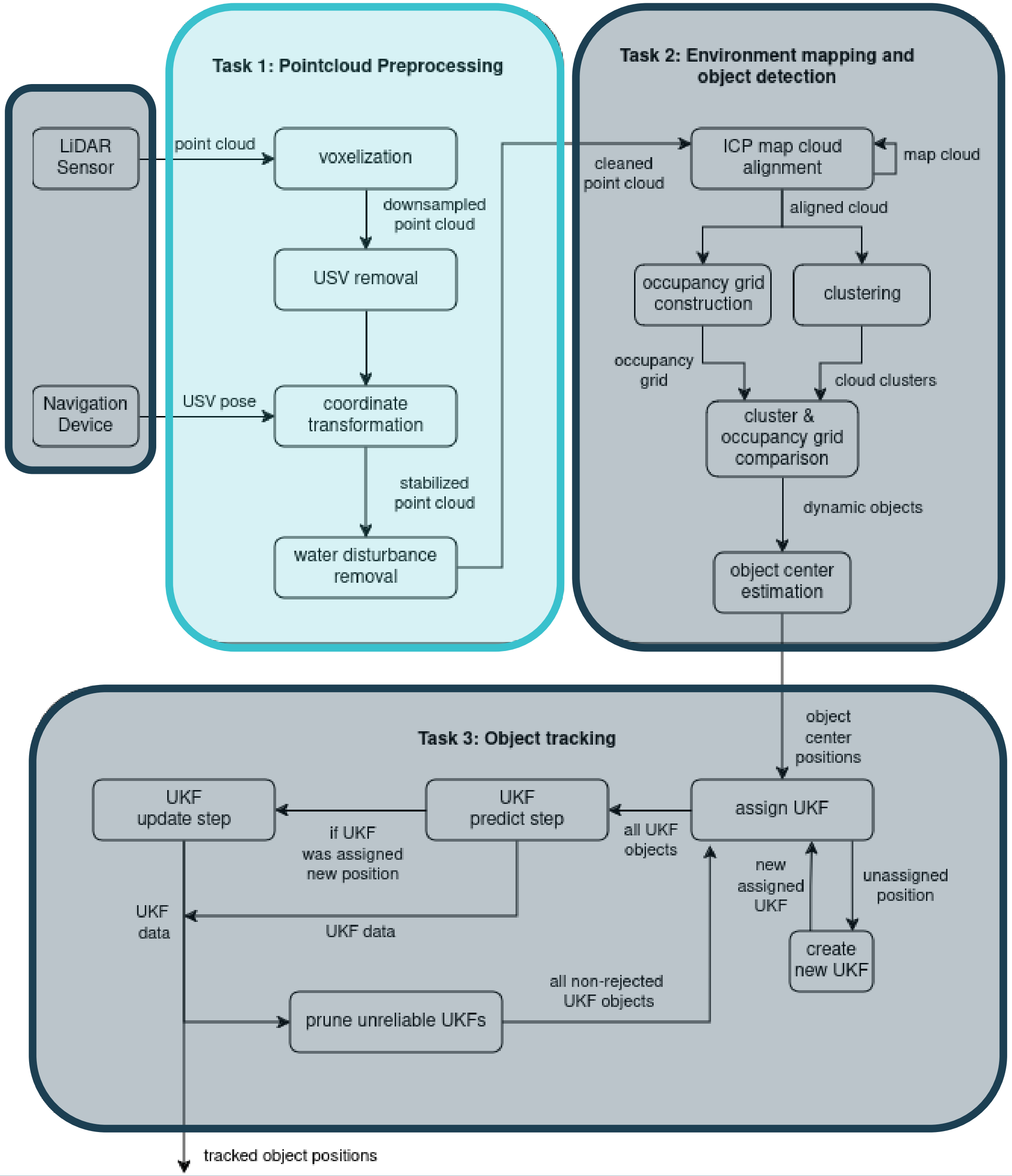
- Removes points from the observing USV (e.g., masts in LiDAR view).

Global Coordinate Alignment:

- Aligns point cloud using USV pose data (roll, pitch, yaw stabilization).
- Translates to global coordinates with GNSS data for fixed positioning.

Surface Noise Removal:

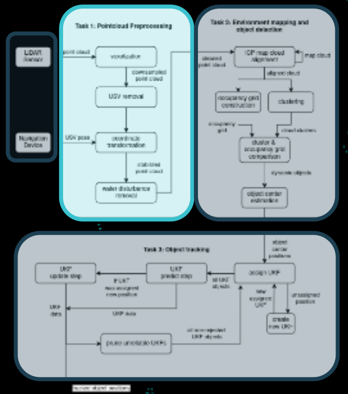
- Filters out water splashes and wakes, aligned after stabilization.



Fraunhofer CML

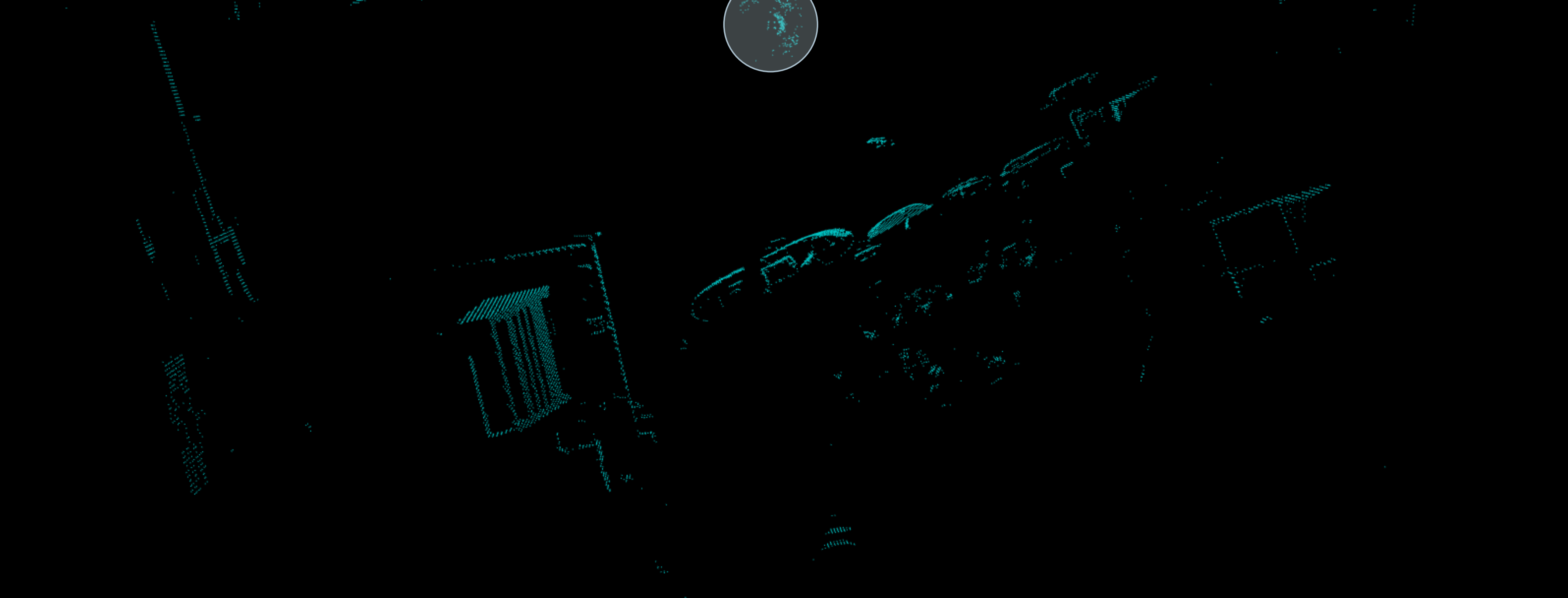
Pipeline

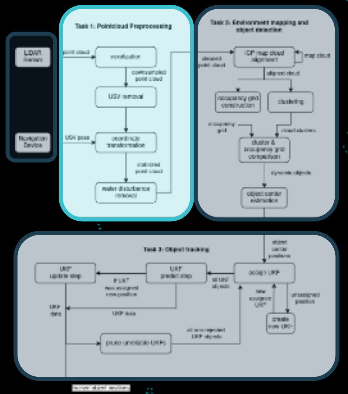
Pre-processing



Pipeline

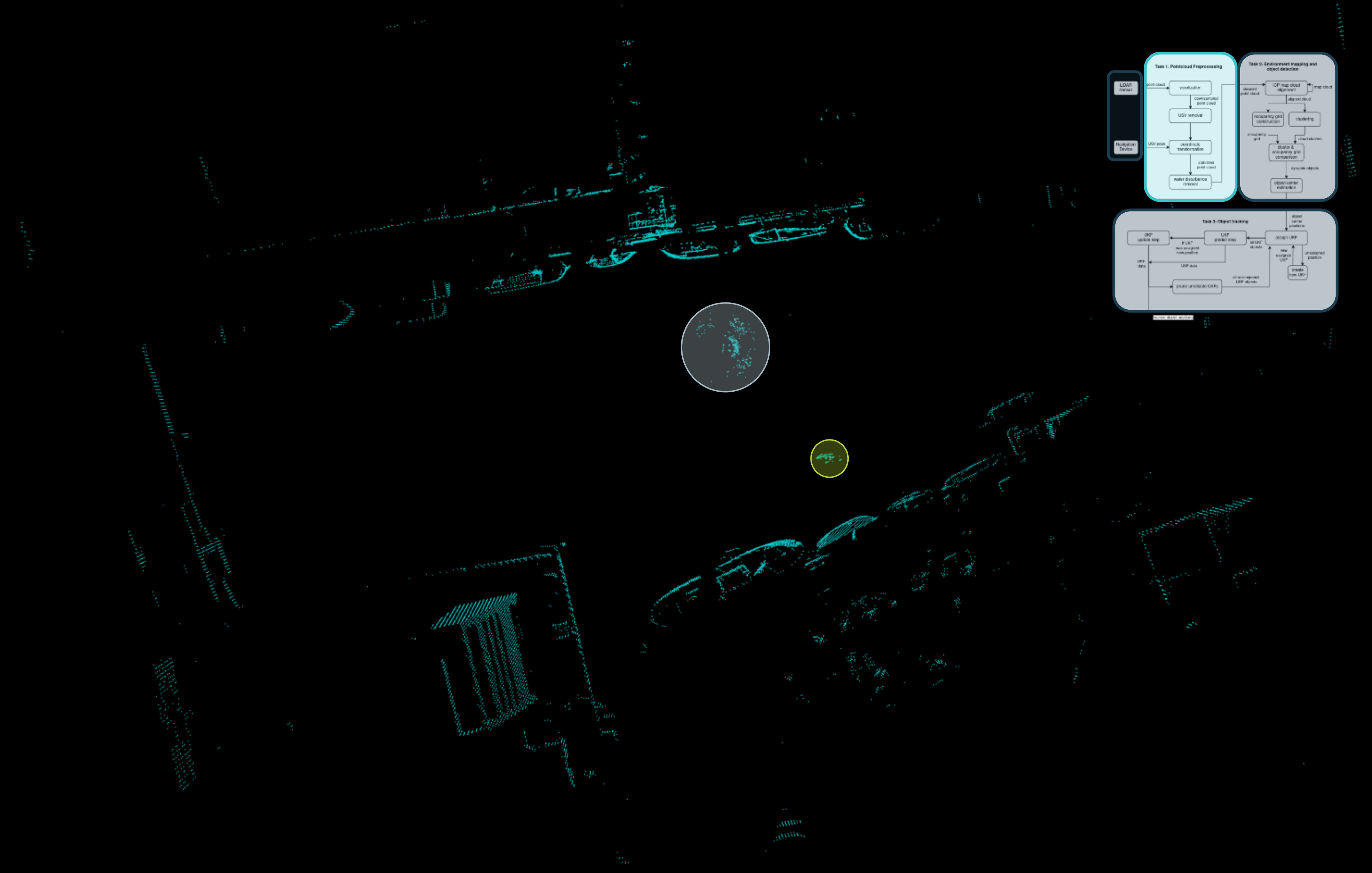
Pre-processing





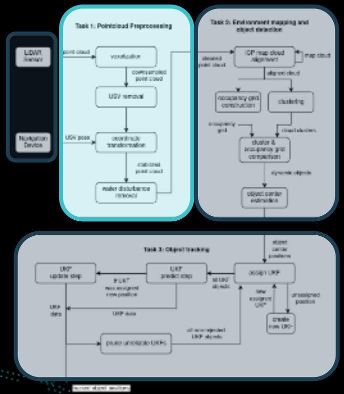
Pipeline

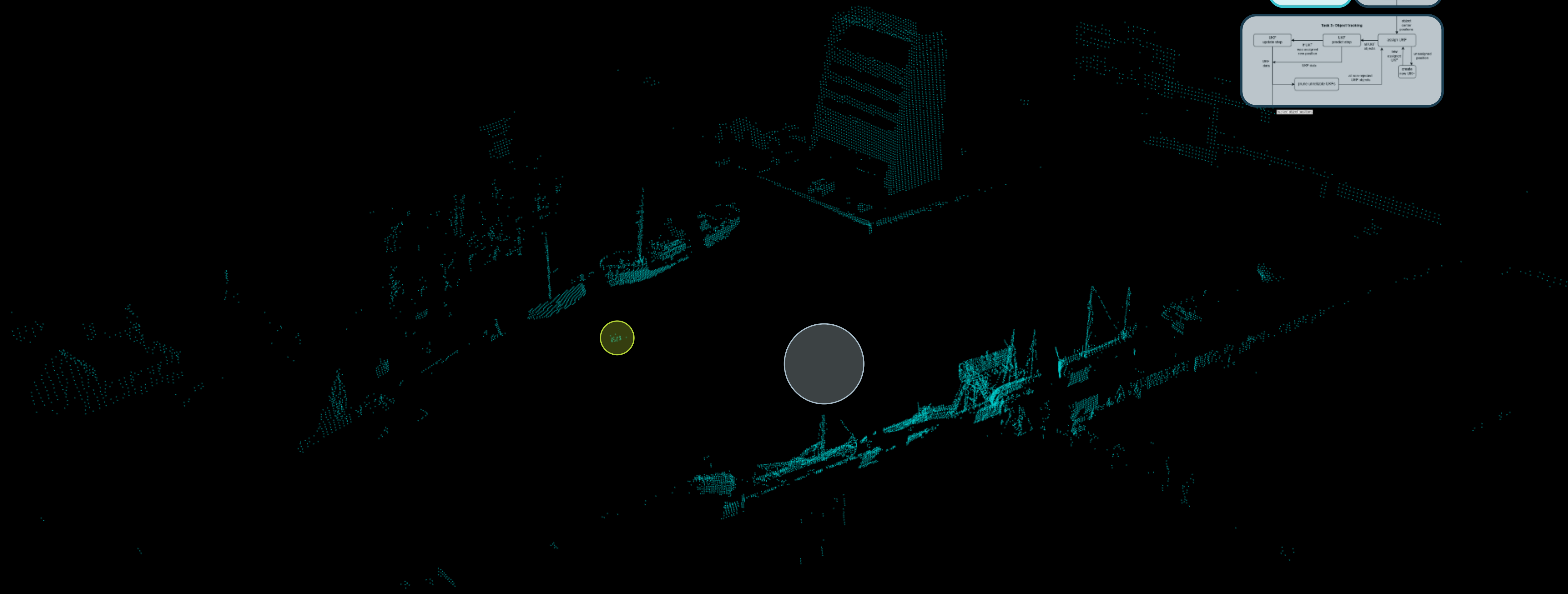
Pre-processing



Pipeline

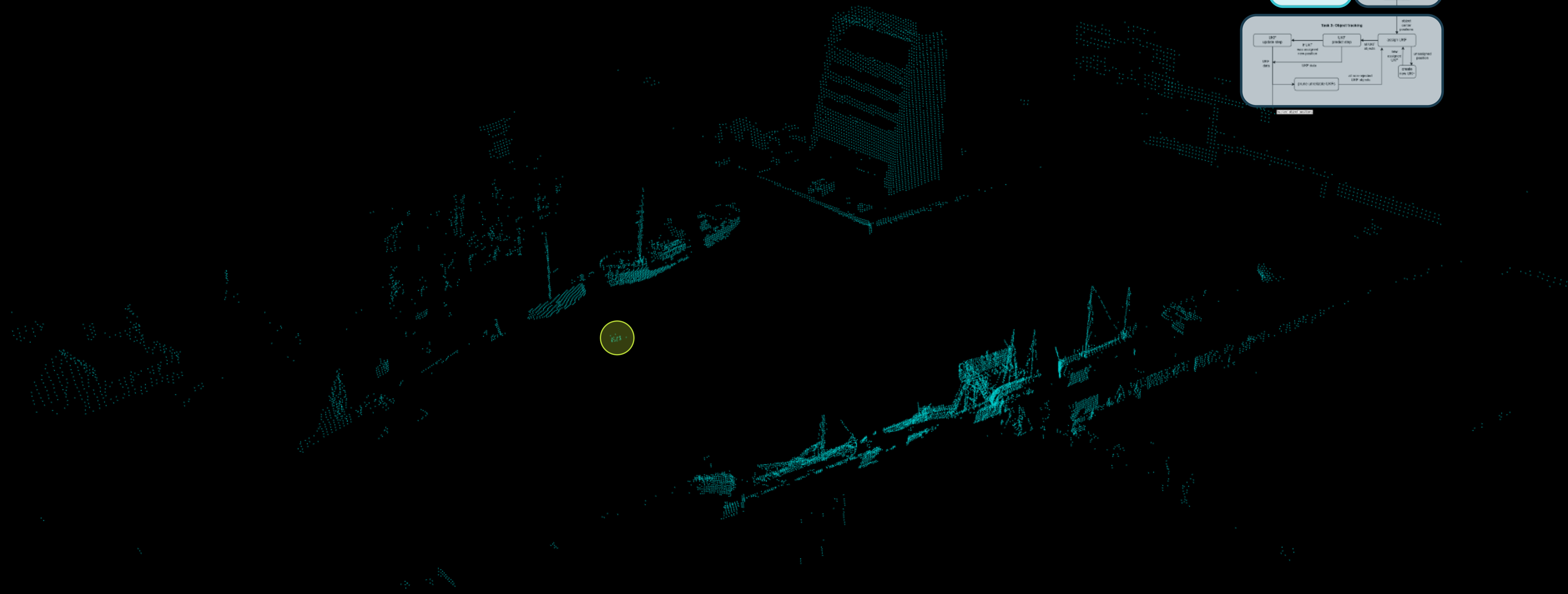
Pre-processing

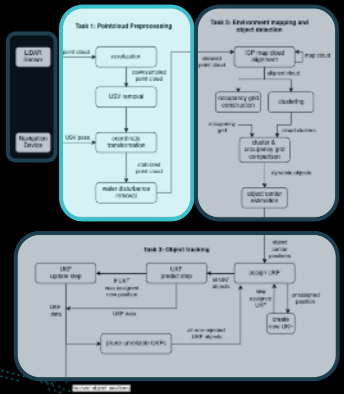




Pipeline

Pre-processing





Developed Pipeline

Task 2

Environment Mapping and Object Detection

Initial Point Cloud Alignment:

- ICP Algorithm: Iteratively aligns incoming point clouds to a base map.
- Initial Cloud: Sets the reference point for subsequent data alignment.

Dynamic Occupancy Grid Construction:

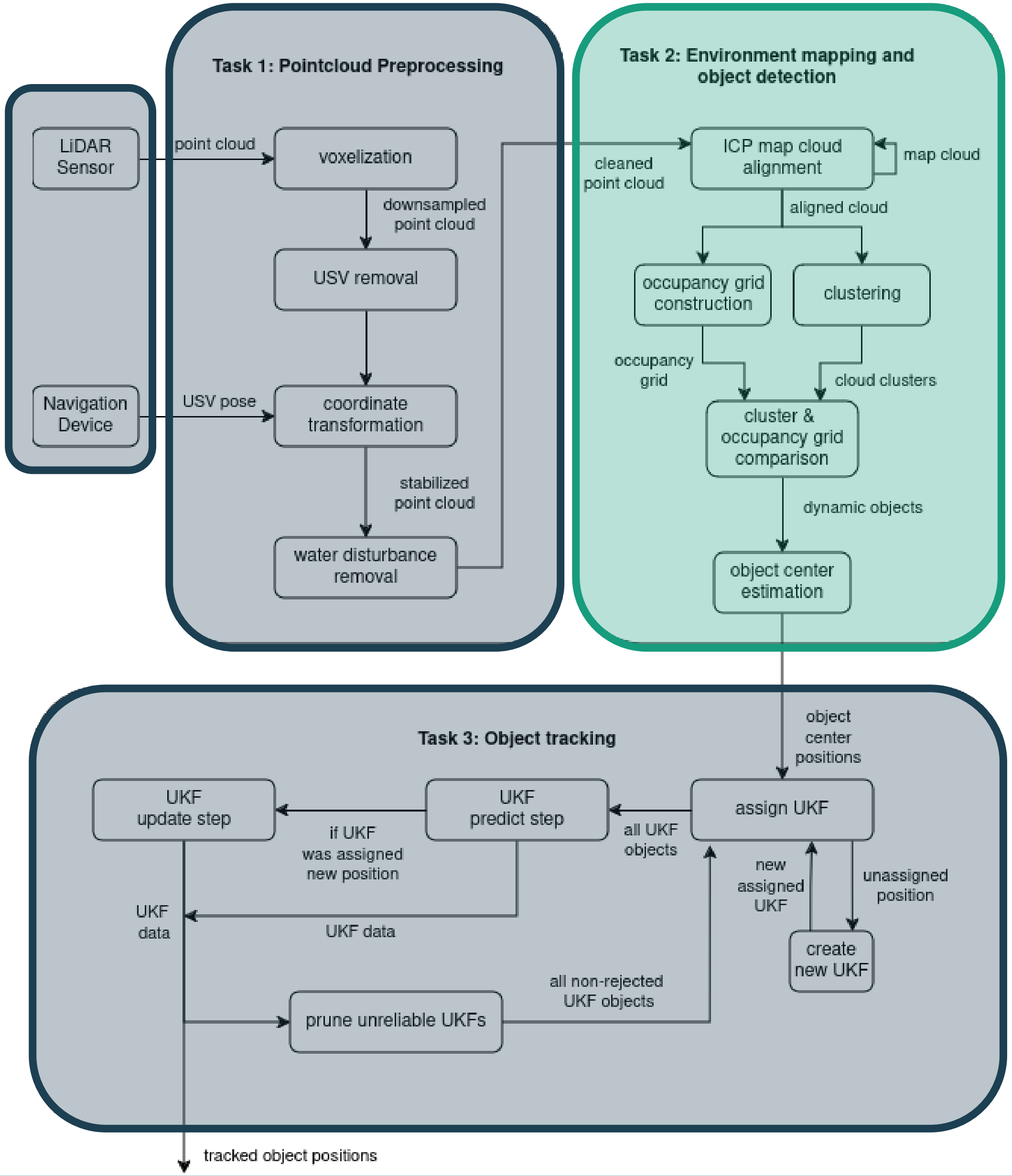
- Grid Cell Values: Range from -1 (unknown) to 100 (static obstacle).
- Dynamic Updates: Grid cells updated with each new aligned cloud.

Static vs. Dynamic Object Identification:

- Static Objects: Cells with high values (≥80) mark.
- Dynamic Objects: Moving clusters identified and tracked if not covering marked land cells.

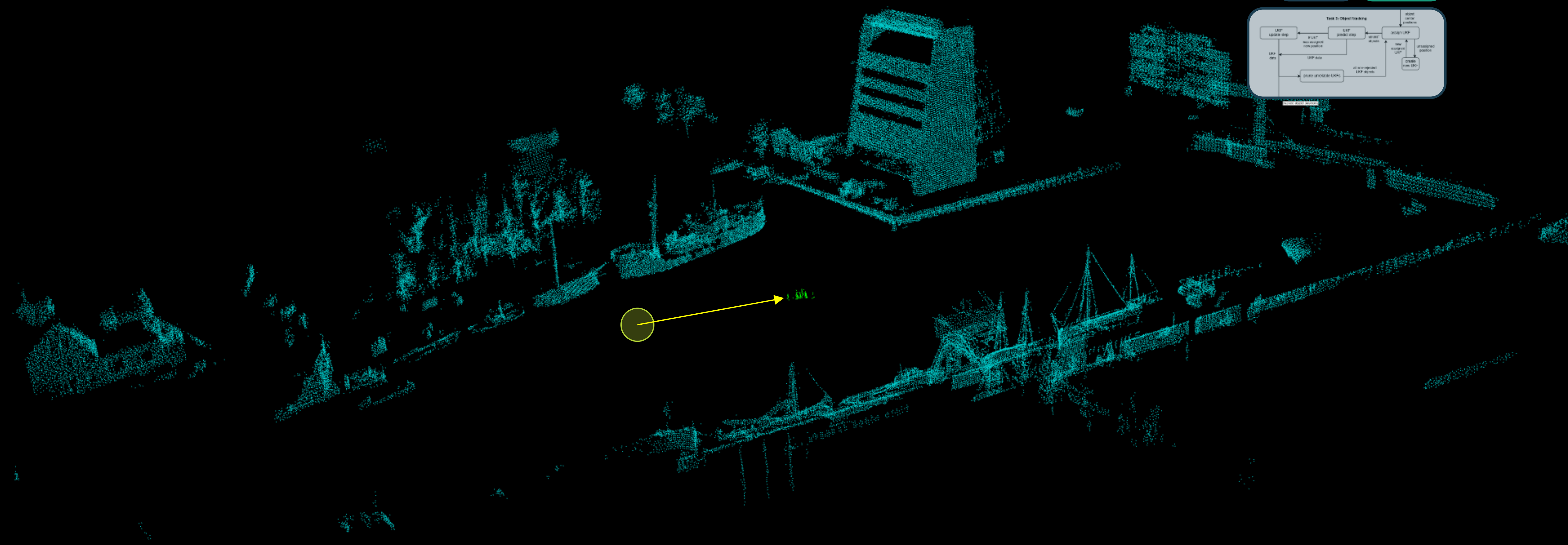
Dynamic Obstacle Detection:

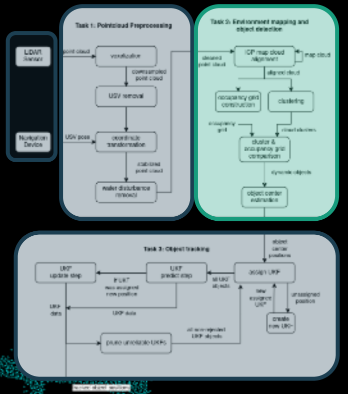
- Cluster centroids calculated and passed to object tracker for dynamic tracking.



Pipeline

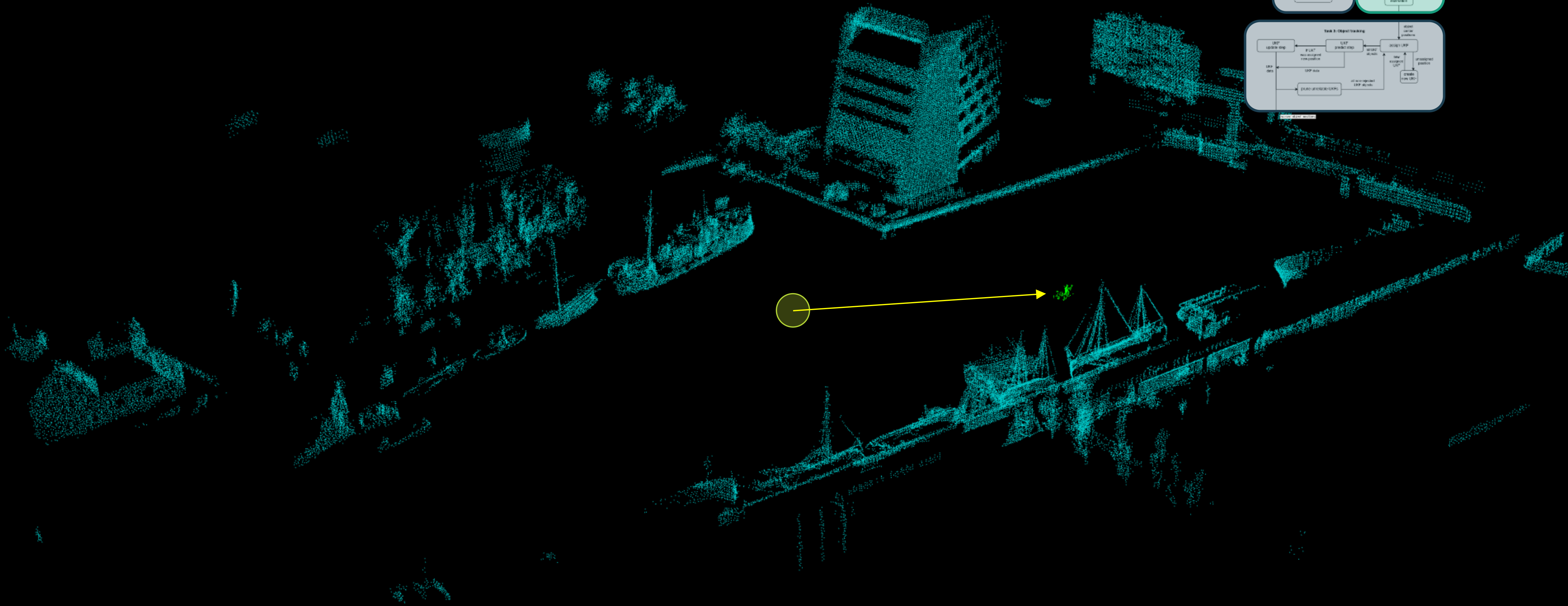
Mapping – 15 seconds

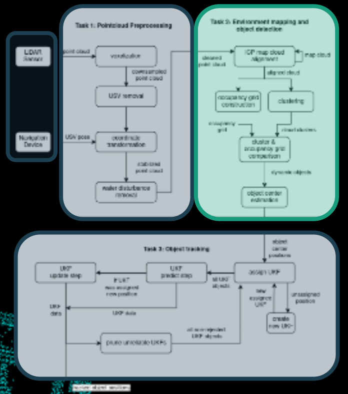




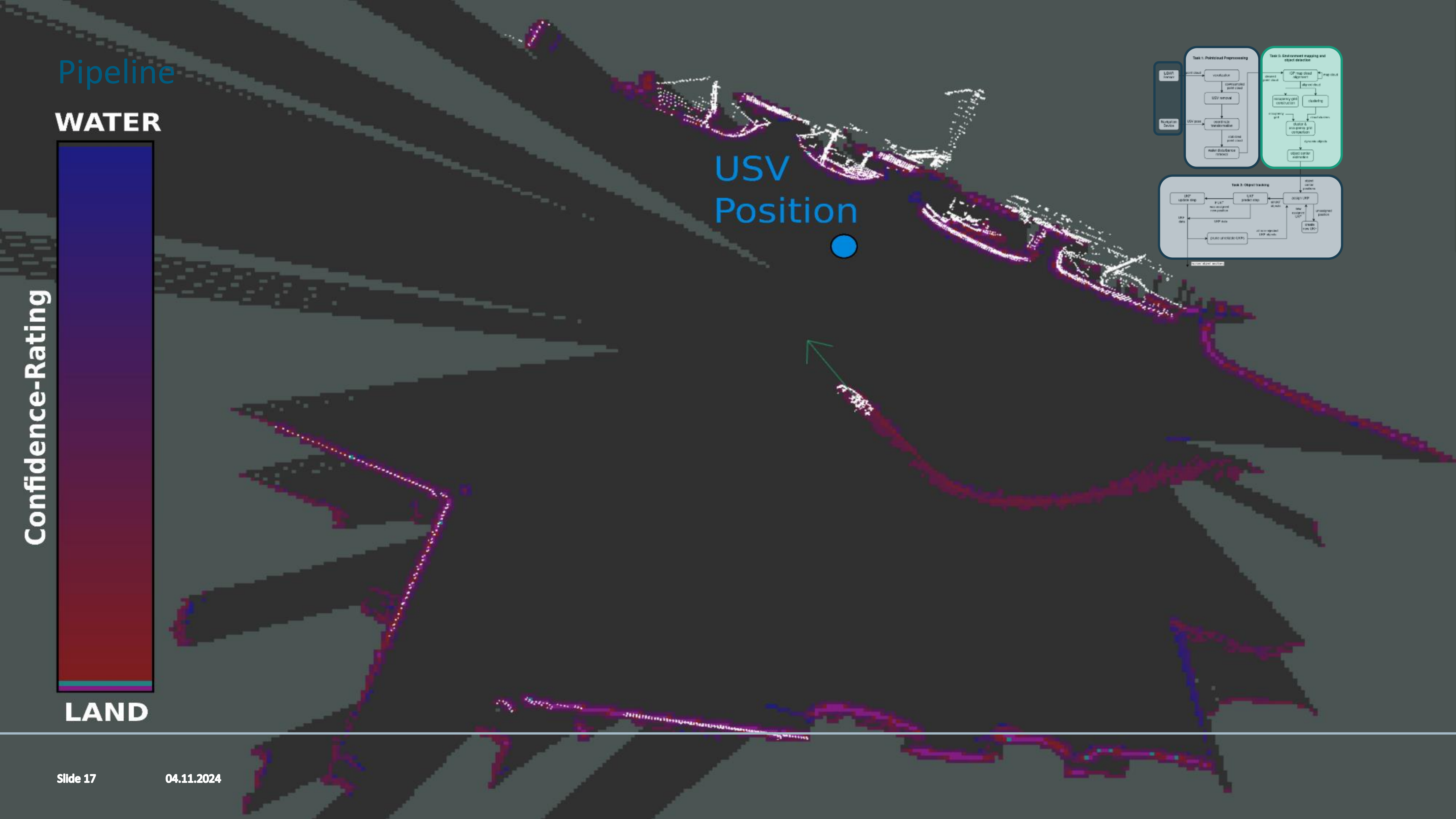
Pipeline

Mapping – 30 seconds





Pipeline



Developed Pipeline

Task 3

Object Tracking

Vessel Movement Modeling**:**

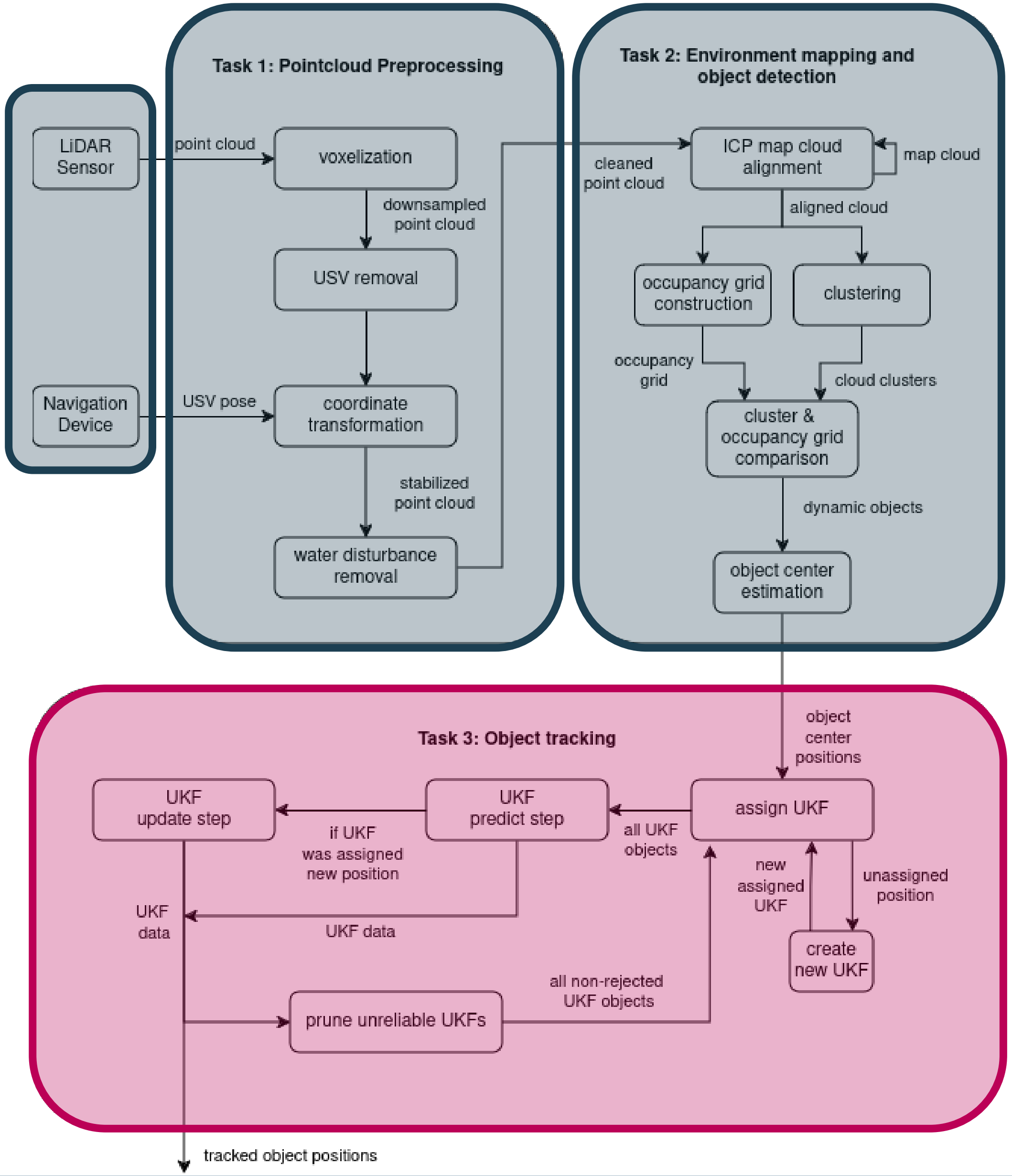
- Constant Turn Rate and Velocity (CTRV) Model
- Key tracked states: Position, Velocity, Heading.

Dynamic UKF Tracking Process:

- Centroid Matching: Checks new centroids against existing UKF instances.
- Measurement Update: Updates tracker if an existing UKF is within range.
- New Object Detection: Creates new UKF tracker if no match is found.

Tracker Management:

- Position Estimation: Continues estimation if no new data is available.
- Tracker Pruning: Removes UKF instances when objects go out of view.
- Allows for independent and concurrent tracking of multiple targets.



Experimental Setup
Test Location

Lotsekanal (Pilot Channel), Hamburg, Germany
- Enclosed, controlled channel in the southern port.
- Protected by a lock—minimal current and tidal effects.
- Trial conducted in February 2024.

Test Area Dimensions:
- **200 m long** and **65 m wide** (restricted by docked vessels).

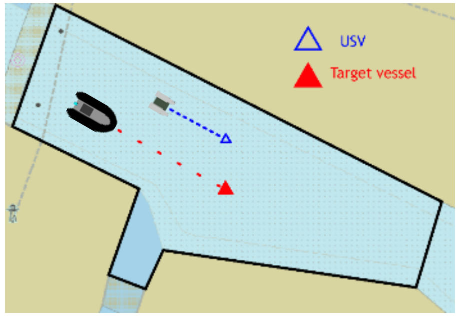
Environmental Conditions:
- Wind Speeds: 6 m/s to 8 m/s (11 to 16 knots).
- Wind Directions: N, NE, E.
- Main disturbance: Wind, with minimal current influence.

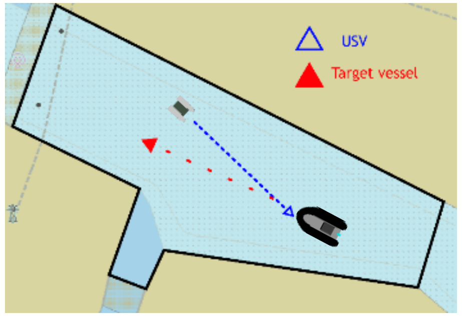
Target Boat:

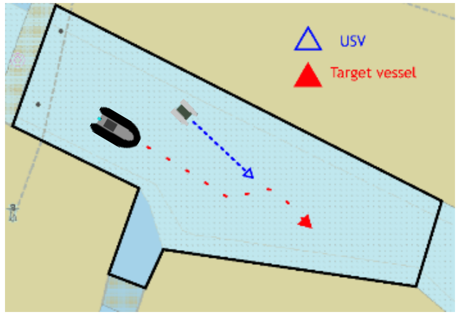
Fraunhofer CML

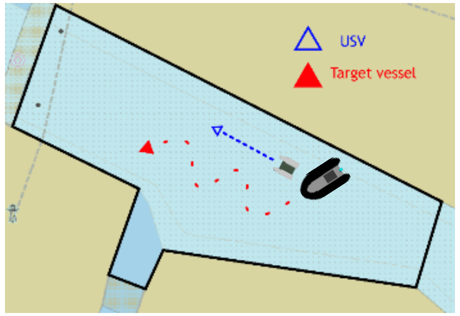
Experimental Setup

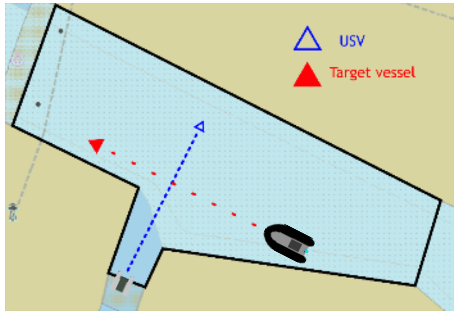
Test Scenarios











Scenario 1:
Target vessel moving in the Same Direction

Scenario 2:
Target Vessel Moving in the Opposite Direction

Scenario 3:
Target Vessel Overtaking the USV

Scenario 4:
Target Vessel Moving in a Sinusoidal Curve

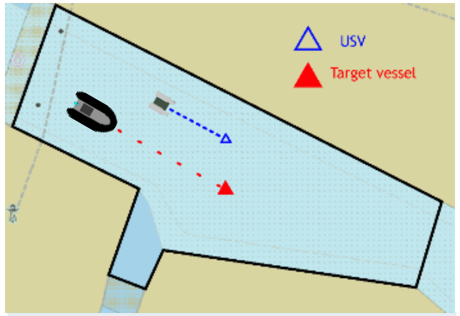
Scenario 5:
Target Vessel Moving Perpendicularly

Results

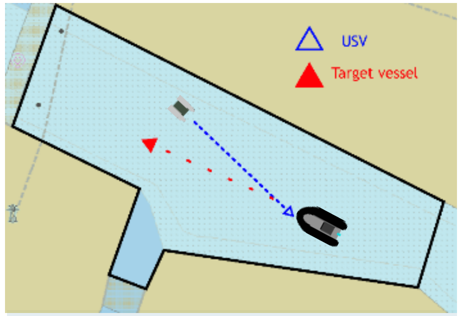
Tracking

Overview of the tracking errors across the five different scenarios.

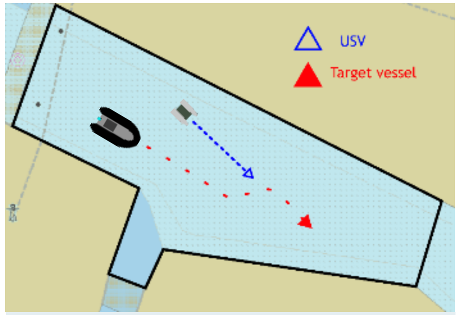
Scenario	RMSE Tracking Error [m]
1	3.3
2	5.4
3	2.9
4	4.1
5	3.5
Average	3.8



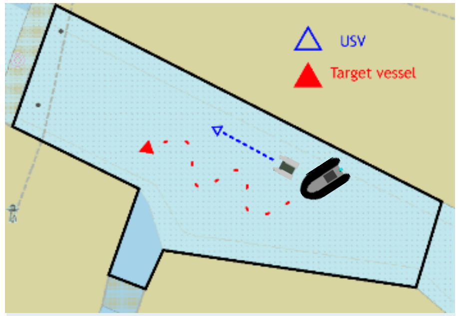
Scenario 1



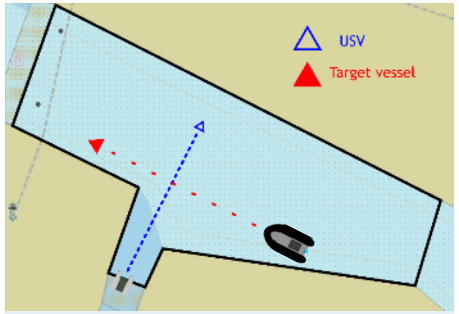
Scenario 2



Scenario 3:



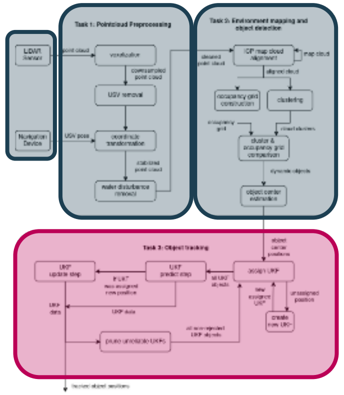
Scenario 4

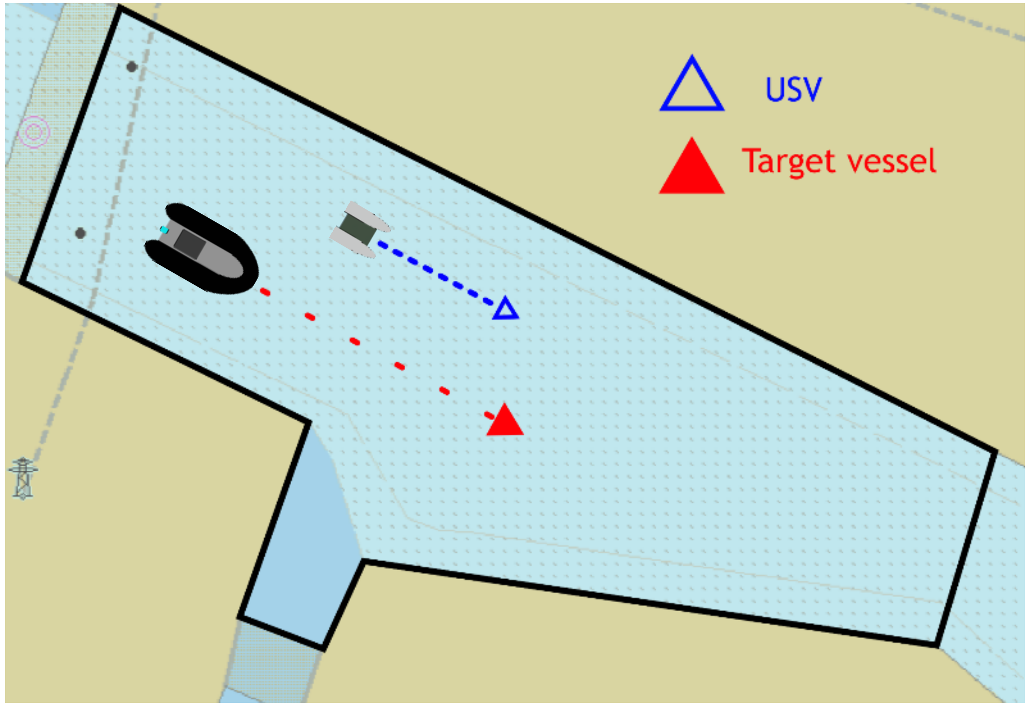


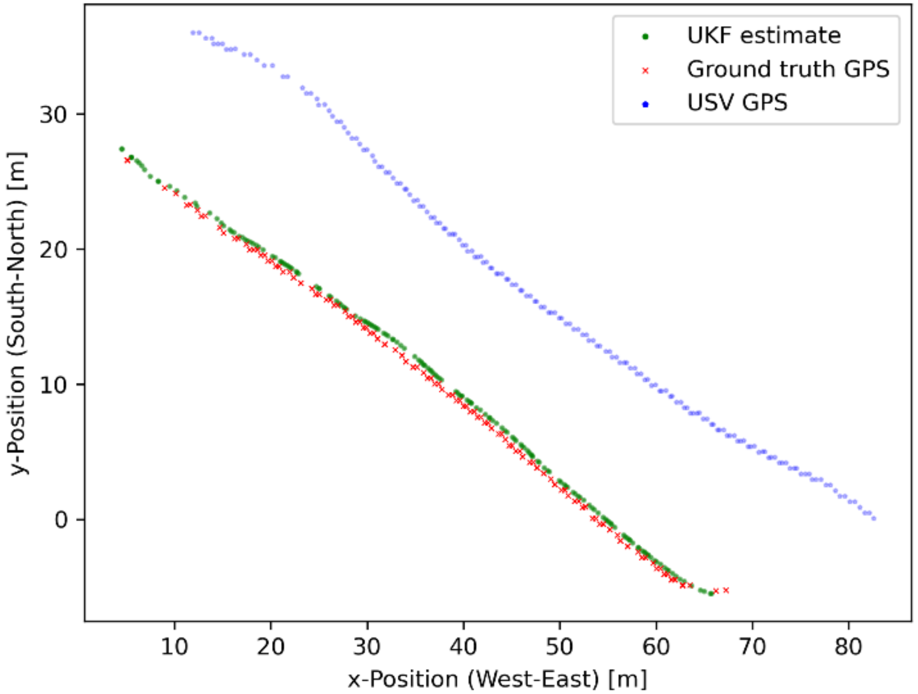
Scenario 5

Results

Tracking Scenario 1





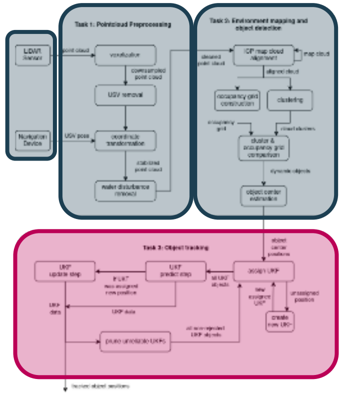


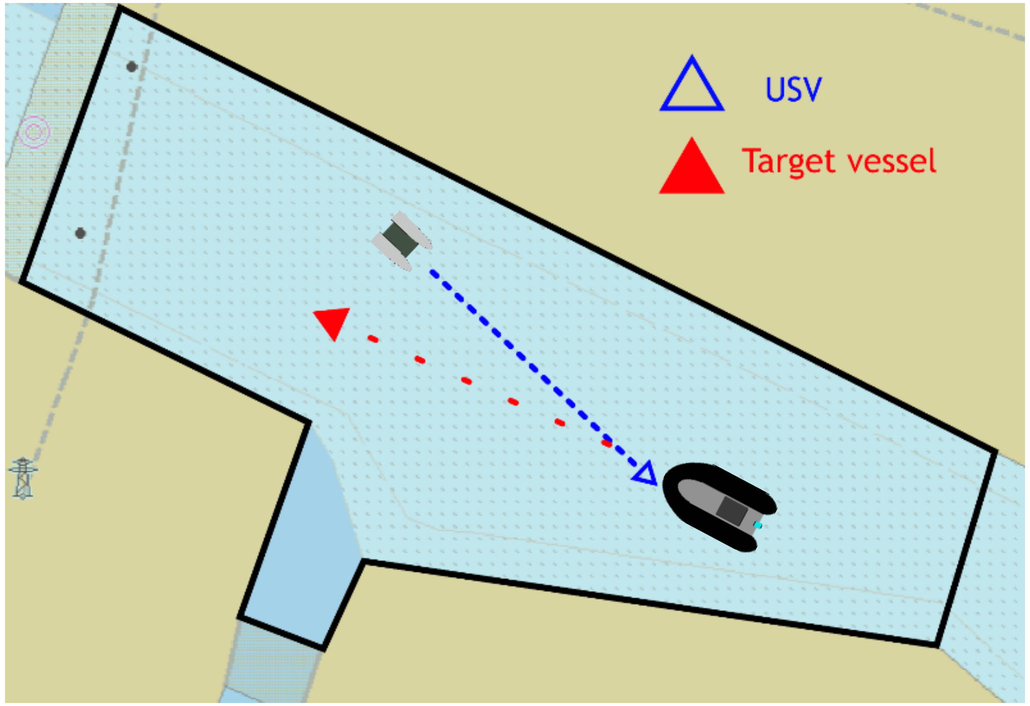
Tracking error
green position vs
red position

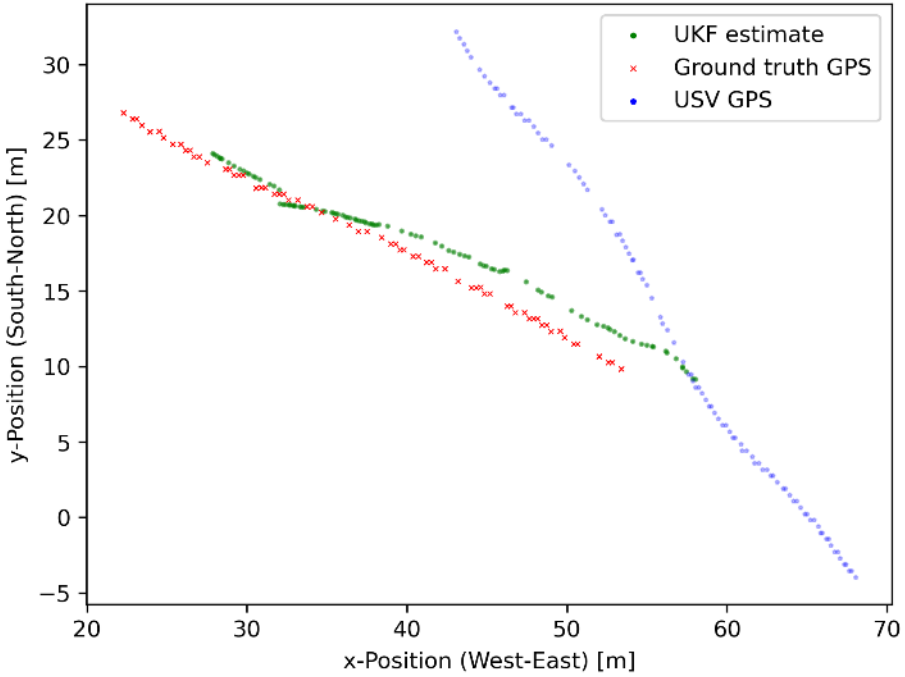
3.3 m

Results

Tracking Scenario 2







Tracking error

green position vs red position

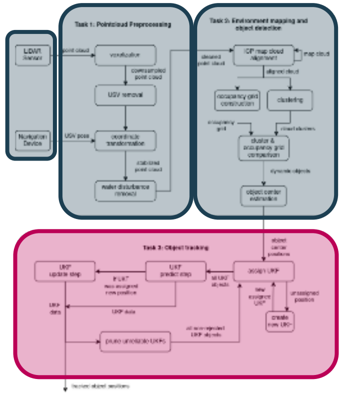
5.4 m

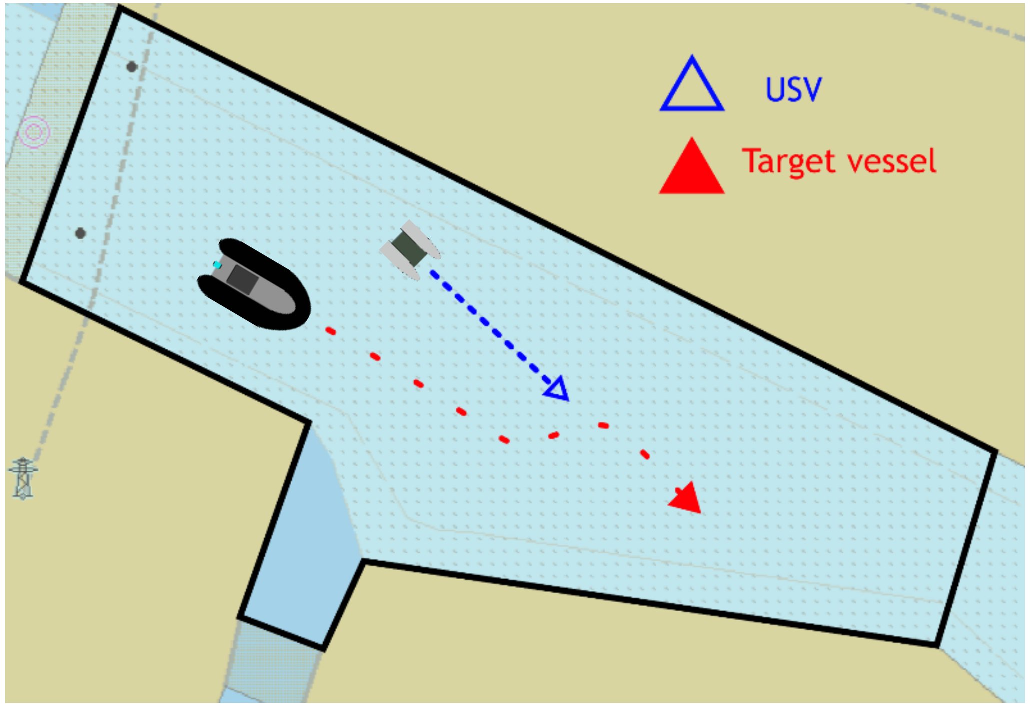
  Public information

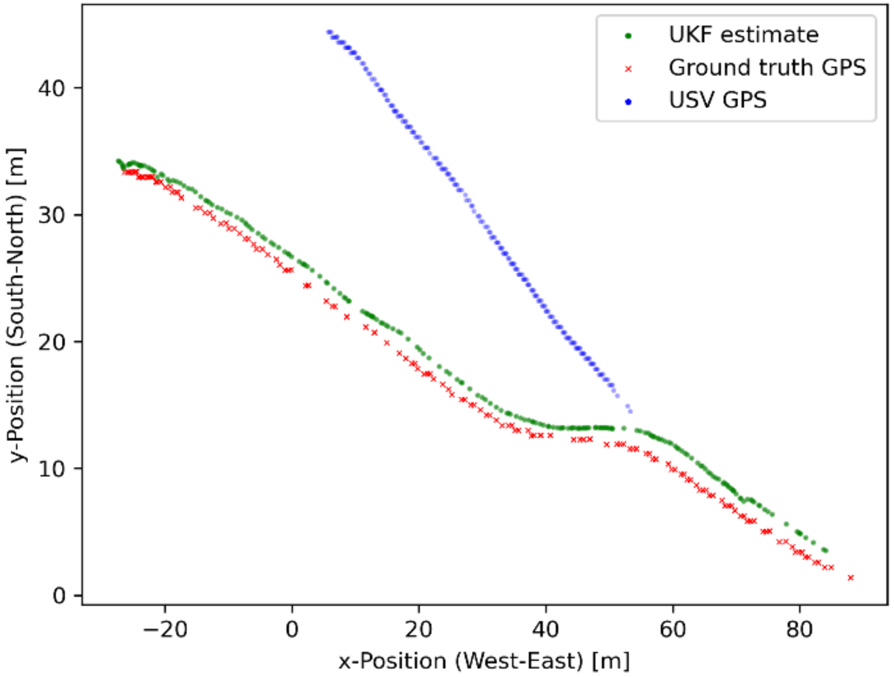
Fraunhofer CML

Results

Tracking Scenario 3





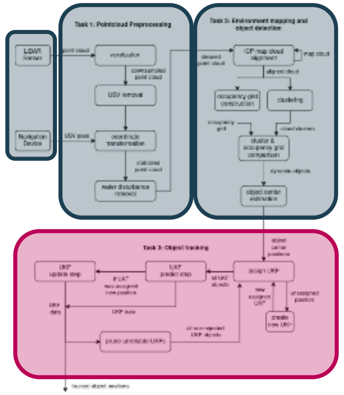


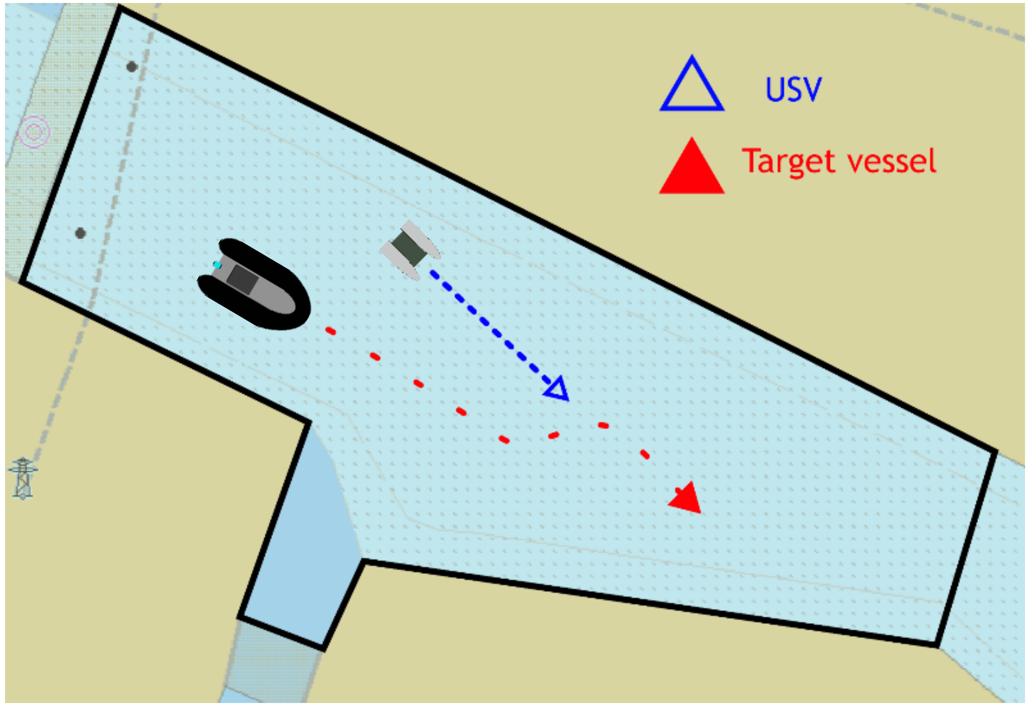
Tracking error
green position vs
red position

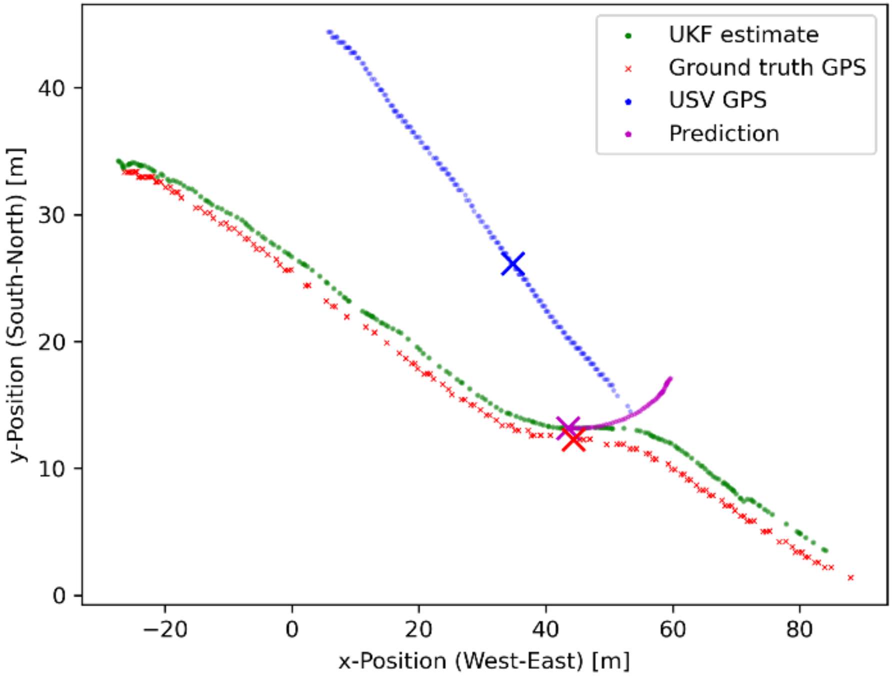
2.9 m

Results

Prediction Scenario 3







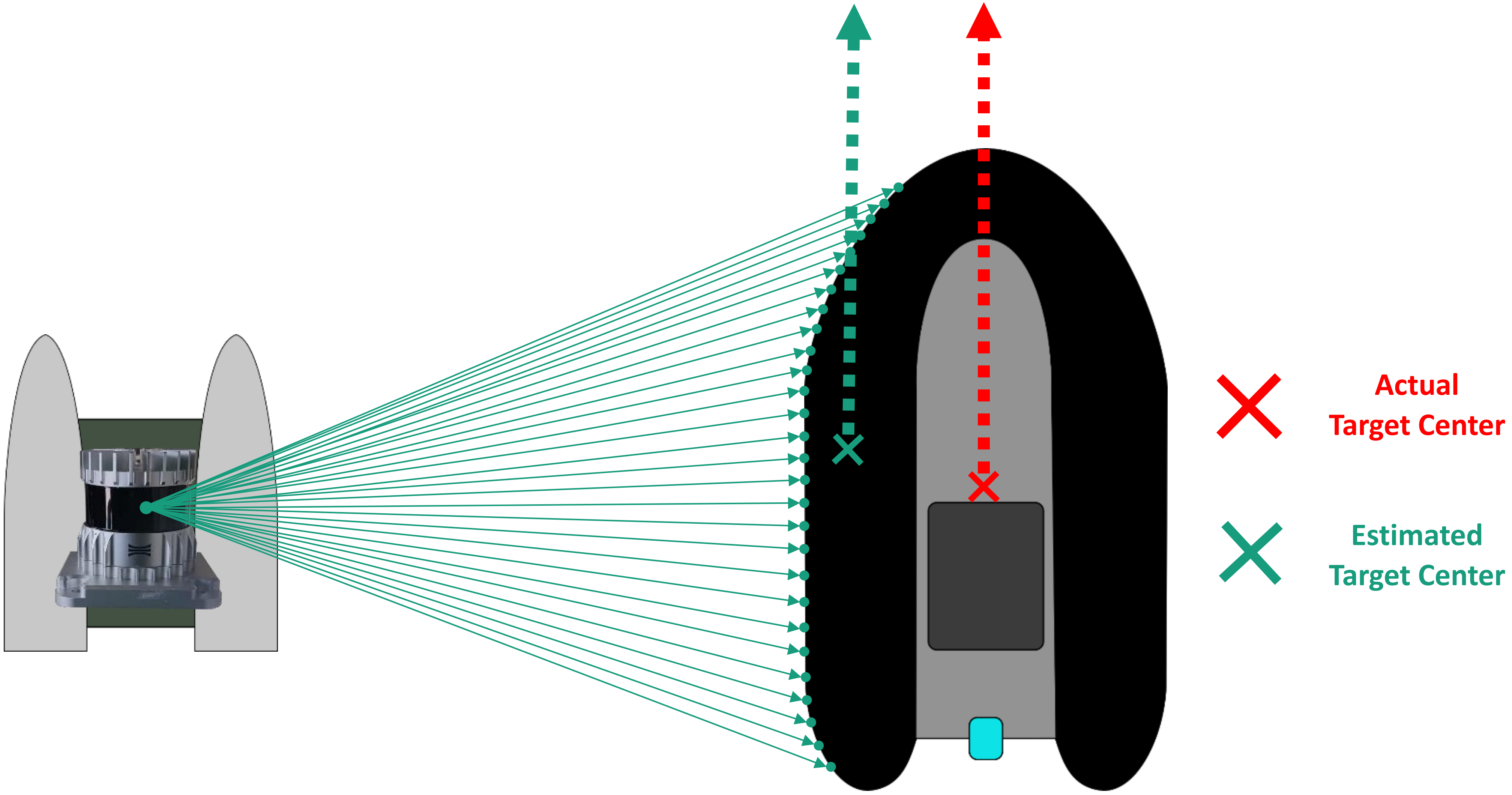
Tracking error

green position vs red position

2.9 m

Results

Discussion



Conclusion

Lidar-Based Obstacle Detection and Path Prediction

Key Achievements:

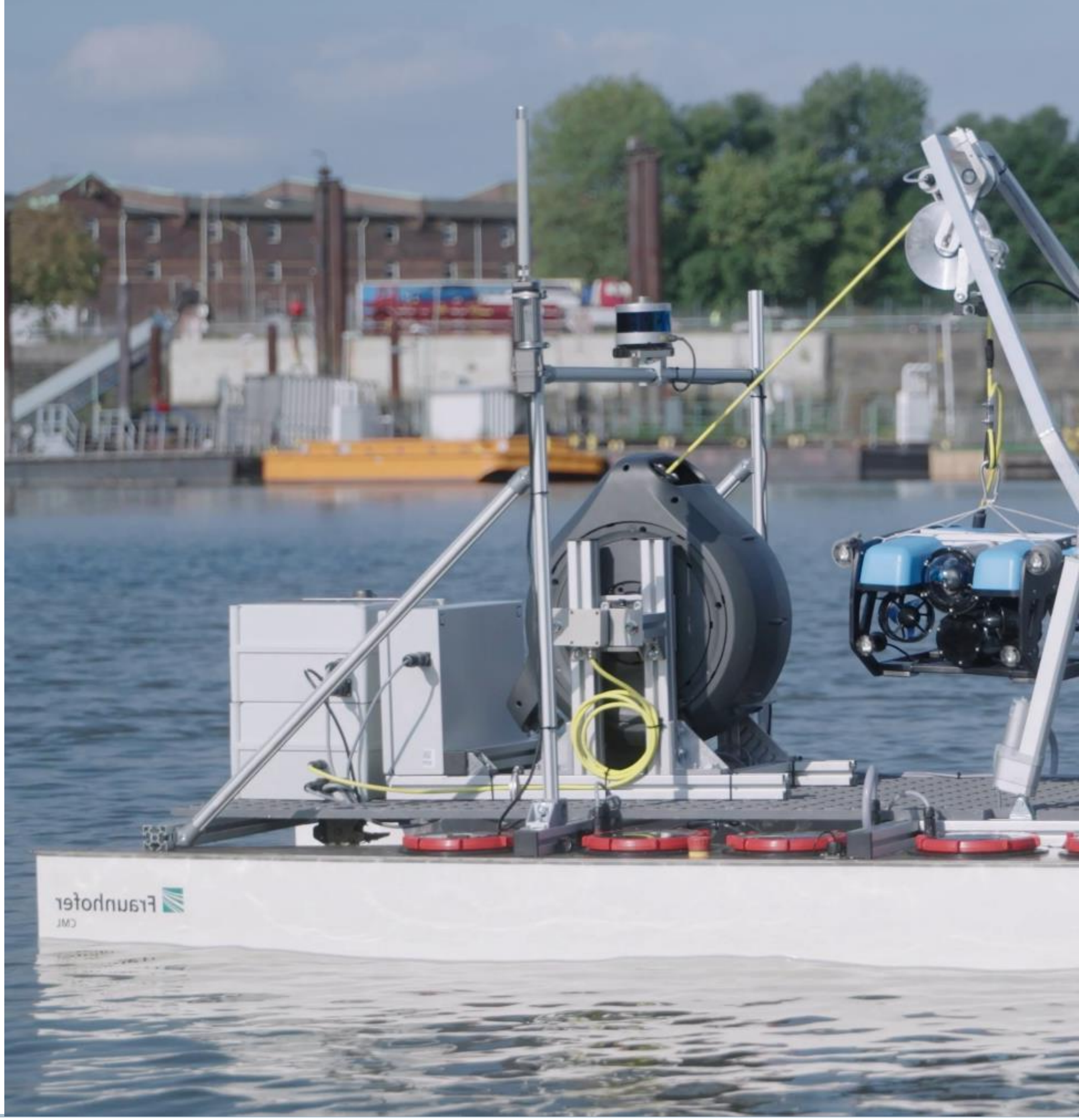
- Developed a novel perception pipeline for obstacle detection and path prediction.
- Overcame limitations of traditional methods in narrow, crowded environments like the Lotsekanal.

Innovative Approach:

- Used occupancy grid data for static land removal.
- Improved obstacle avoidance by integrating dynamic obstacle trajectories.

Future Enhancements:

- Advanced path planning with extrapolated dynamic trajectories.
- Explore AI-based object detection with 2D CNN PointPillars for greater accuracy and speed.



Fraunhofer CML

Fraunhofer-Center für Maritime Logistik und Dienstleistungen CML

Contact

Dipl. -Ing. Nico Zantopp
Department Sea Traffic and Nautical Solutions
Tel. +49 40 271 6461-1519 nico.zantopp@cml.fraunhofer.de