EVALUATING LIDAR AND RADAR BASED OBSTACLE DETECTION FOR DECISION SUPPORT IN VESSEL REMOTE OPERATIONS

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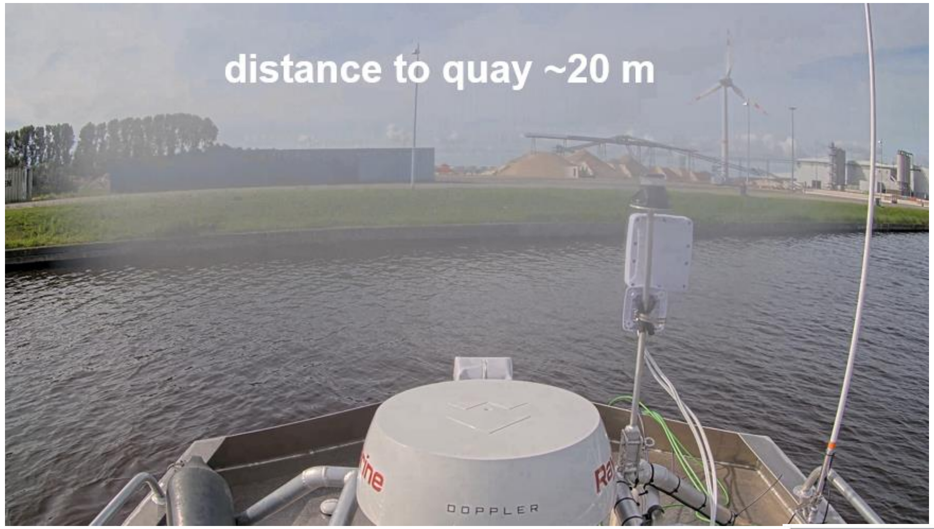
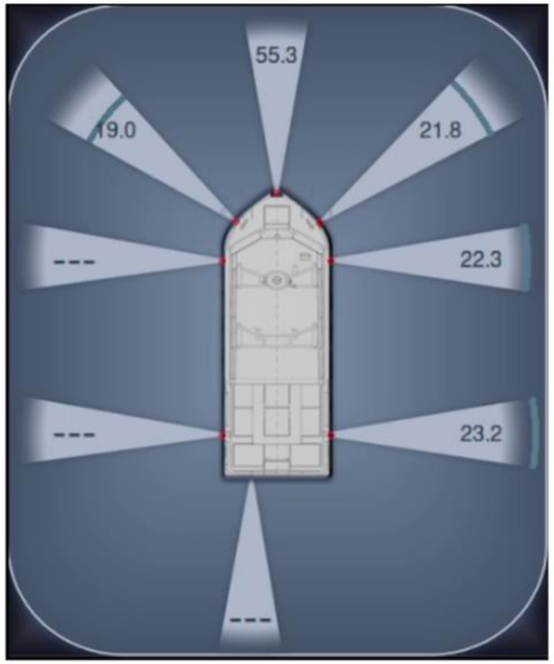
Motivation





- ⚠ Remote Operations: distance hard to estimate from camera footage
- ⚠ Challenging in harbor environment (e.g. locks)
- ✔ Solution: Assistance systems for precise distance determination.

Motivation

Radar and LiDAR are widely used for collision avoidance of MASS, e.g. [1], [2], [3], [4]

1D Radar

3D LiDAR

+ more robust against fog and rain
+ cost efficient
- lower resolution
- limited FOV

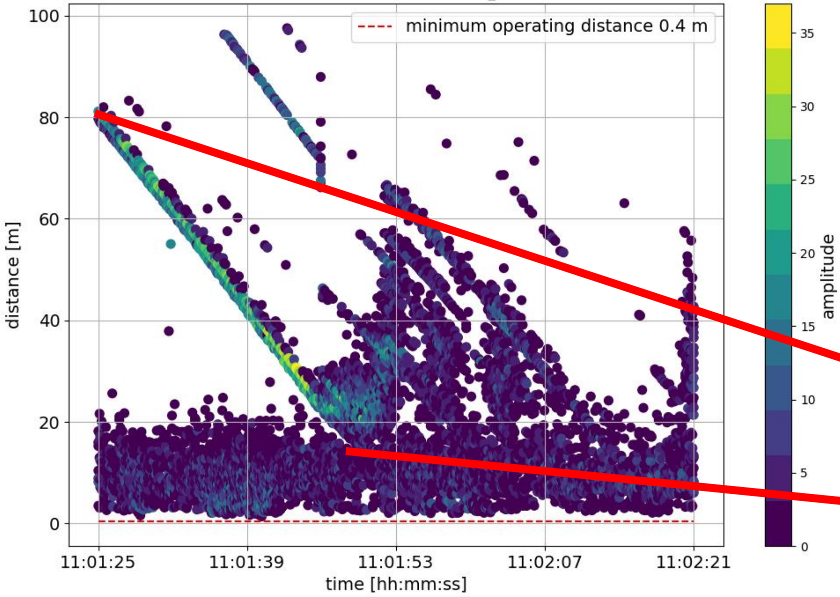
+ high resolution
+ 360° FOV
- more affected by fog and rain

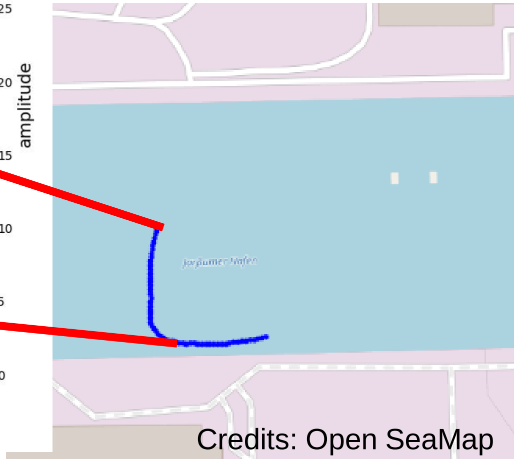
[1] 10.1109/SCIS-ISIS.2018.00119 [2] 10.23919/FUSION59988.2024.10706500 [3] 10.1109/USYS56283.2022.10073415 [4] 10.1109/OCEANS.2018.8604803

LiDAR and 1D Radar Data in the Maritime Environment

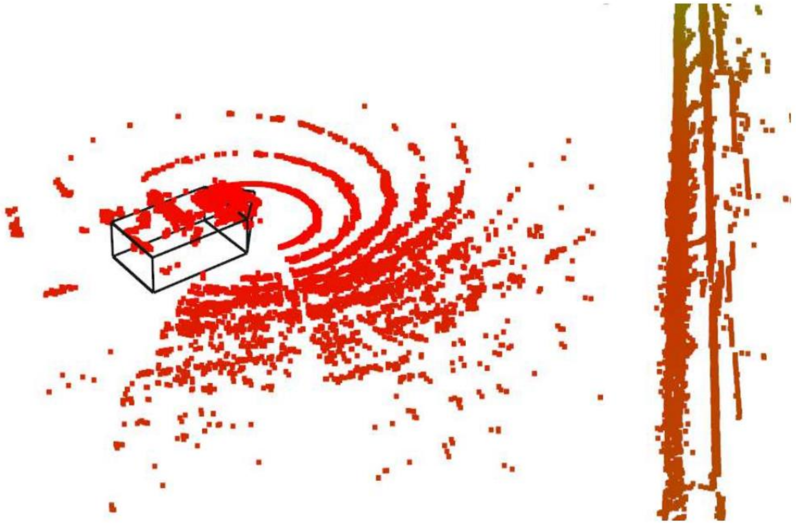
1D Radar 

LiDAR 





Credits: Open SeaMap



disturbing signals e.g. from rain, fog or water surface → data processing necessary

Research Questions

- Which data processing steps can be applied to improve Radar and LiDAR based distance measurements in the maritime environment?
- How can the distance measurements be evaluated?
- How accurate are the distance measurements?

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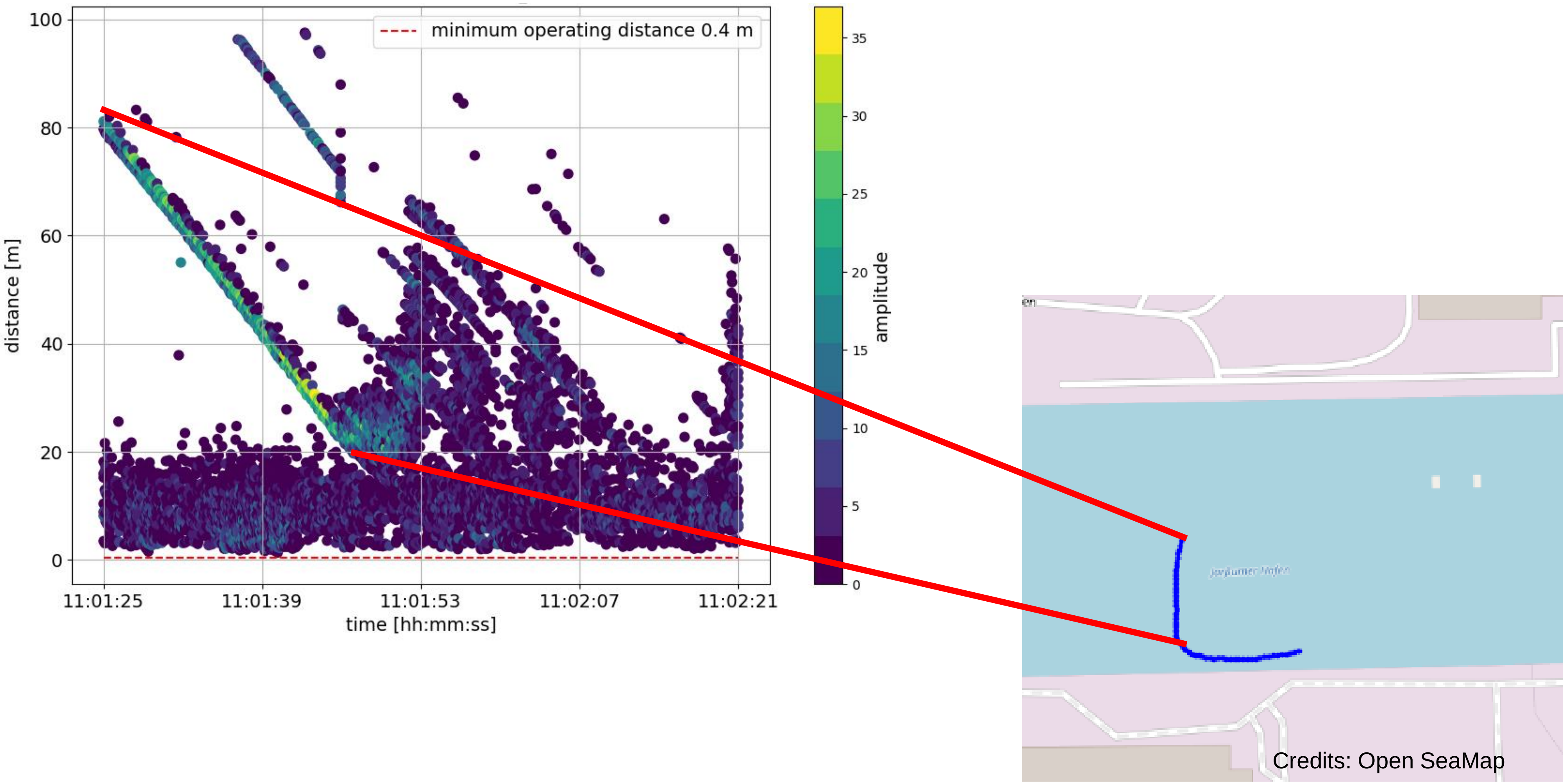
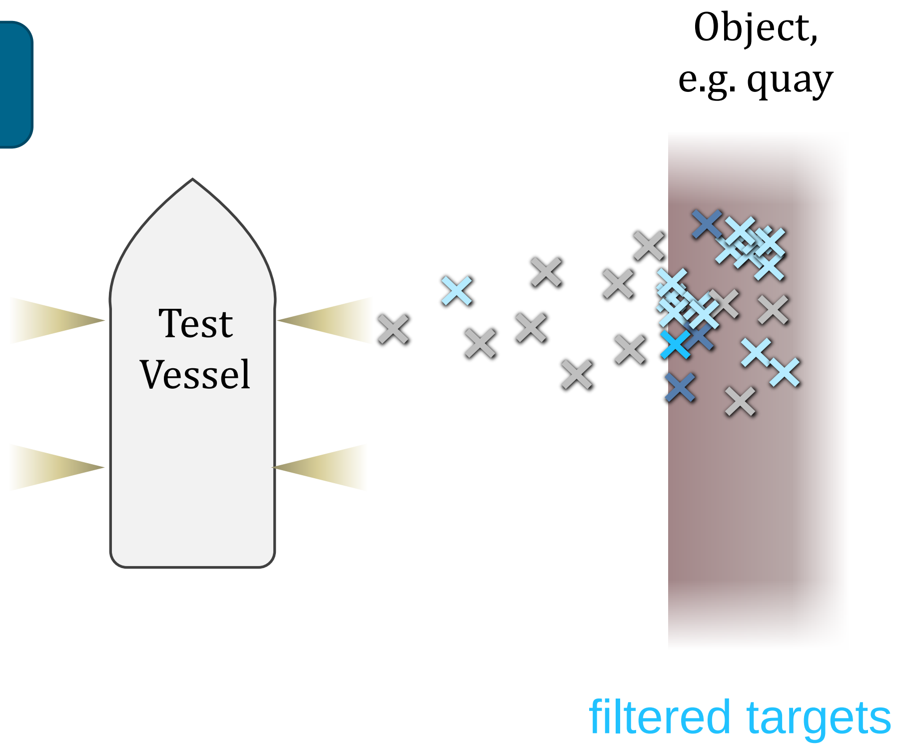

minimum operating distance 0.4 m
distance [m]
100
80
60
40
20
0
11:01:25
11:01:39
11:01:53
11:02:07
11:02:21
time [hh:mm:ss]
amplitude
35
30
25
20
15
10
5
0
Credits: Open SeaMap

Radar Data Processing

1) Filter data based on signal amplitude and radial velocity

$$A > A_{\mathrm{min}} \wedge v_{\mathrm{rad}} < v_{\mathrm{rad,max}}$$



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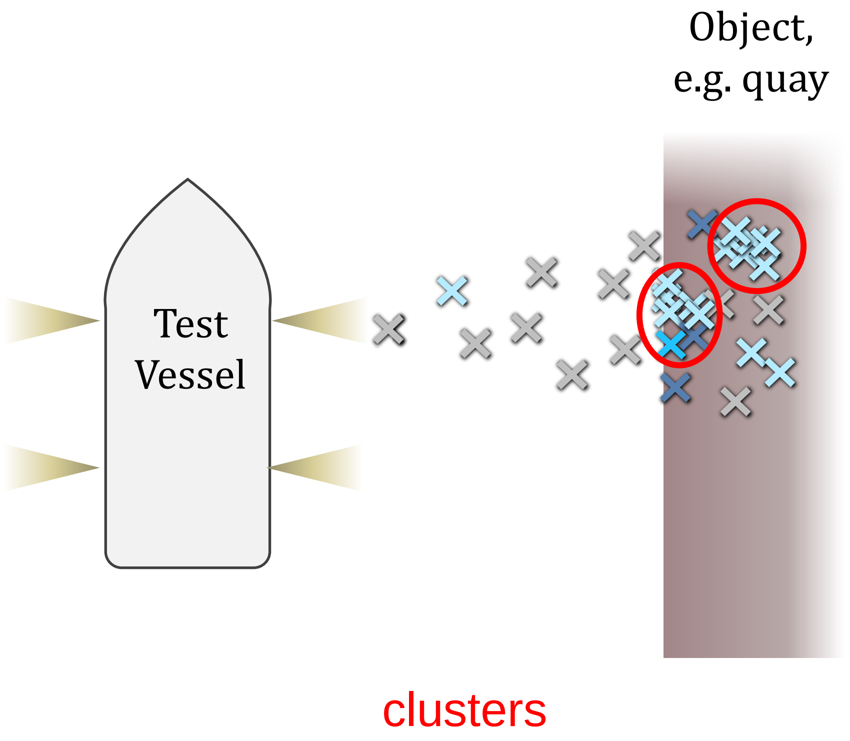
Radar Data Processing

1) Filter data based on signal amplitude and radial velocity

2) Density-based clustering (e.g. DBSCAN)



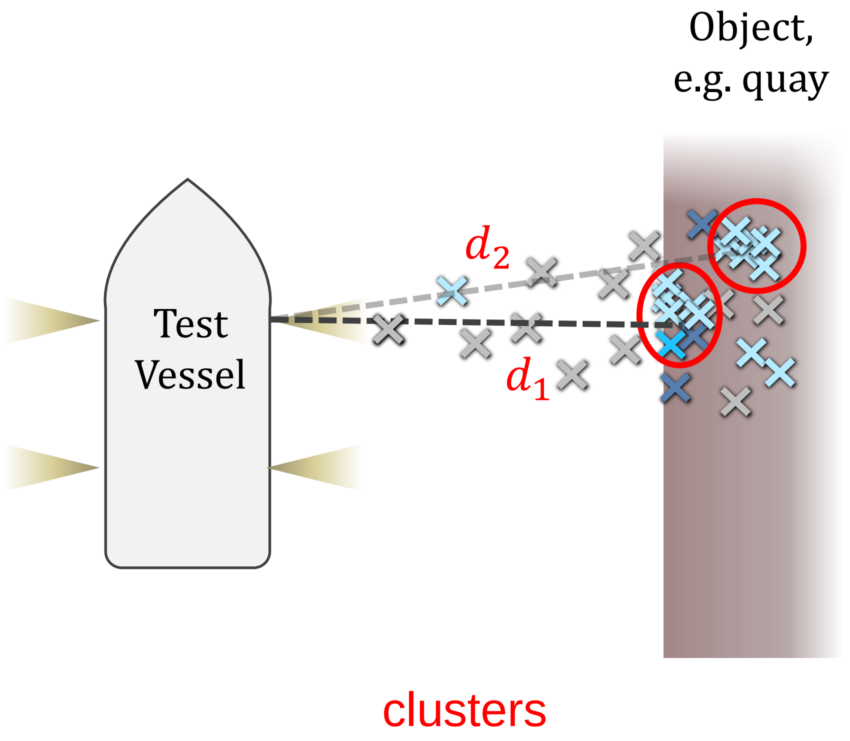
10.23919/FUSION59988.2024.10706500

Radar Data Processing

1) Filter data based on signal amplitude and radial velocity

2) Density-based clustering (e.g. DBSCAN)

3) Calculate **weighted average distance** for the two largest clusters



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Radar Data Processing

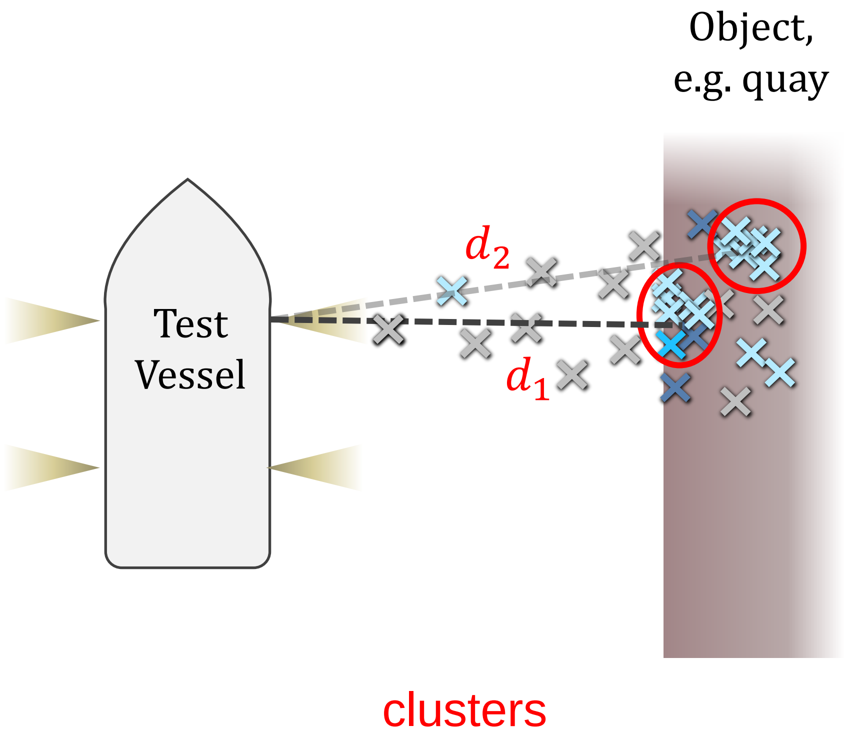
10.23919/FUSION59988.2024.10706500

1) Filter data based on signal amplitude and radial velocity

2) Density-based clustering (e.g. DBSCAN)

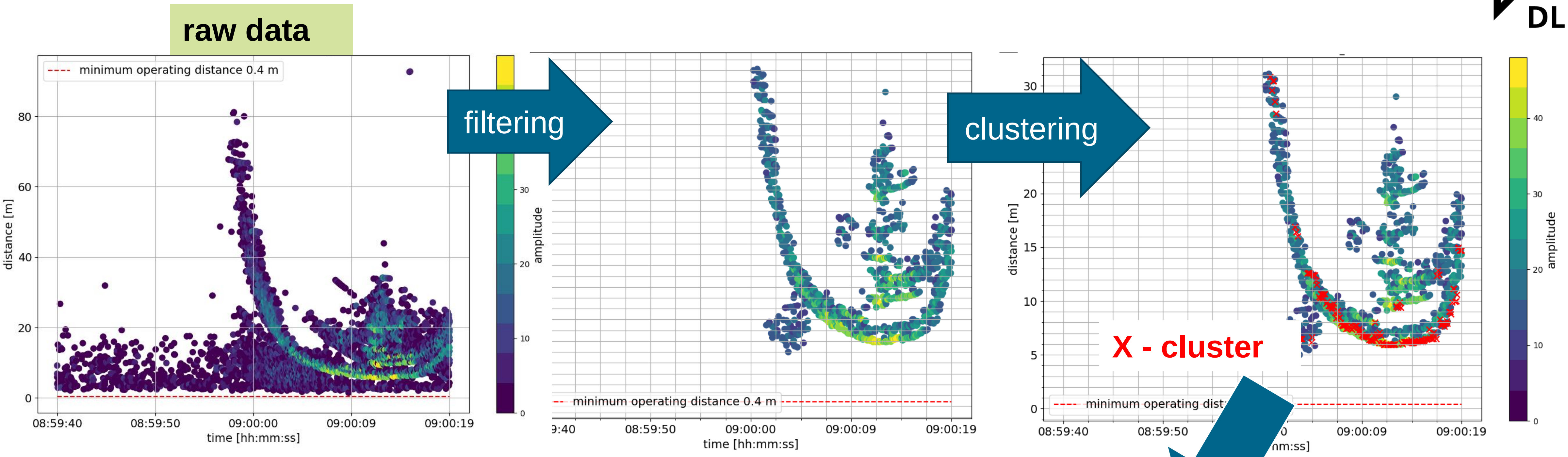
3) Calculate **weighted average distance** for the two largest clusters

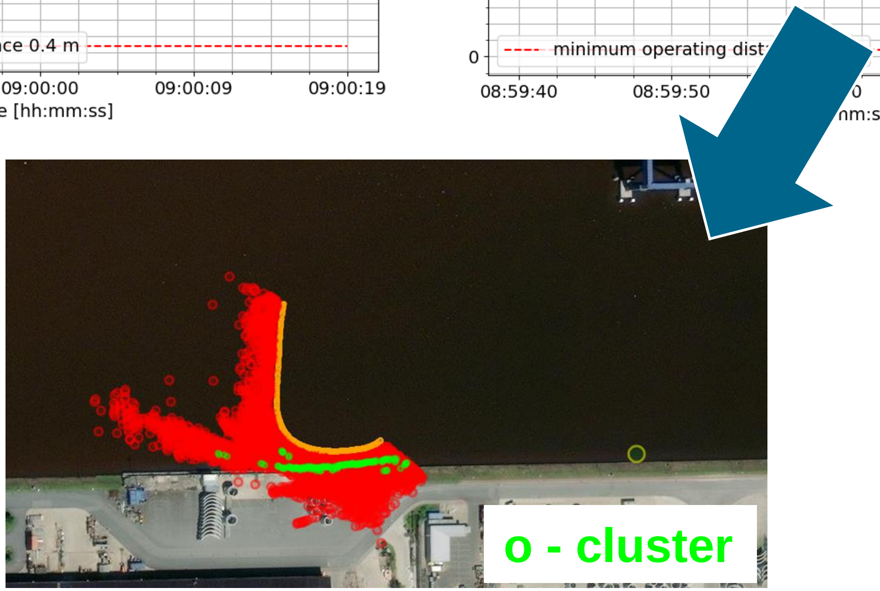
4) Select closer distance



$$d_{\text{final}} = d_1$$

Radar Data Processing: Effects on the Data



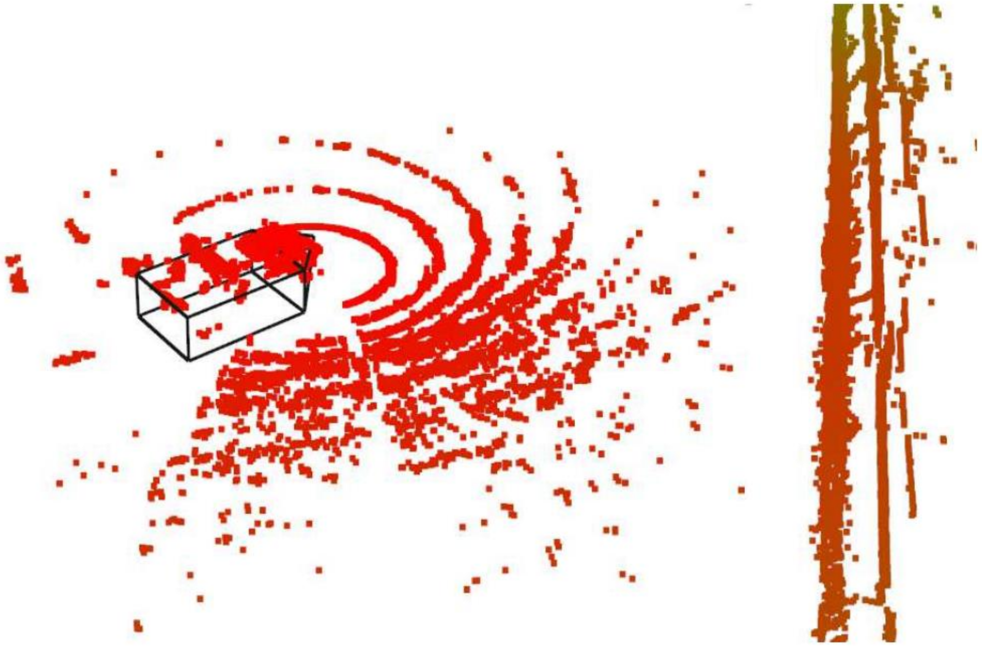


Satellite image from Esri, *World Imagery [basemap]*
https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9#!

10.23919/FUSION59988.2024.10706500

LiDAR Data Processing

1) Fit a plane to the water surface with RANSAC

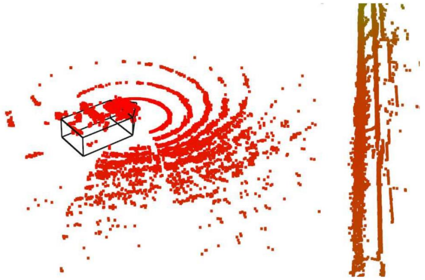


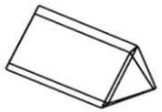
10.1109/MARIS64137.2025.11139524

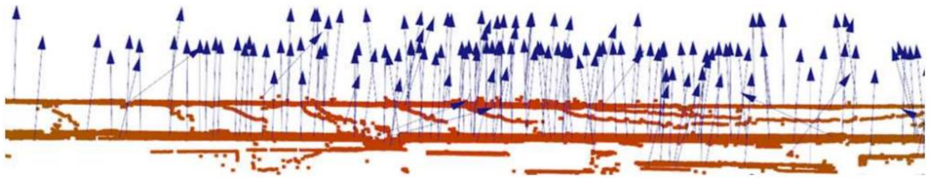
LiDAR Data Processing

1) Fit a plane to the water surface with RANSAC

2) Determine normal direction at each point from local surface







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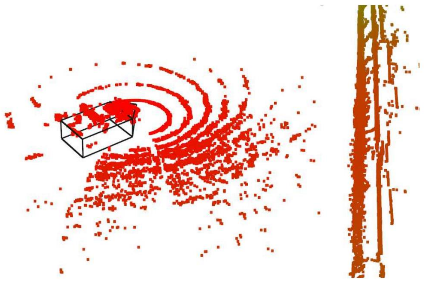
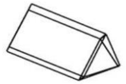
LiDAR Data Processing

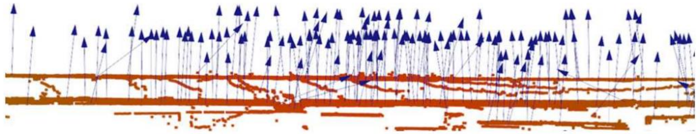


1) Fit a plane to the water surface with RANSAC

2) Determine normal direction at each point from local surface

3) Consider only surfaces with normal direction parallel to water plane for collision avoidance.





10.1109/MARIS64137.2025.11139524

LiDAR Data Processing

10.1109/MARIS64137.2025.11139524

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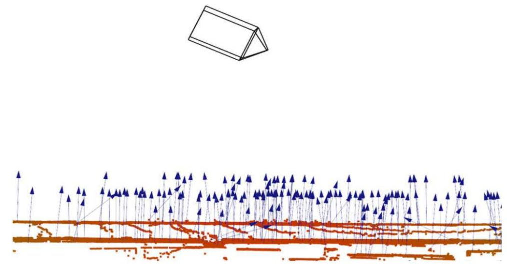
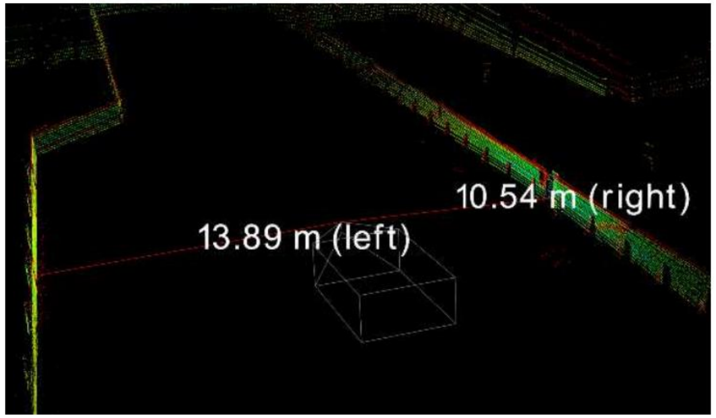


3) Consider only surfaces with normal direction parallel to water plane for collision avoidance.

4) Determine shortest distance to harbor structures for collision avoidance



Research Questions

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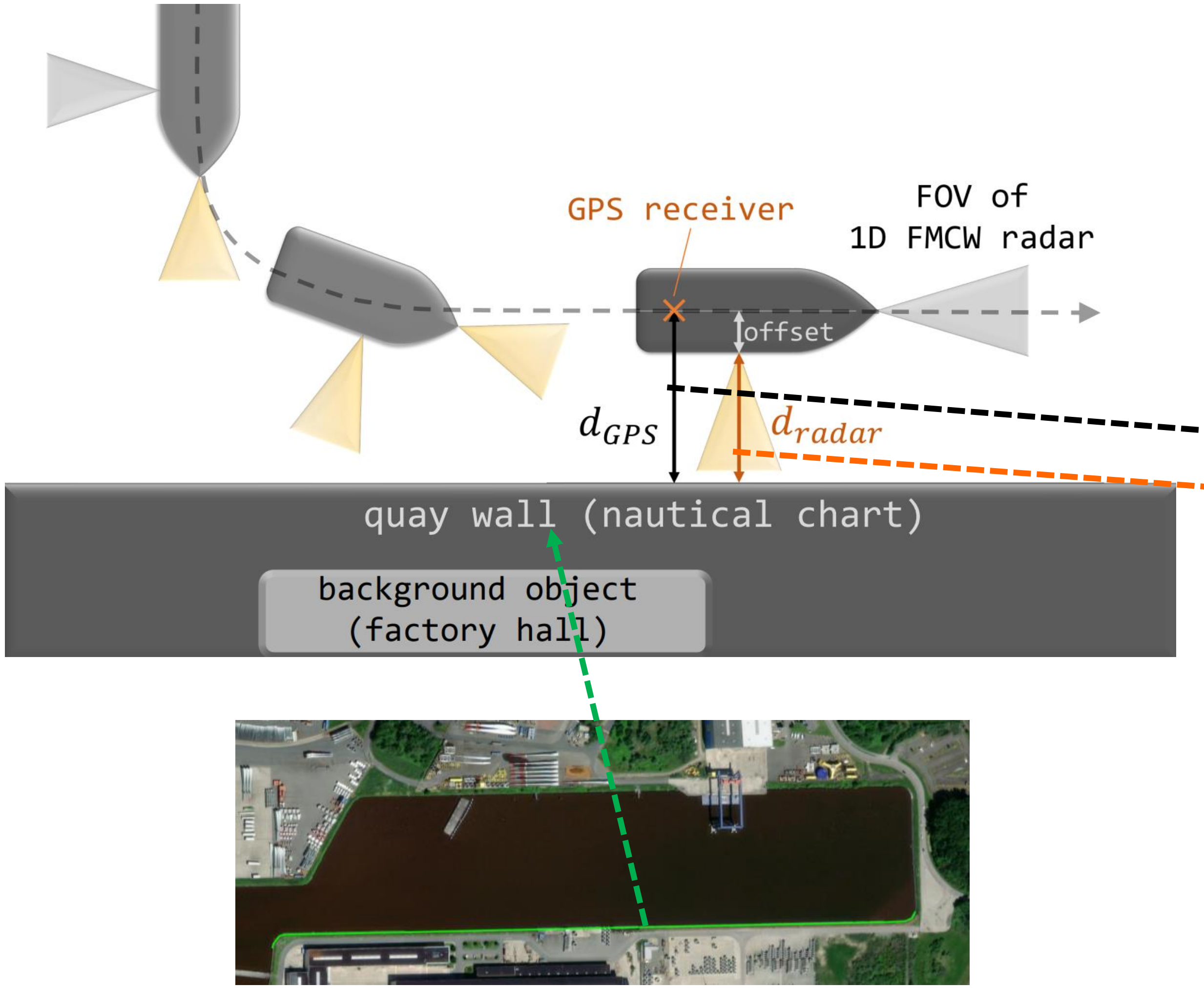
- How accurate are the distance measurements?

Evaluation: Experimental Setup

- Test vessel „Sally“ of the eMaritime Integrated Reference Platform (eMIR)
- One 3D LiDAR at the bow of the test vessel; 8 1D Radar sensors at (2 port, 2 starboard, 3 bow, 1 aft)

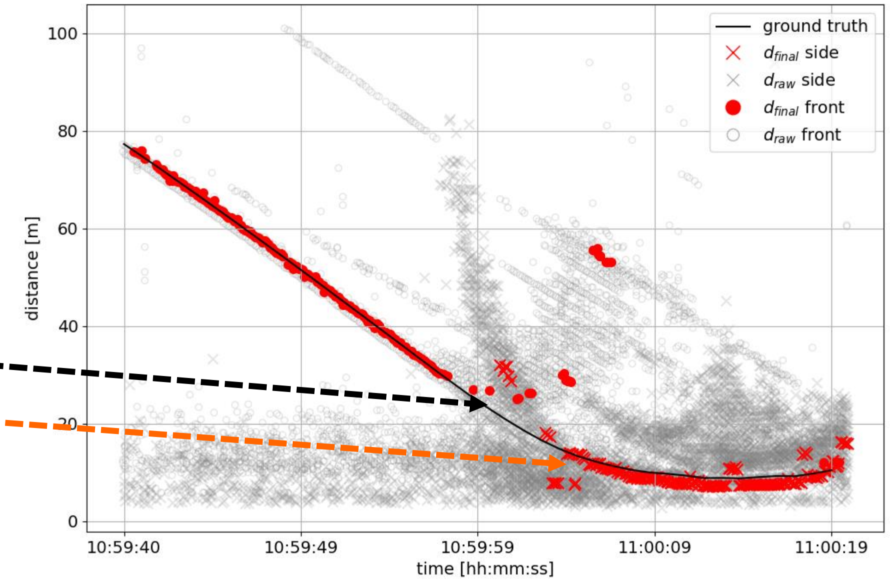
Further information on eMIR Testbed

Evaluation: DGPS based Ground Truth



Satellite image from Esri, *World Imagery [basemap]*
https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9#!

plot over time



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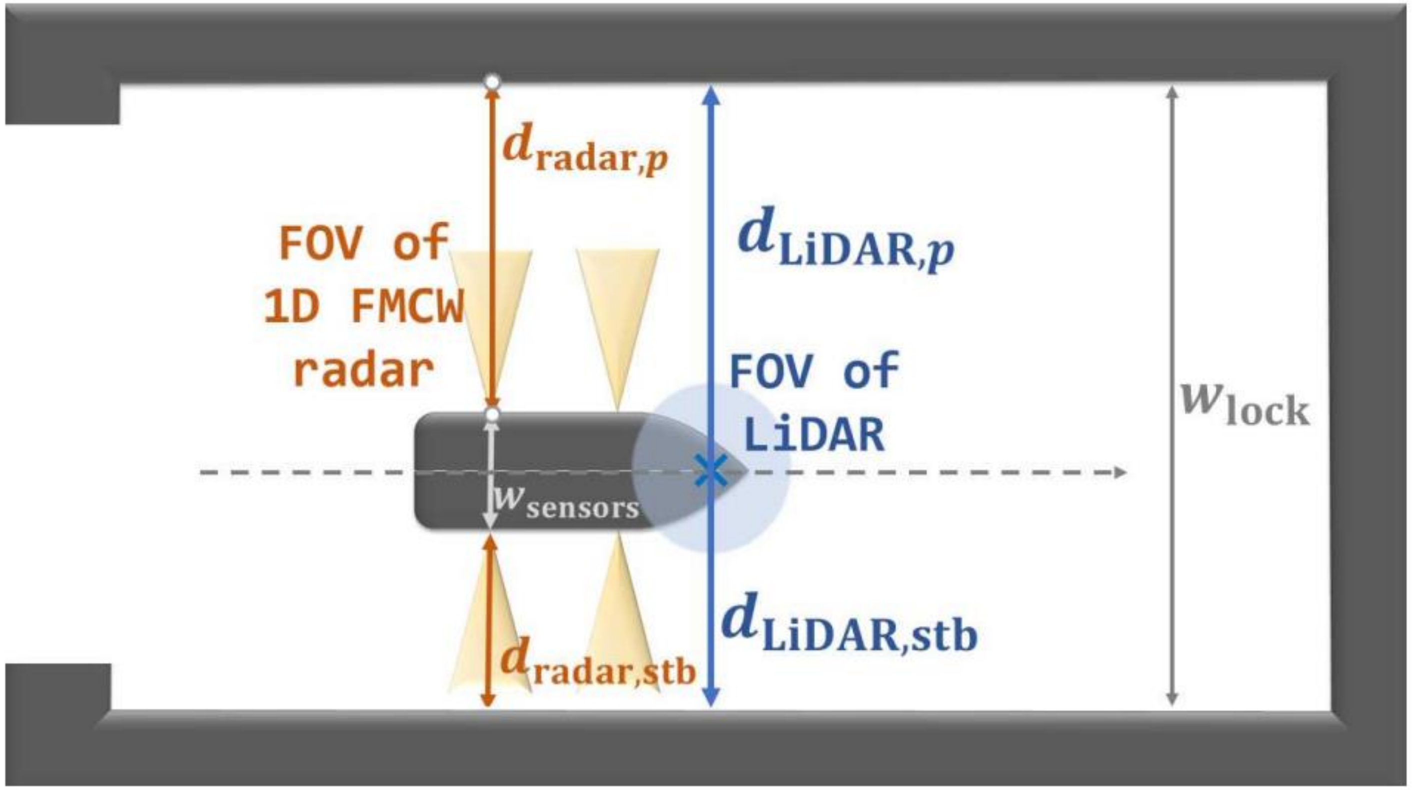
10.1109/MARIS64137.2025.11139524

Evaluation: Nominal Lock Width as Ground Truth



10.1109/MARIS64137.2025.11139454

- Measure distances to side lock walls
- Compare LiDAR and Radar distances to the nominal lock width

Research Questions

- **Which data processing steps can be applied to improve Radar and LiDAR based distance measurements in the maritime environment?**
- **How can the distance measurements be evaluated?**
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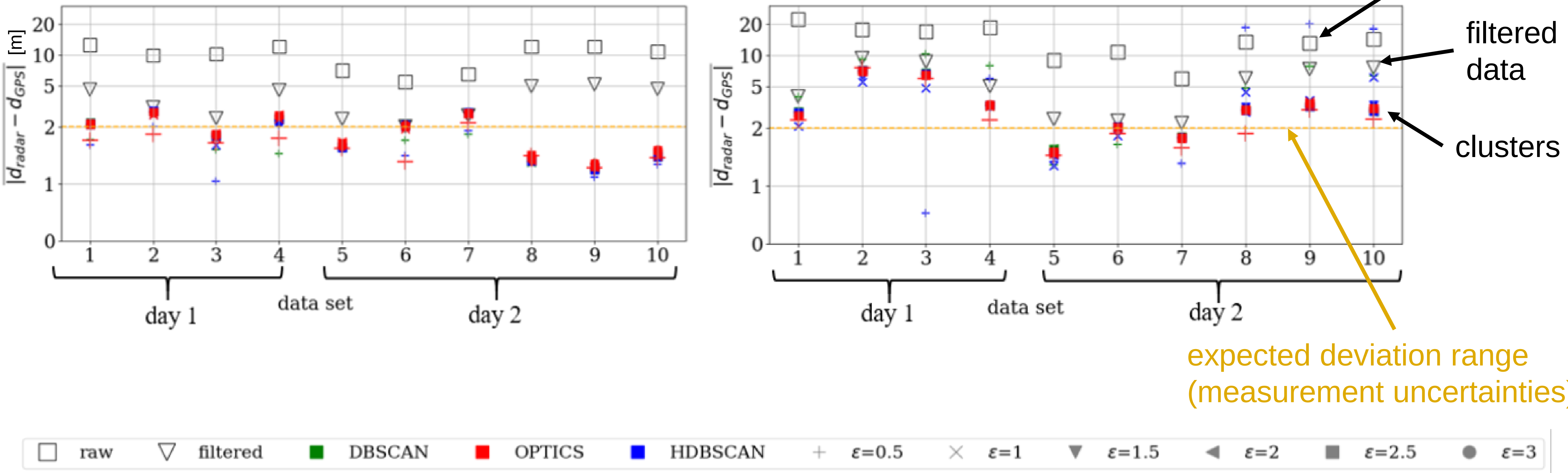
Evaluation: Results Radar

Deviation from GPS based ground truth

starboard sensor

front sensor



raw data

filtered data

clusters

expected deviation range (measurement uncertainties)

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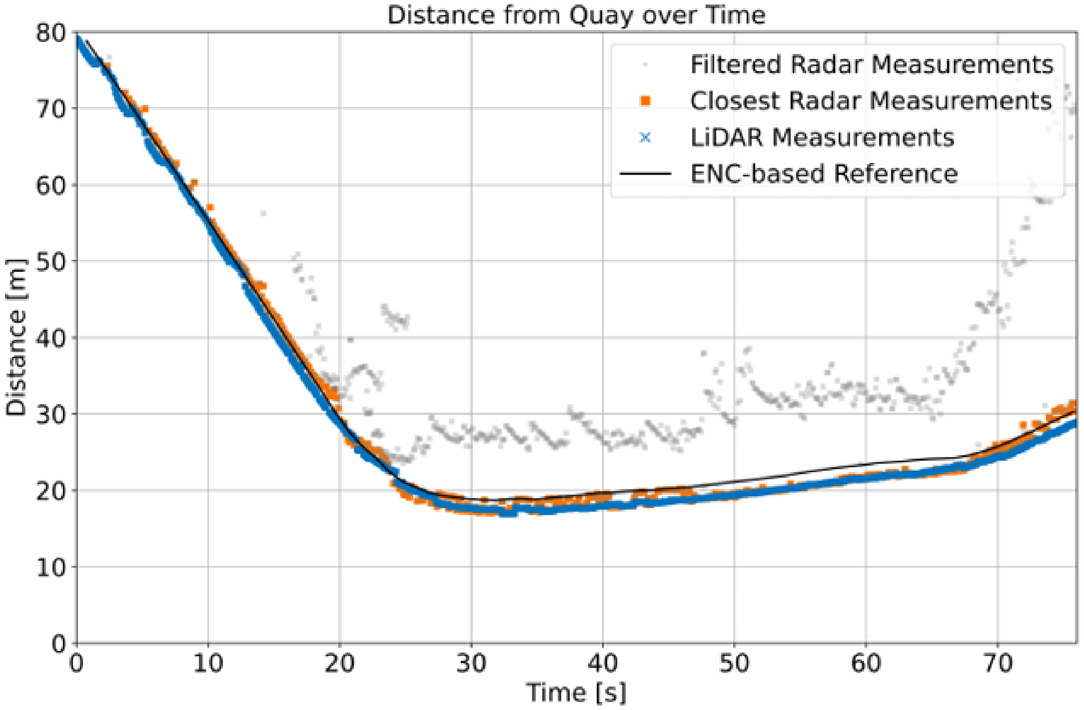
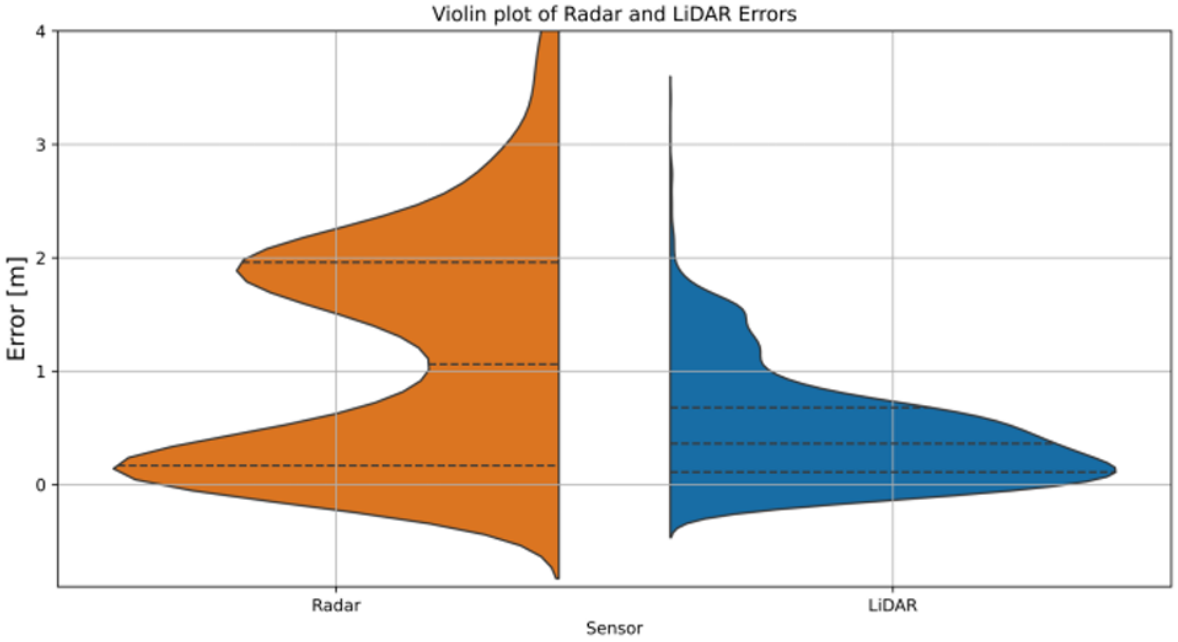
Evaluation Results: Radar and LiDAR

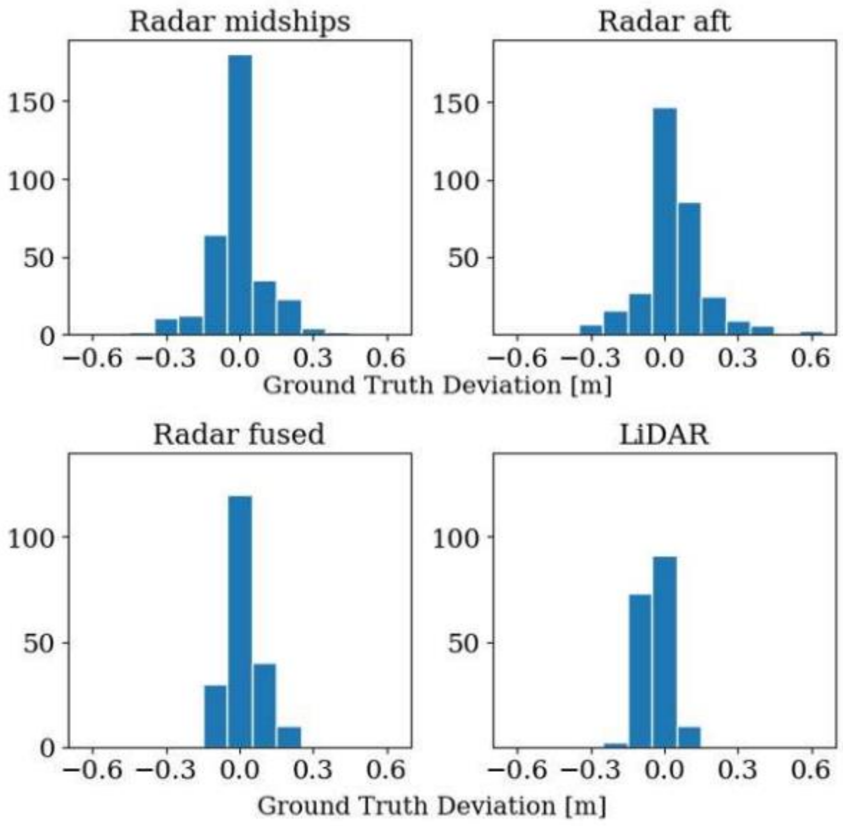


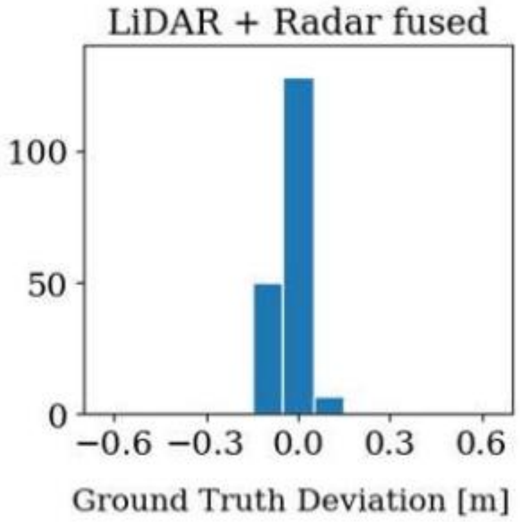


Figures from Pieper et al. 2025:

10.1109/MARIS64137.2025.11139524

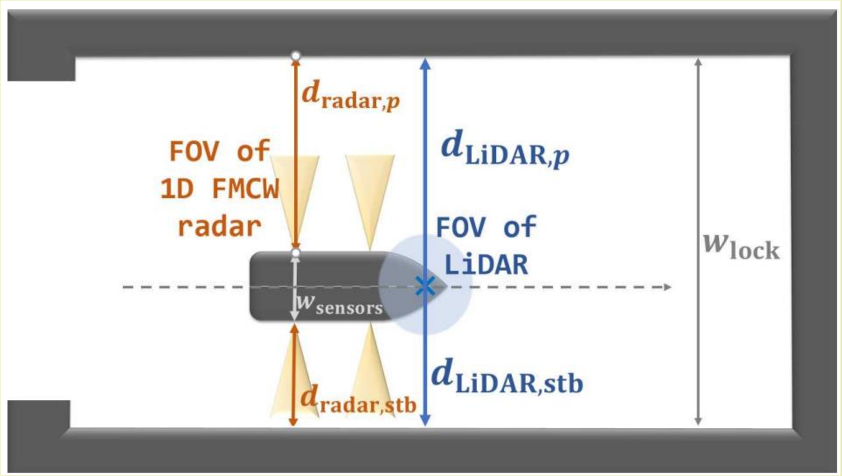
Evaluation: Results Radar & LiDAR in Lock





Ground Truth Deviation

$= (d_{\text{sens,stb}} + d_{\text{sens,p}} + w_{\text{sensors}}) - w_{\text{lock}}$



→ Improved accuracy through fusion

Summary and Outlook

Summary

- **Applied data processing to utilize 1D Radar and LiDAR data in maritime environment**
- **Conducted sea trials to evaluate distance measurements; ground thruth: DGPS position & nominal lock width**
- **LiDAR better suited to detect objects with low radar cross section**
- **Data Fusion:** multiple Radar sensors, Radar and LiDAR

➢ **Fusion increases distance accuracy**

Future Work

- Apply **different fusion algorithms**; introduce **reliability metric for weighted fusion**
- Test system in **more complex port infrastructure collision avoidance scenarios**
- **Compare information in nautical charts to detected objects**

Thank you for your attention!

Further information on eMIR Testbed

DLR

Bundesministerium
für Bildung
und Forschung

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Imprint

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Institute:	Systems Engineering for Future Mobility
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