KU LEUVEN

IMP Intelligent Mobile Platforms

IW-NET final event

Ghent
12/10/2023
KU Leuven – IMP
Prof. Peter Slaets

Overview

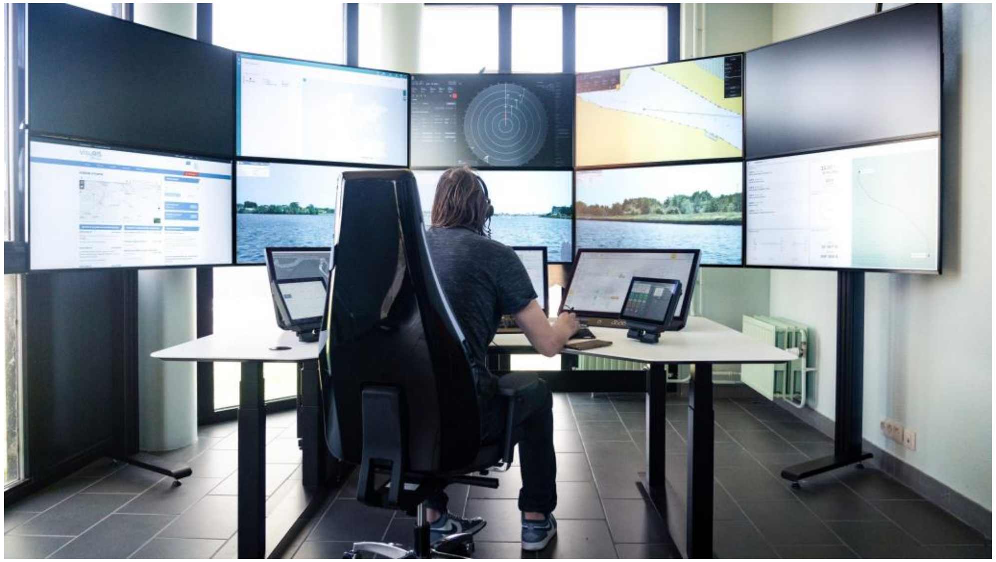
- **Context**
- Sensor box design
- Software architecture
- Demonstration

Context

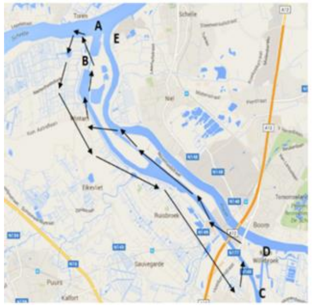
- A lot of autonomous vessels are emerging:

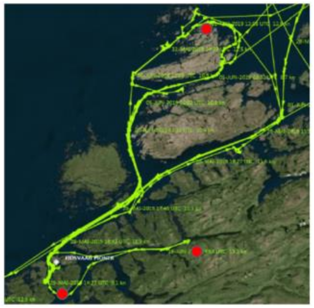
Context

- **Autoship H2020 project (2023):**
- Shore Control Center + Autonomous Navigation System (waypoints) + Situational awareness (camera)



https://www.nt.nl/binnenvaart/2023/06/02/autonoom-binnenvaartschip-legt-succesvolle-proefvaart-af-in-belgie/





Context

- **KU Leuven IW-NET solution:**

- - Sensor box (vs. integrated)
- - Catamaran (vs. retrofit barge)
- - Electric propulsion (vs. diesel)
- - Over-actuated (vs. under-actuated)

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Overview

- Context
- **Sensor box design**
- Software architecture
- Results

Sensor box – version 1

Enclosed components:

- Cincoze DS-1100 embedded computer
- Velodyne VLP-16 LiDAR
- Septentrio AsteRx-U Marine GNSS
- Xsens MTi-G-710 IMU
- FLIR PTU-E46 Pan-tilt platform

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Sensor box – version 2

- **Enclosed components:**

- RobotSense 32 Lidar
- AsteRx-i3 S Pro+ GNSS/INS
- QUARK-ELEC AIS receiver
- Annke I91BM camera
- 1.5U Rackmount Intel Coffee Lake Computer

Sensor box – version 2

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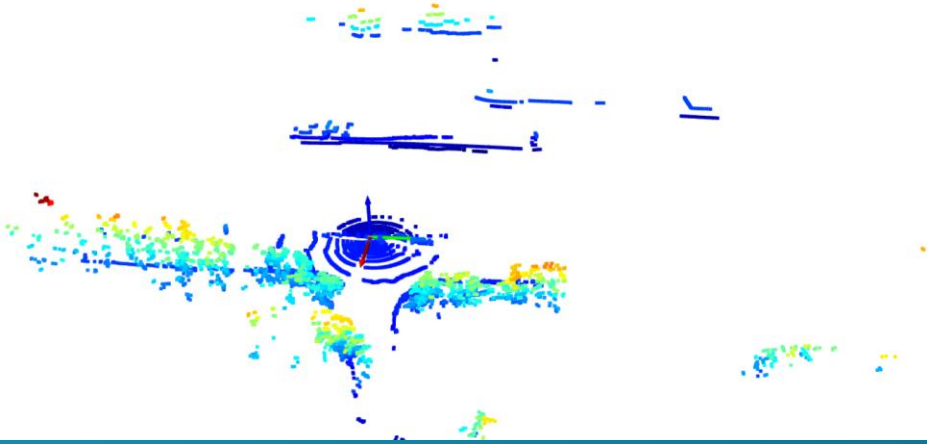
Sensor box – version 2

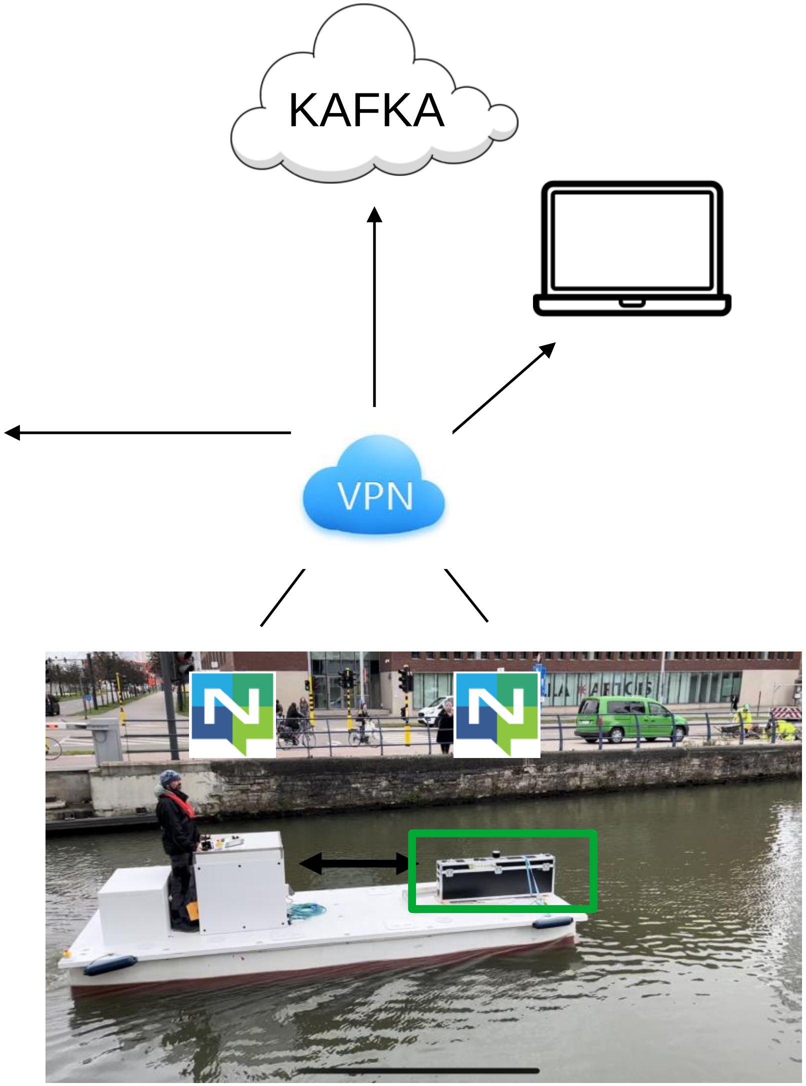


Overview

- Context
- Sensor box design
- **Software architecture**
- Results

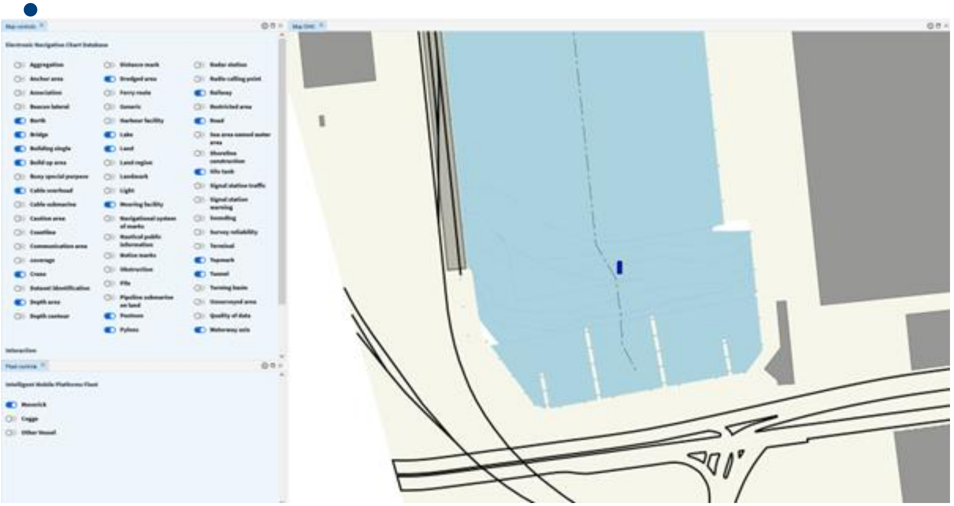
Open communication architecture

- **Distributed system**
-
- Publish-Subscribe system
- External sensor box
- VPN server
- Shore control center
- KAFKA cloud streaming
-
-
-
-

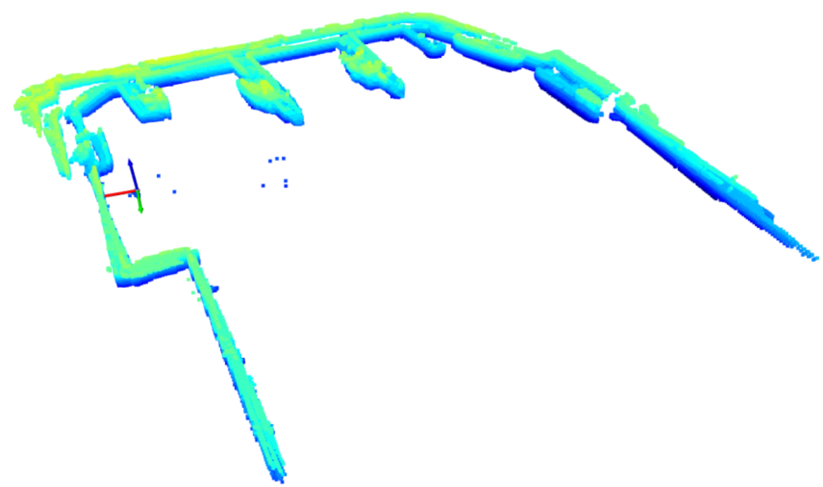


Custom designed visualization

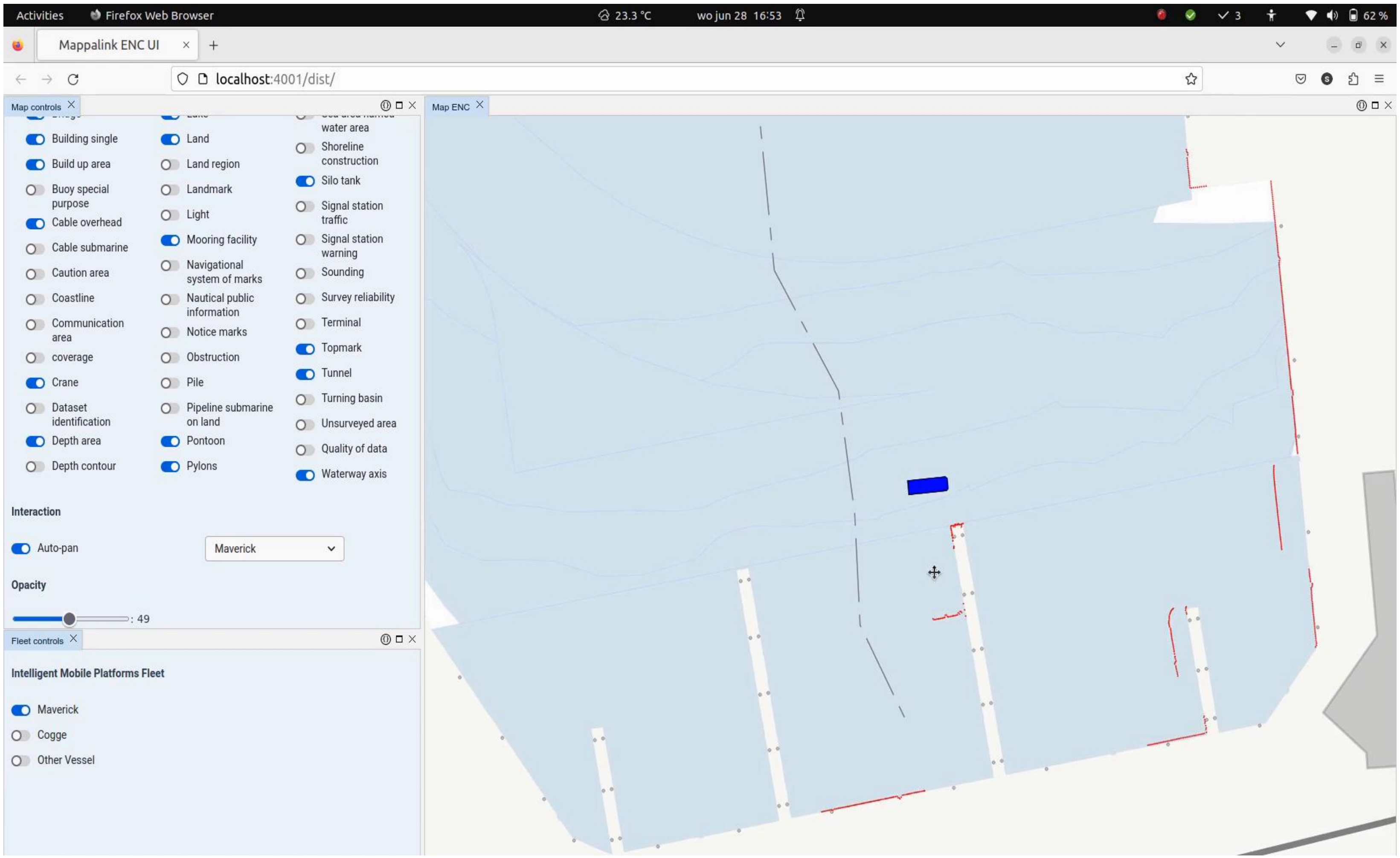
- Custom IENC map



- Real-time LiDAR visualization



Custom designed visualization



Overview

- Context
- Ship design
- Software architecture
- **Results**

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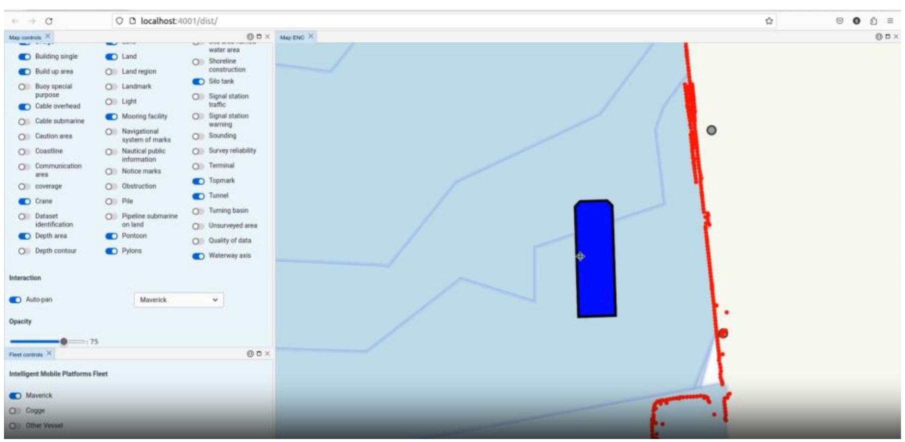
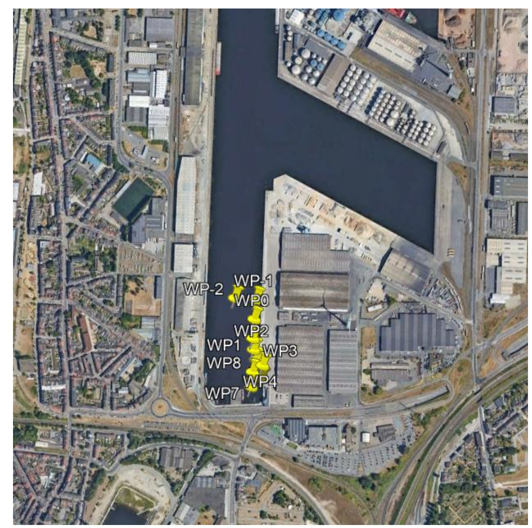
Demonstration

- Waypoint following (using GNSS)
- Lidar based navigation (in between waypoints)

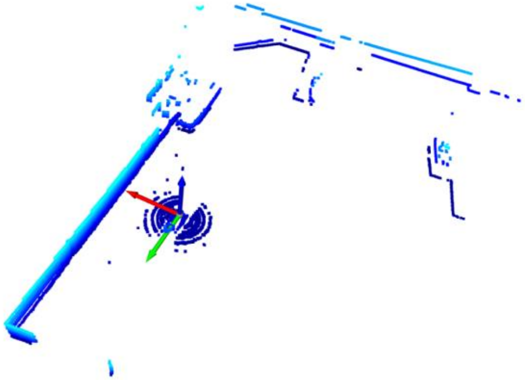


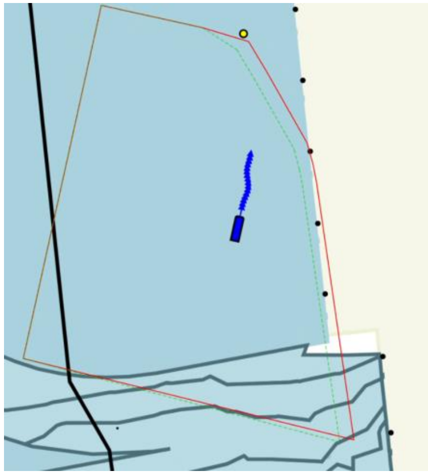


Research and Activities: Demonstration

IW-NET: Lidar based navigation

- **Requirements**:
  - LIDAR-based navigation through **unknown (static) environments** with limited dependence on GNSS
- **Implementation**:
  - Overactuated test vessel **Maverick**
- **Assumptions**:
  - Simplified operating conditions
  - ISV surroundings can be locally approximated as a convex polytope
- **Methodology**:
  - Deriving convex polytopes for attainable positions directly from segmented LIDAR data based on work of A. B. Martinsen[29]





Research and Activities: Demonstration

IW-NET: Obstacle Avoidance

- **Model Predictive Control (MPC)**

$$\min_{x,u} J(x,u,S)$$

$$\min_{x,u,S} J(x,u,S) = \|x - x_{waypoint}\| + K_s \sum_i S_i + K_u \|u_\delta\|$$

$$\text{s.t.} \quad \forall_i \in [1,\dots,N]$$

$$g(x,u) = 0$$

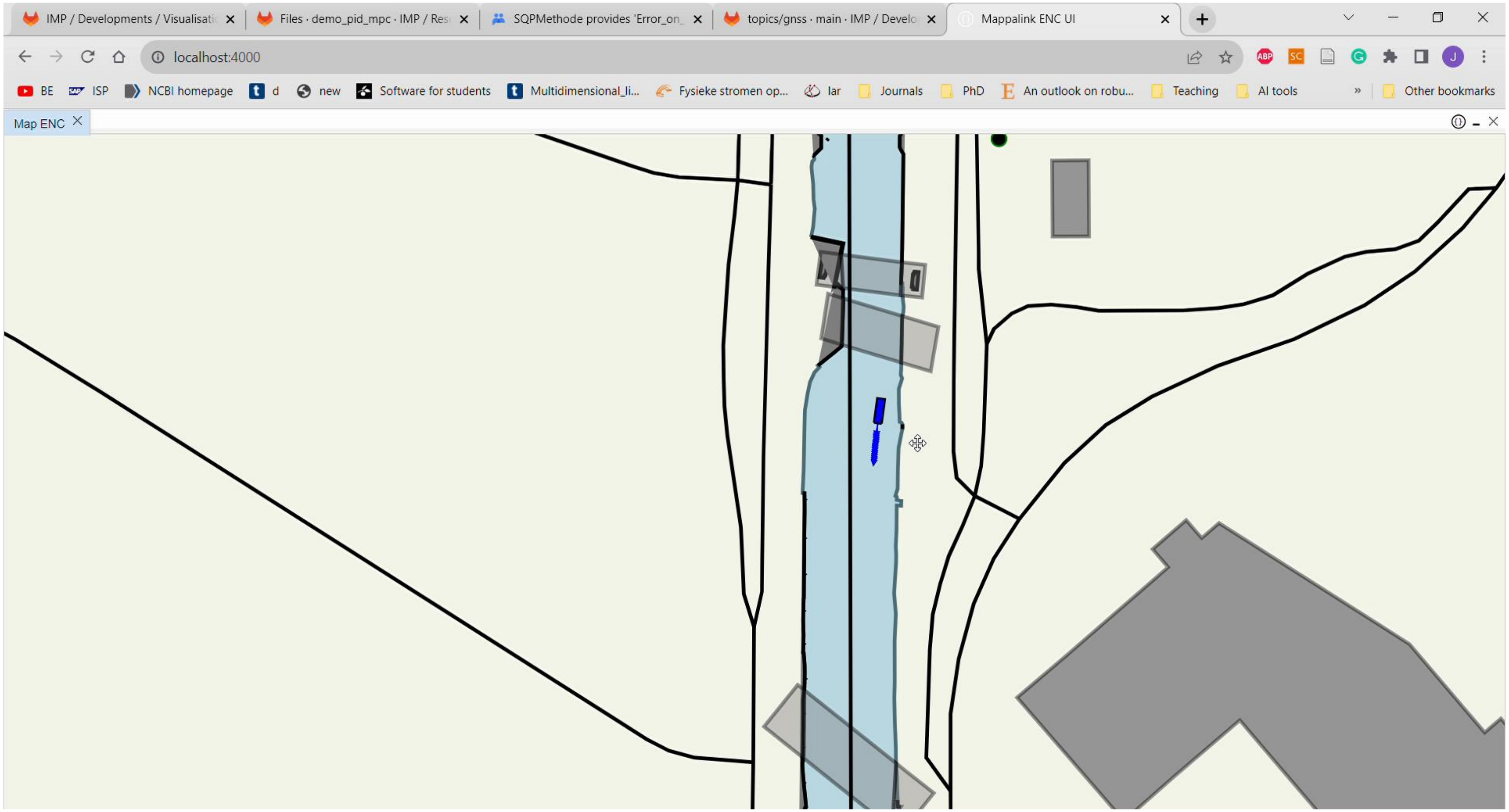
$$Ap_i - b + 4 - S_i \leq 0$$

$$0 \leq S_i \leq 3$$

  - g includes model-related, multiple shooting and terminal constraints
  - S_i is slack on exceeding a spatial boundary to avoid infeasibility
  - A and b can change at a different frequency than of the MPC loop (ideally at the same rate)

Research and Activities: Demonstration

IW-NET: Simulation



Engineering Technology, Department of Mechanical Engineering , IMP

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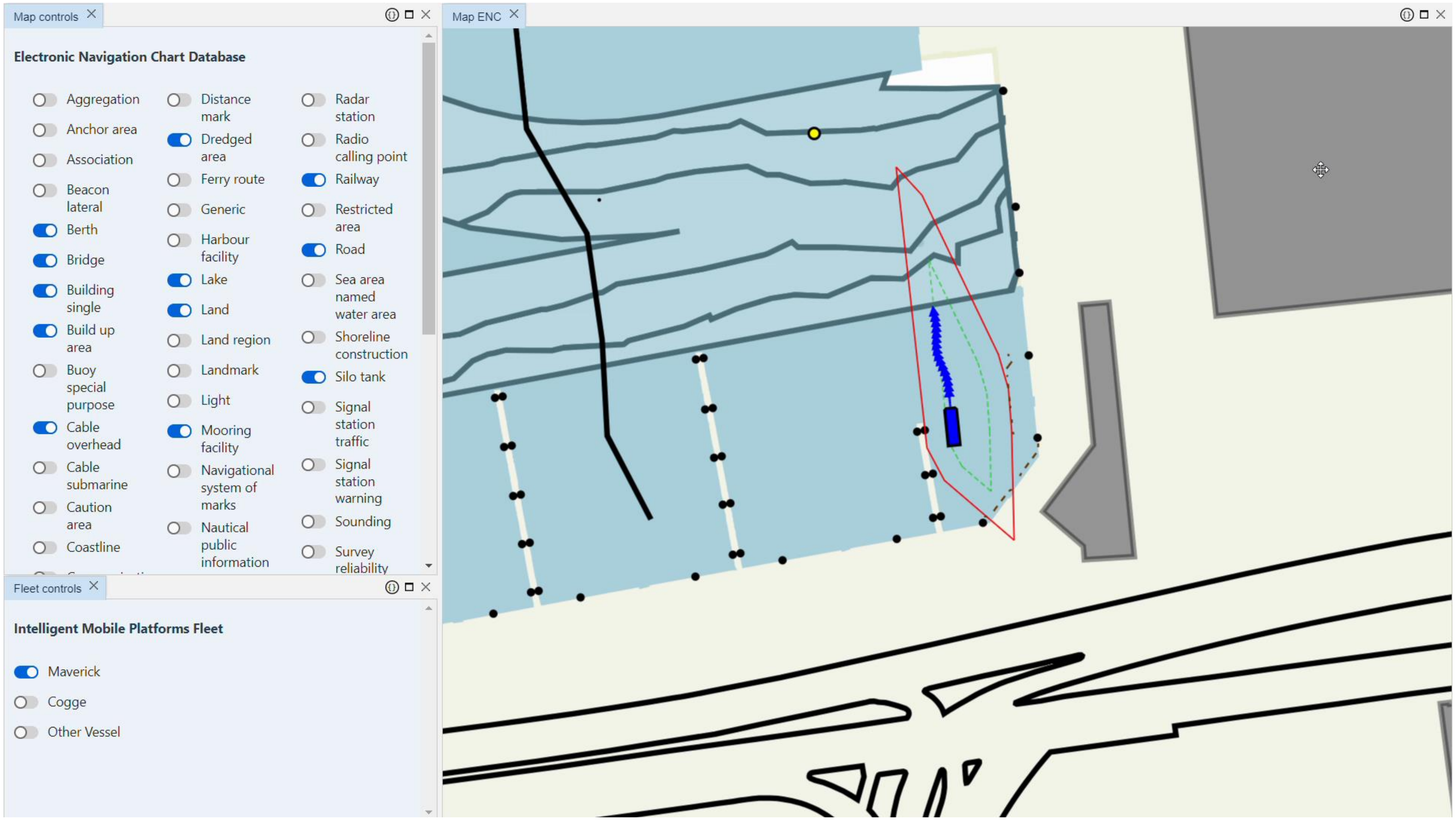
Research and Activities: Demonstration

IW-NET:



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Team effort







Q&A

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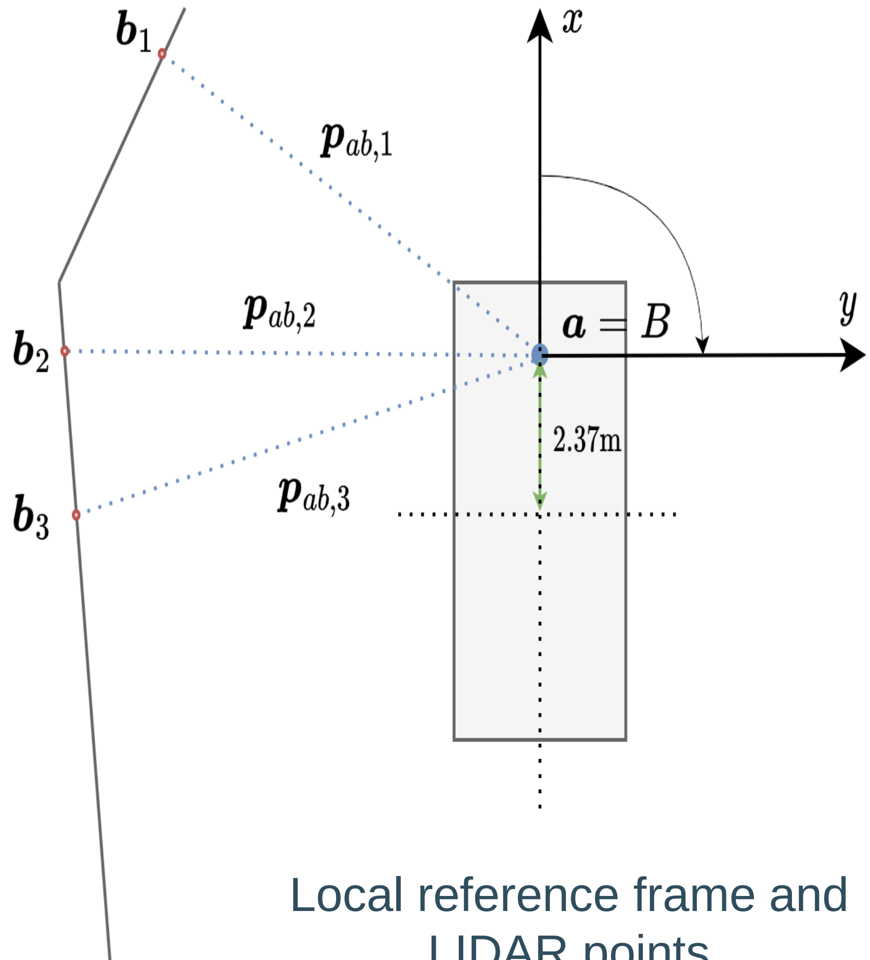
Research and Activities: Demonstration

IW-NET:

- **Methodology**

- $$\underbrace{\begin{bmatrix} \frac{(\boldsymbol{p}_{ab,1})^\top \boldsymbol{\Sigma}}{\|(\boldsymbol{p}_{ab,1})\boldsymbol{\Sigma}\|_2} \\ \frac{(\boldsymbol{p}_{ab,2})^\top \boldsymbol{\Sigma}}{\|(\boldsymbol{p}_{ab,2})\boldsymbol{\Sigma}\|_2} \\ \vdots \\ \frac{(\boldsymbol{p}_{ab,M})^\top \boldsymbol{\Sigma}}{\|(\boldsymbol{p}_{ab,M})\boldsymbol{\Sigma}\|_2} \end{bmatrix}}_{\boldsymbol{A}} \boldsymbol{p}_i \leq \underbrace{\begin{bmatrix} \frac{(\boldsymbol{p}_{ab,1})^\top \boldsymbol{\Sigma} \boldsymbol{p}_{ab,1}}{\|(\boldsymbol{p}_{ab,1})\boldsymbol{\Sigma}\|_2} \\ \frac{(\boldsymbol{p}_{ab,2})^\top \boldsymbol{\Sigma} \boldsymbol{p}_{ab,2}}{\|(\boldsymbol{p}_{ab,2})\boldsymbol{\Sigma}\|_2} \\ \vdots \\ \frac{(\boldsymbol{p}_{ab,M})^\top \boldsymbol{\Sigma} \boldsymbol{p}_{ab,M}}{\|(\boldsymbol{p}_{ab,M})\boldsymbol{\Sigma}\|_2} \end{bmatrix}}_{\boldsymbol{b}}$$



Local reference frame and LIDAR points

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Research and Activities: Demonstration

IW-NET:

- **Methodology**

- $$\underbrace{\begin{bmatrix} \frac{(\boldsymbol{p}_{ab,1})^\top \boldsymbol{\Sigma}}{\|(\boldsymbol{p}_{ab,1})\boldsymbol{\Sigma}\|_2} \\ \frac{(\boldsymbol{p}_{ab,2})^\top \boldsymbol{\Sigma}}{\|(\boldsymbol{p}_{ab,2})\boldsymbol{\Sigma}\|_2} \\ \vdots \\ \frac{(\boldsymbol{p}_{ab,M})^\top \boldsymbol{\Sigma}}{\|(\boldsymbol{p}_{ab,M})\boldsymbol{\Sigma}\|_2} \end{bmatrix}}_{\boldsymbol{A}} \boldsymbol{p}_i \leq \underbrace{\begin{bmatrix} \frac{(\boldsymbol{p}_{ab,1})^\top \boldsymbol{\Sigma} \boldsymbol{p}_{ab,1}}{\|(\boldsymbol{p}_{ab,1})\boldsymbol{\Sigma}\|_2} \\ \frac{(\boldsymbol{p}_{ab,2})^\top \boldsymbol{\Sigma} \boldsymbol{p}_{ab,2}}{\|(\boldsymbol{p}_{ab,2})\boldsymbol{\Sigma}\|_2} \\ \vdots \\ \frac{(\boldsymbol{p}_{ab,M})^\top \boldsymbol{\Sigma} \boldsymbol{p}_{ab,M}}{\|(\boldsymbol{p}_{ab,M})\boldsymbol{\Sigma}\|_2} \end{bmatrix}}_{\boldsymbol{b}}$$

- M is the number of LIDAR points to consider

  $$i = 1, \ldots, N$$

N is the MPC horizon

$$\boldsymbol{p}_1 = \boldsymbol{a} = \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} \quad \text{and} \quad x_1 = y_1 = 0$$