Alignability maps for ensuring high-precision localization

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Knowledge Foundation

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October 23, 2022. Kyoto (Japan).

Introduction

Research question: how can we quantify the risk of localization failure?

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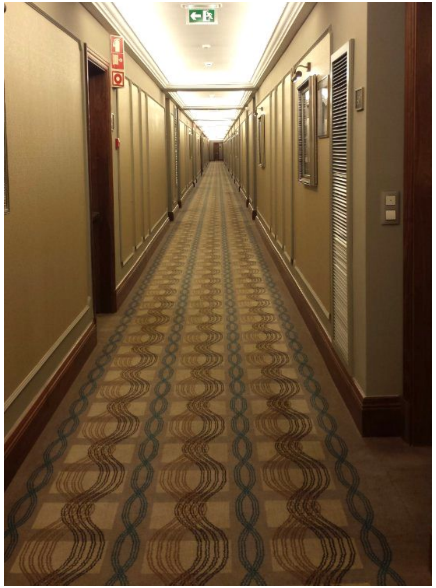
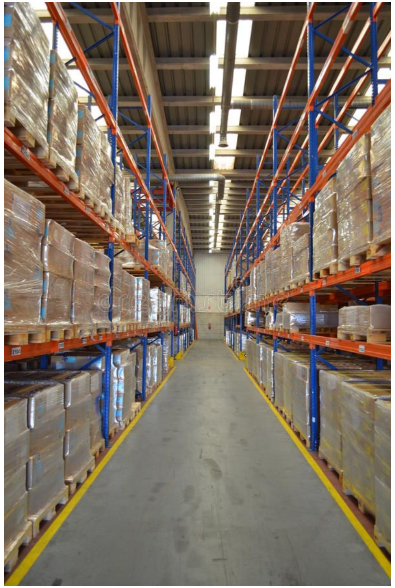
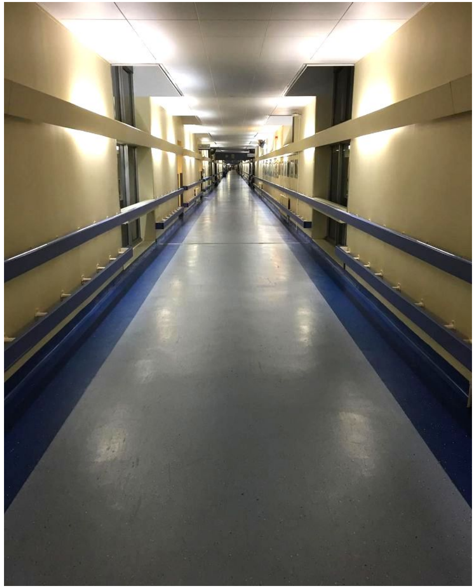
- Localization can still fail in real-world environments



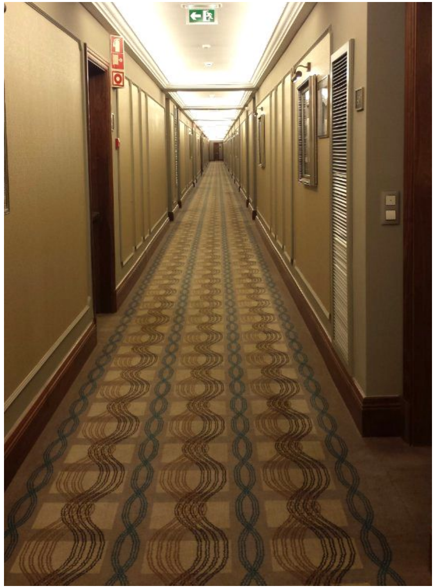


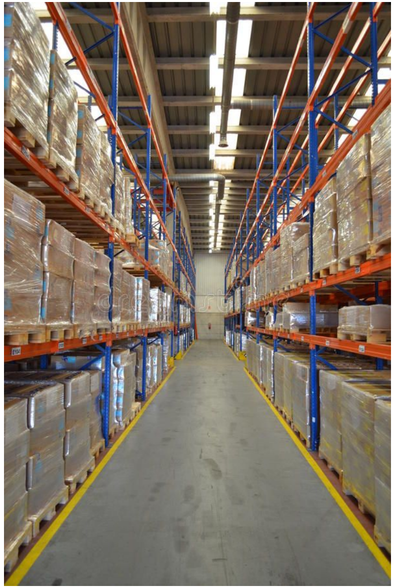


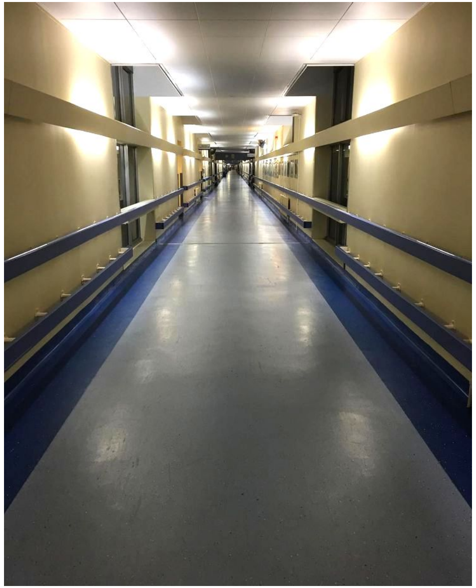
Introduction

Research question: how can we quantify the risk of localization failure?

- Localization can still fail in real-world environments → range-based sensors







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Research question: how can we quantify the <u>risk</u> of localization failure?

- Proposal: compute and represent the level of risk spatially

Environment

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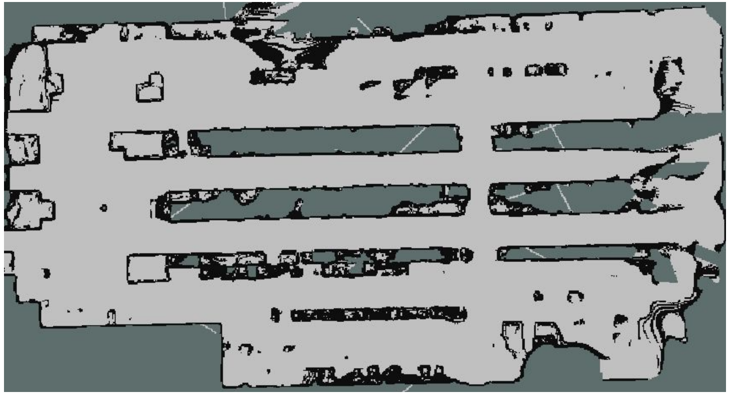
Environment



Occupancy map

Introduction

Research question: how can we quantify the <u>risk</u> of localization failure?

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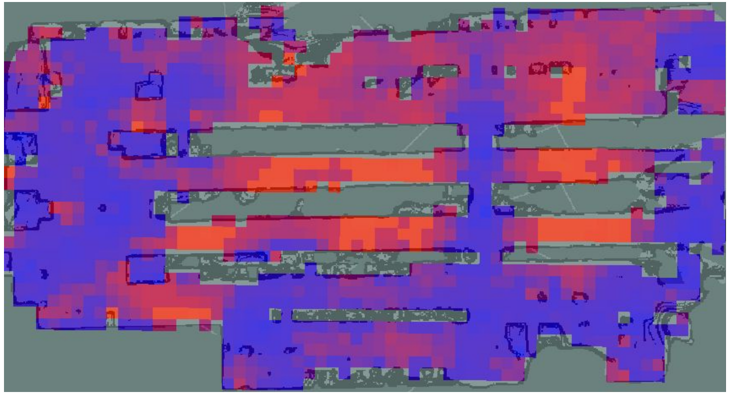
Environment



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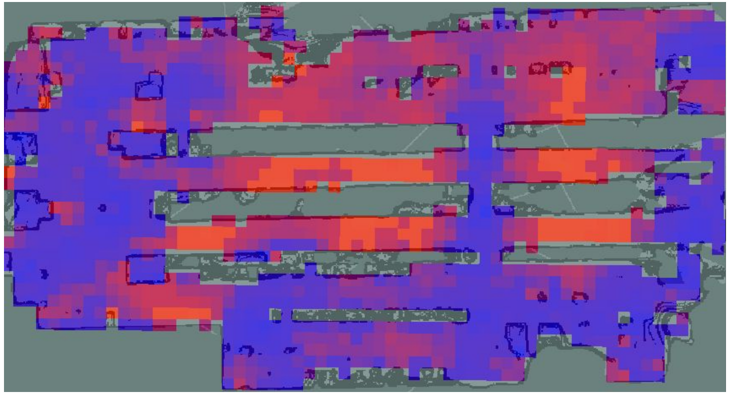


Alignability map

Alignability map

Alignability metric (Nobili et al., 2018)

- Simona Nobili, Georgi Tinchev and Maurice Fallon. ***Predicting Alignment Risk to Prevent Localization Failure***. 2018 IEEE International Conference on Robotics and Automation (ICRA).

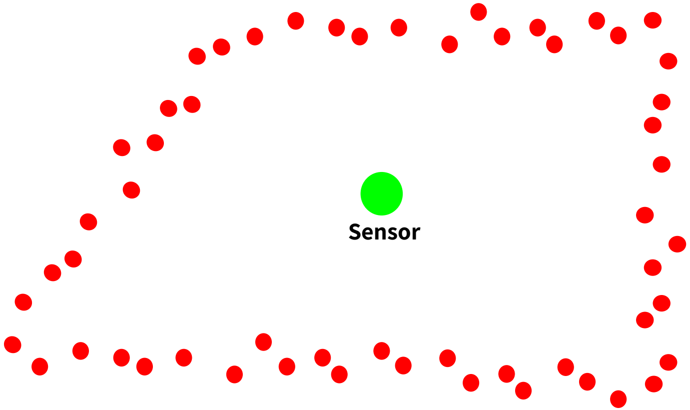
- Capacity of a given range scan to be aligned (zero-to-one scale)

- The higher the value, the lower the risk of localization error

Alignability map

Alignability metric (Nobili et al., 2018)

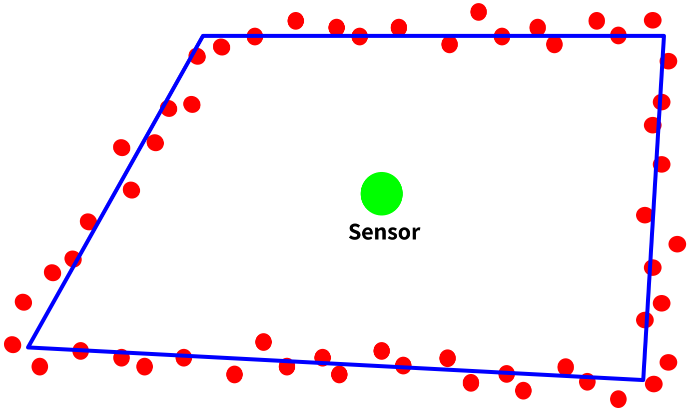
- Capacity of a given range scan to be aligned (zero-to-one scale)
- Computation:



Alignability map

Alignability metric (Nobili et al., 2018)

- Capacity of a given range scan to be aligned (zero-to-one scale)
- Computation:
    - Segment into planar surfaces



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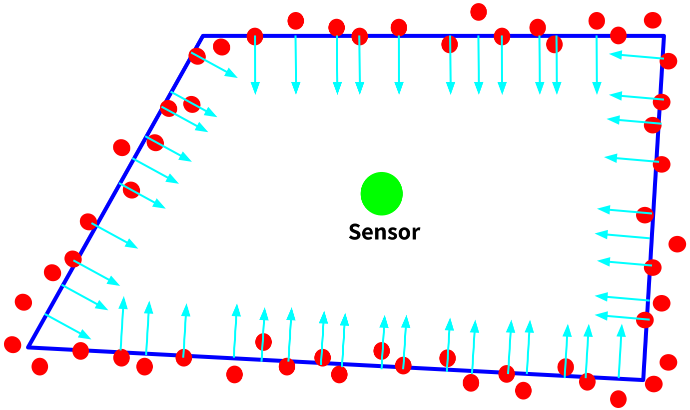
Alignability metric (Nobili et al., 2018)

- Capacity of a given range scan to be aligned (zero-to-one scale)
- Computation:
    - Compute per-point normals



Alignability map

Alignability metric (Nobili et al., 2018)

- Capacity of a given range scan to be aligned (zero-to-one scale)
- Computation:
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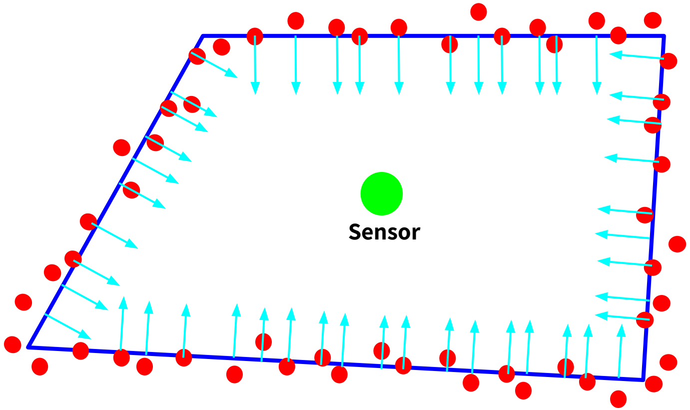

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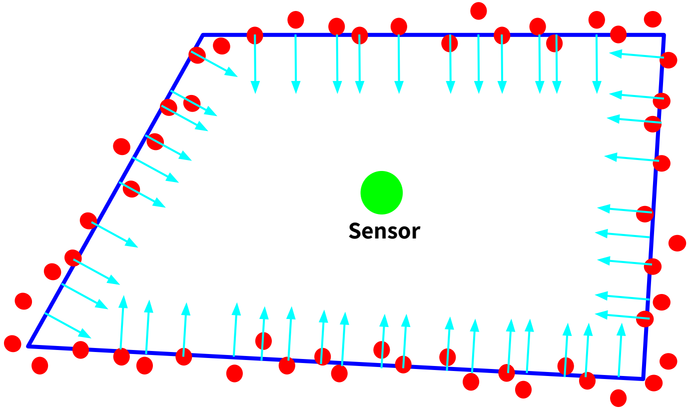
Alignability metric (Nobili et al., 2018)

- Capacity of a given range scan to be aligned (zero-to-one scale)
- Computation:
  - Perform PCA analysis on the normals → $\lambda_a \geq \lambda_b \geq \lambda_c \geq 0$



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- Capacity of a given range scan to be aligned (zero-to-one scale)
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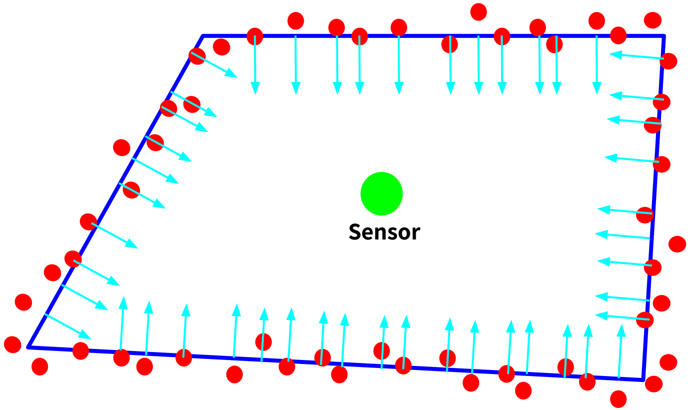

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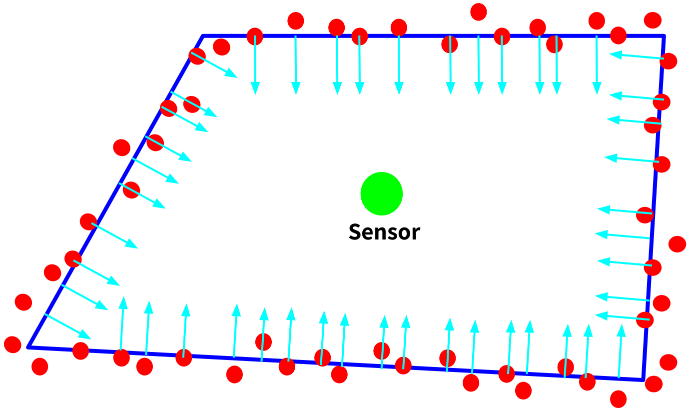

➡ **High alignability situation**

$\alpha \gg 0$

Alignability map

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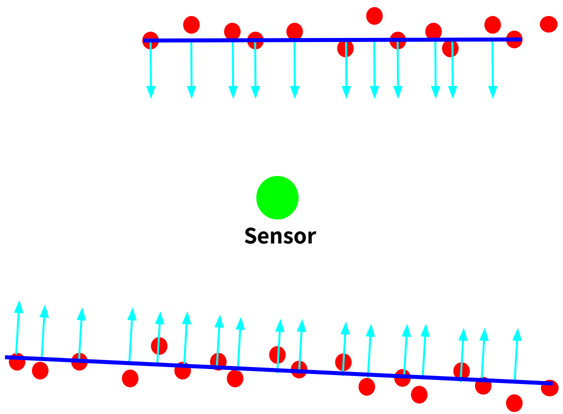

→ **Low alignability situation**

$\alpha \approx 0$

Alignability map

Implementation

- A 2D **grid map** that captures **alignability** in an environment

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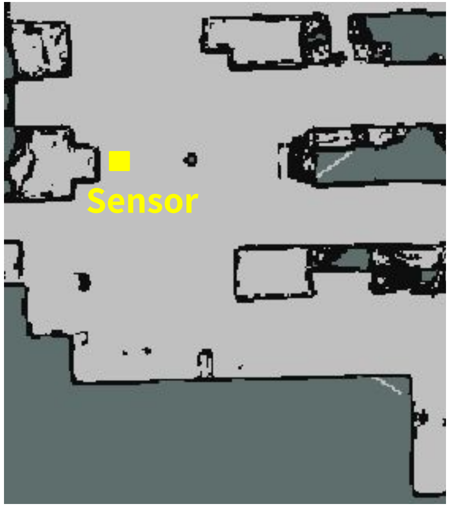
- For each cell (i,j):

Alignability map

Implementation

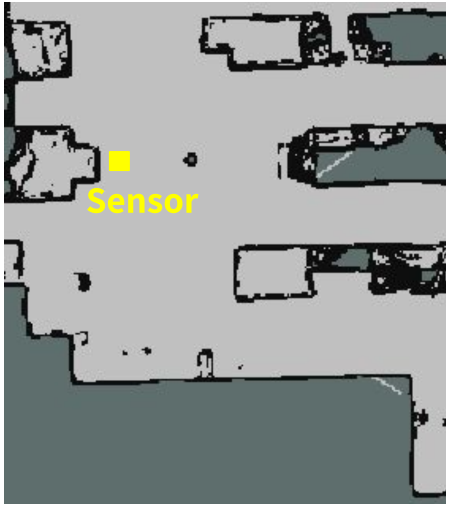
- A 2D **grid map** that captures **alignability** in an environment
- For each cell (i,j):
  - Place sensor in the corresponding region



Alignability map

Implementation

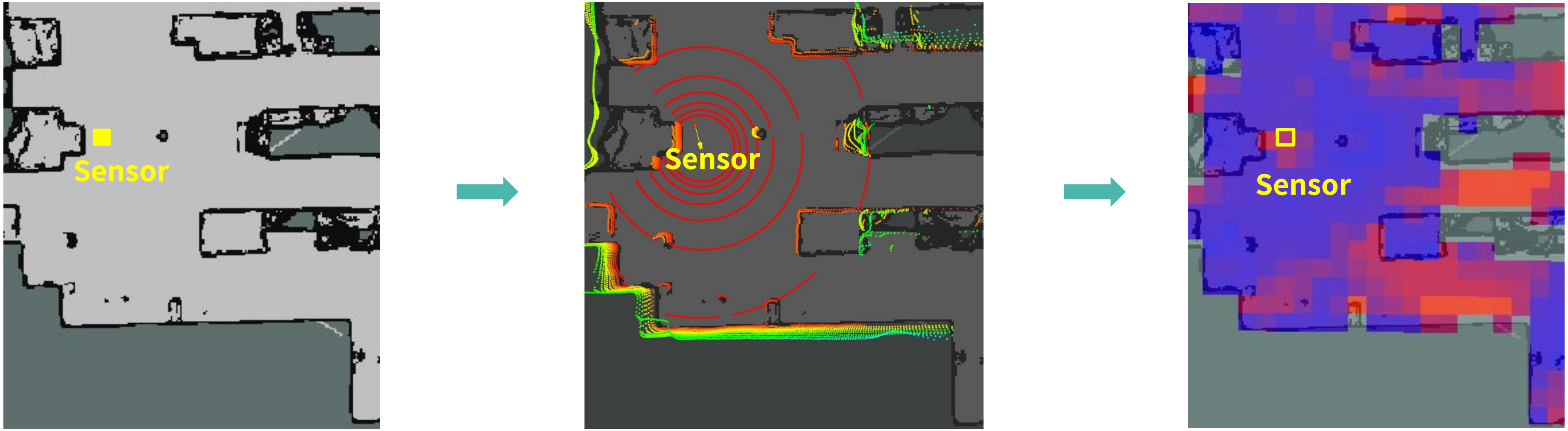
- A 2D **grid map** that captures **alignability** in an environment
- For each cell (i,j):
  - Get alignability samples from scans in that region $\mathbf{a} = (\alpha_1, \alpha_2, ..., \alpha_n)$



Alignability map

Implementation

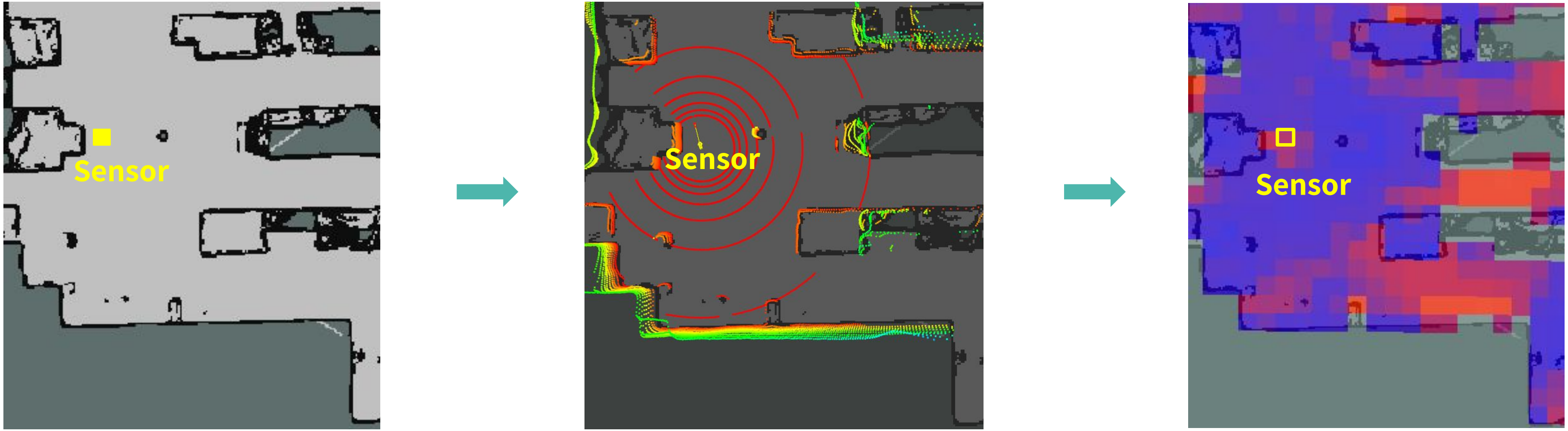
- A 2D **grid map** that captures **alignability** in an environment
- For each cell (i,j):
    - Annotate the cell with the median alignability value, i.e., $\mathcal{A}(i,j) = \mathrm{median}(\mathbf{a})$



Alignability map

Implementation

- A 2D **grid map** that captures **alignability** in an environment
- For each cell (i,j):
  - For simplicity, we assume 360º field of view



Validation

Building of an alignability map

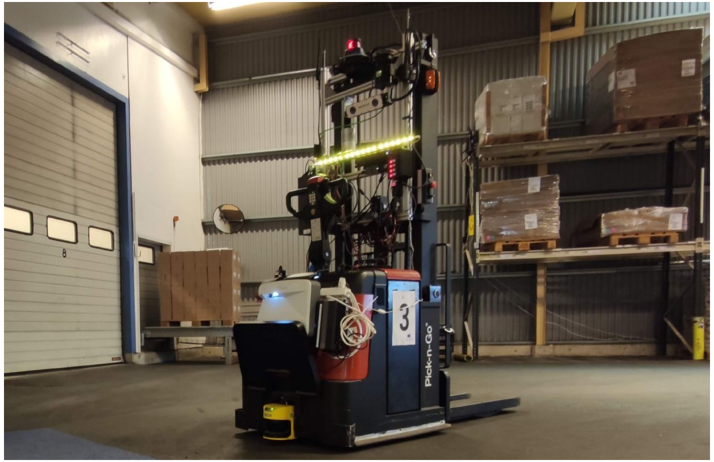
- Validation in both virtual and real environments

Validation

Building of an alignability map

- Validation in virtual environment (built upon real data)
  - Toyota BT SAE200 stacker truck (with 3D Velodyne HDL-32E lidar)

Warehouse environment

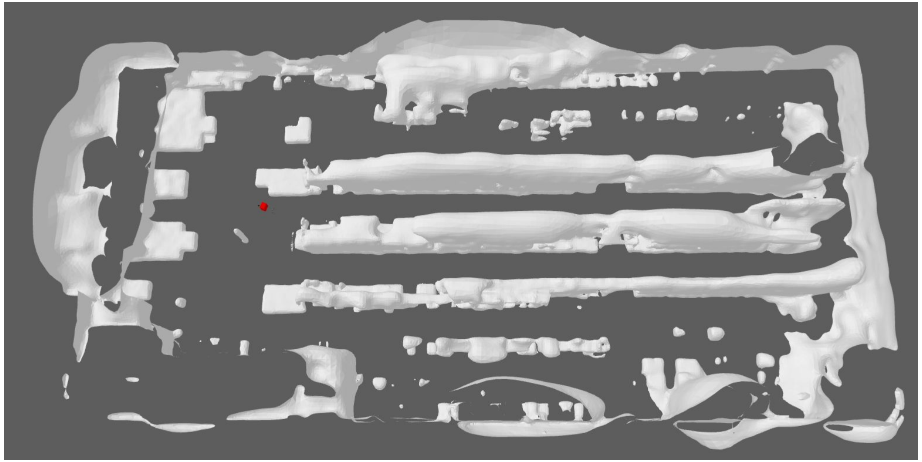


Forklift robot

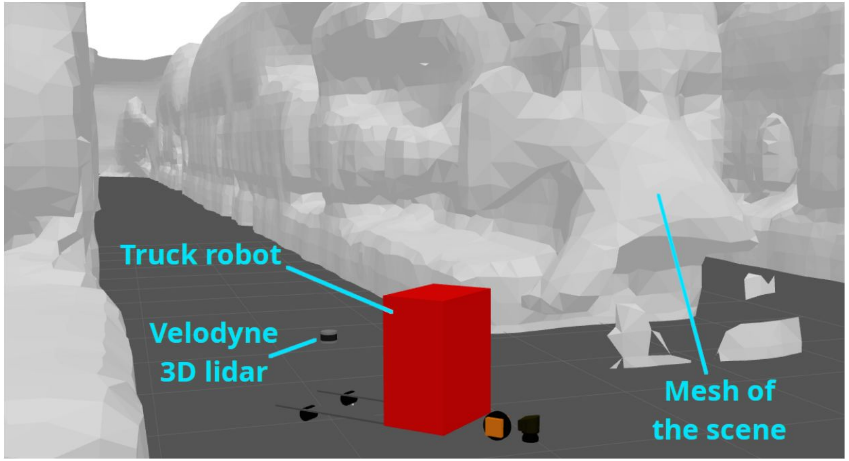
Validation

Building of an alignability map

- Validation in virtual environment (built upon real data)



Warehouse environment in Gazebo

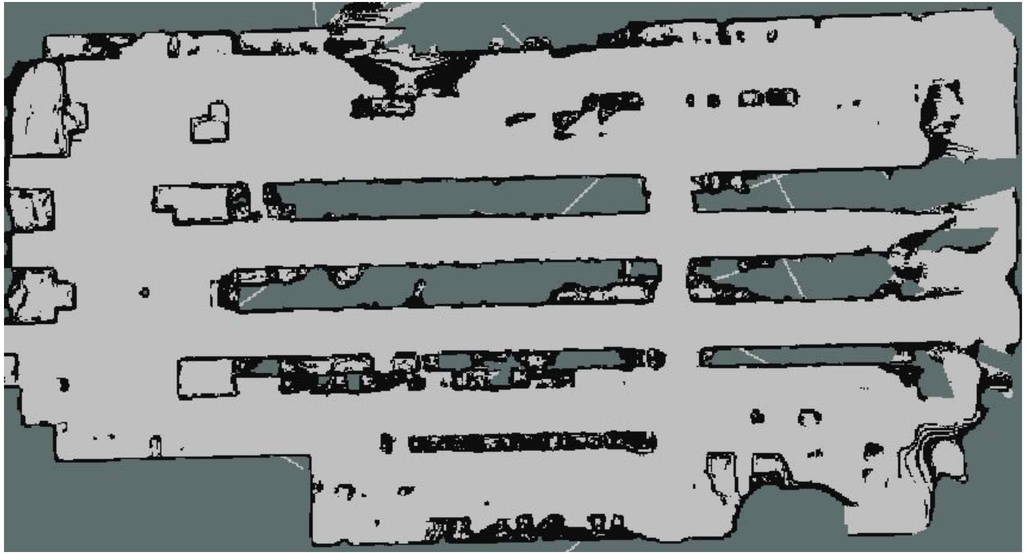


Simulated forklift robot

Validation

Building of an alignability map

- Validation in virtual environment (results)
  - Occupancy map



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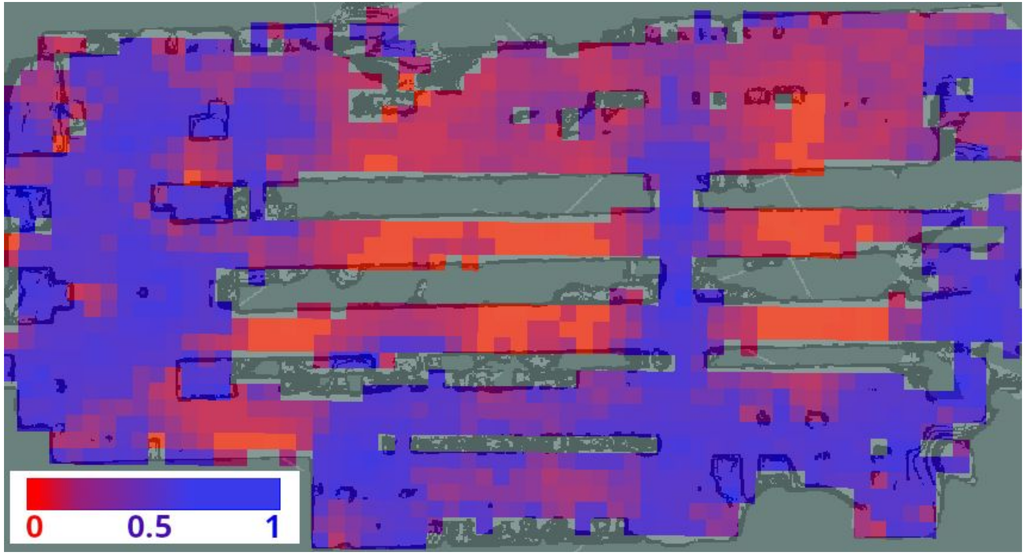

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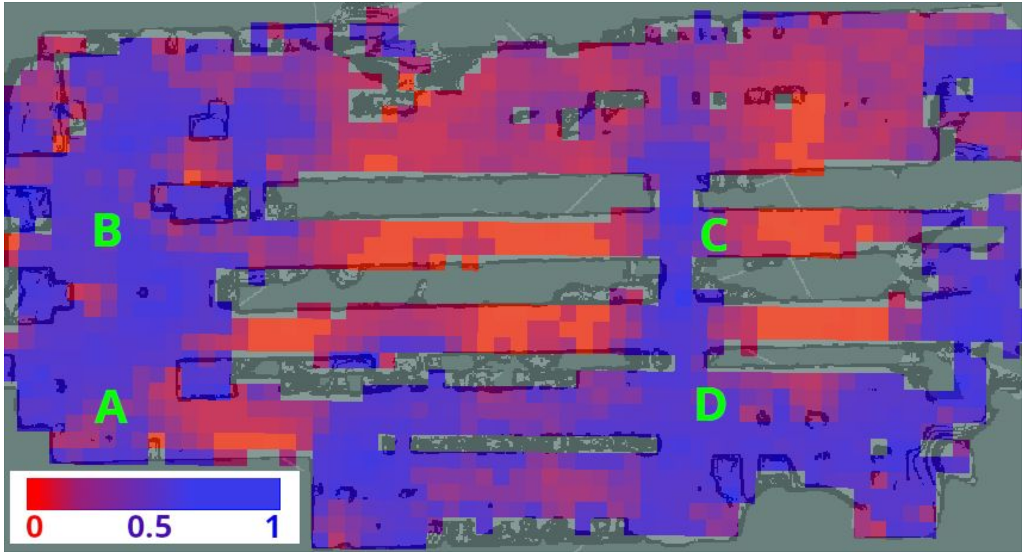

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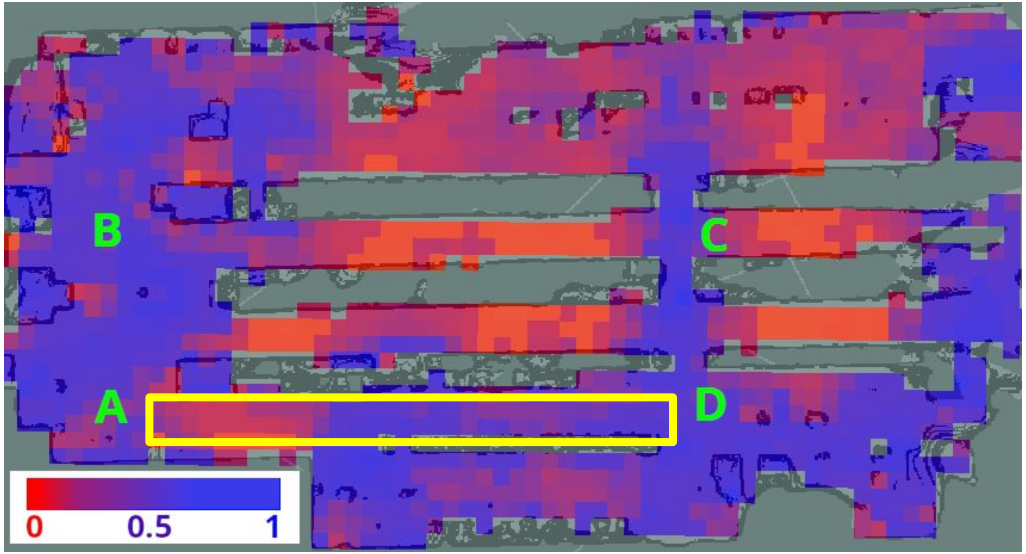

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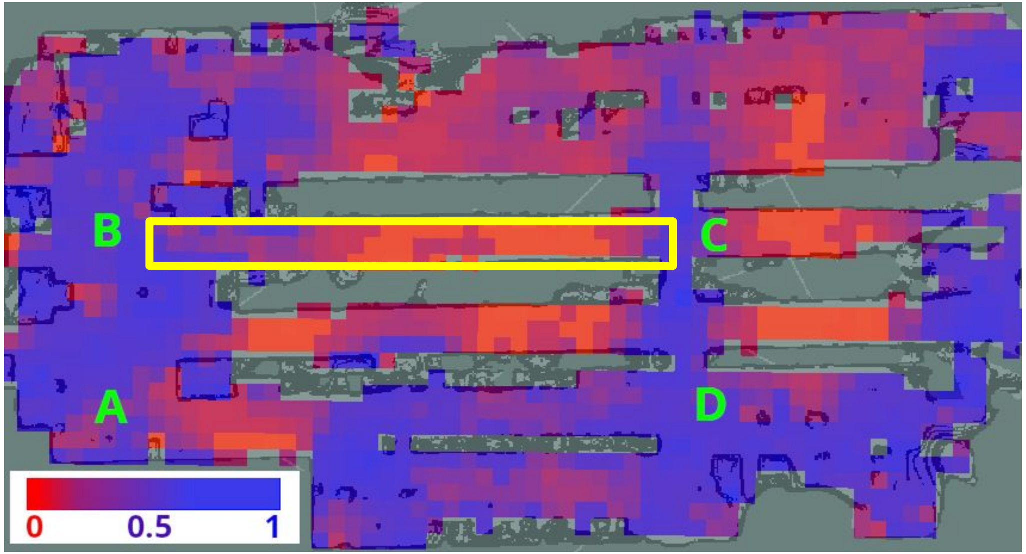
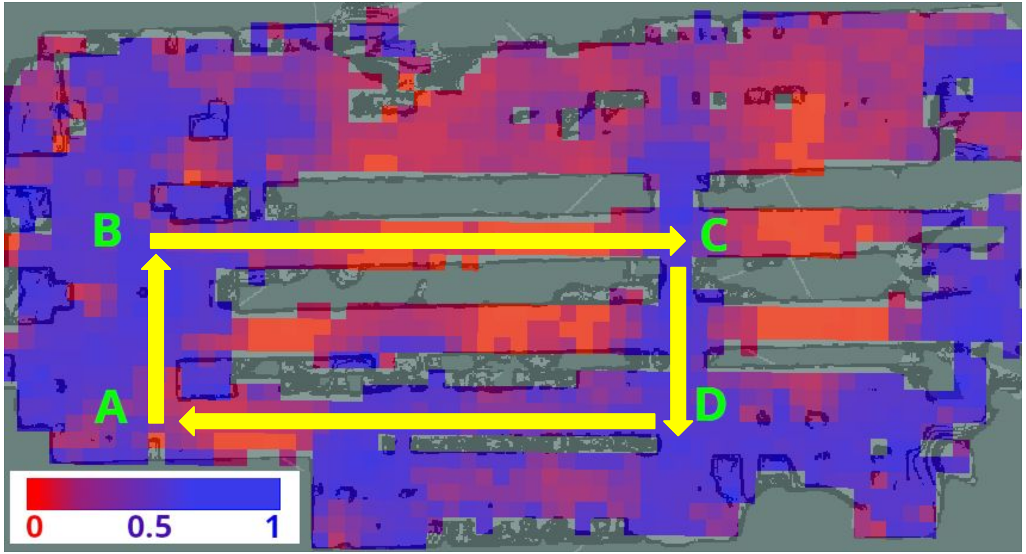


Validation

Alignability as a predictor of localization errors

- Validation in virtual environment (results)
    - Driving experiment



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  - We measured localization errors (NDT-MCL method w.r.t Gazebo's ground truth)

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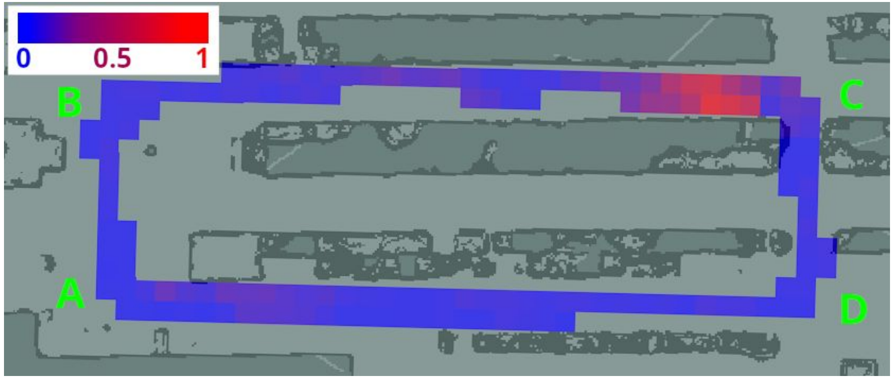

Error map

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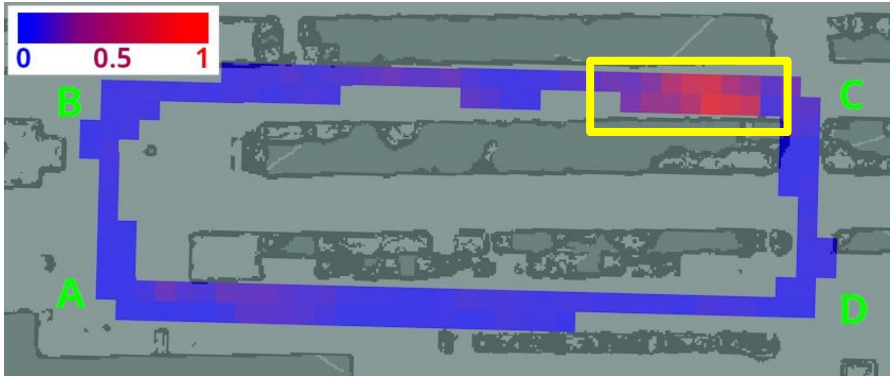

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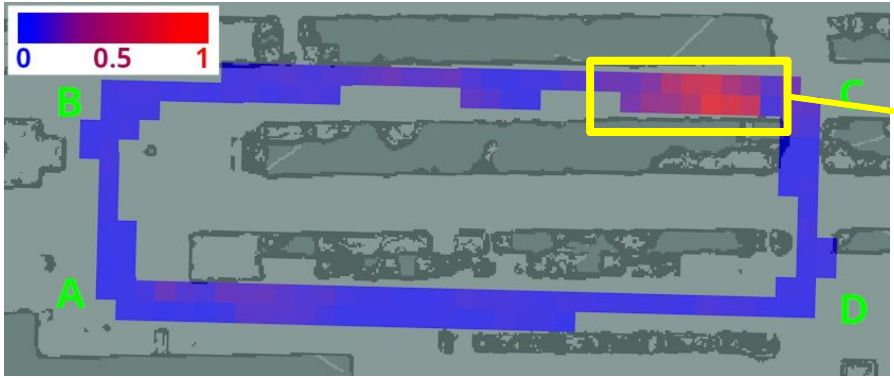

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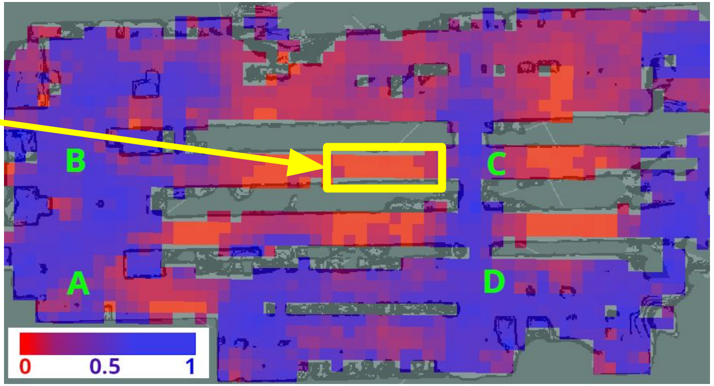
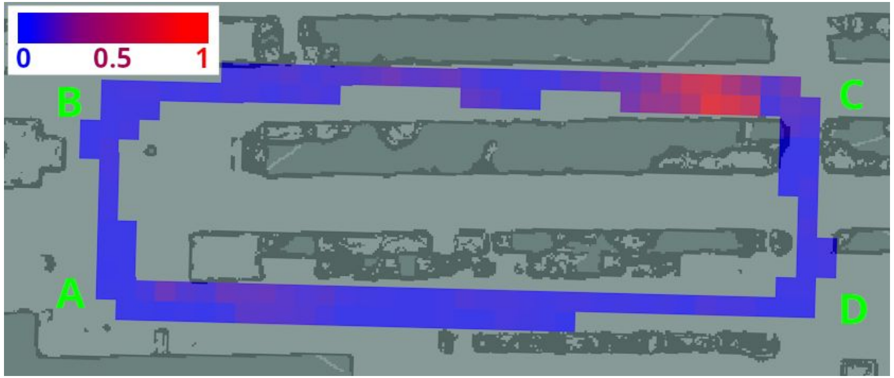


Validation

Alignability as a predictor of localization errors

- Validation in virtual environment (results)
  - We studied the correlation between alignability and localization error



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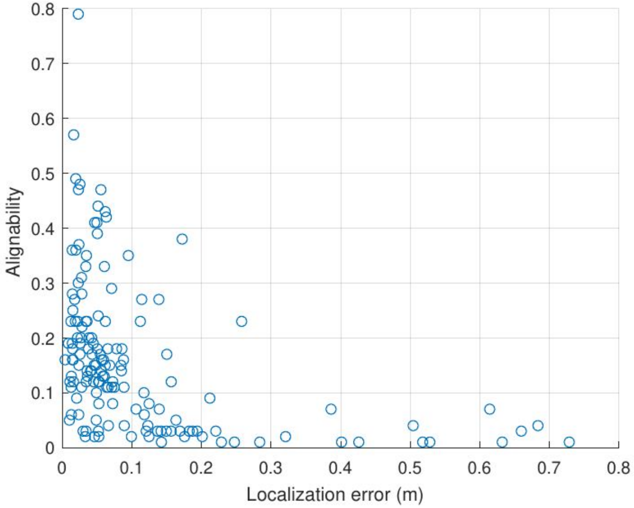

Correlation plot

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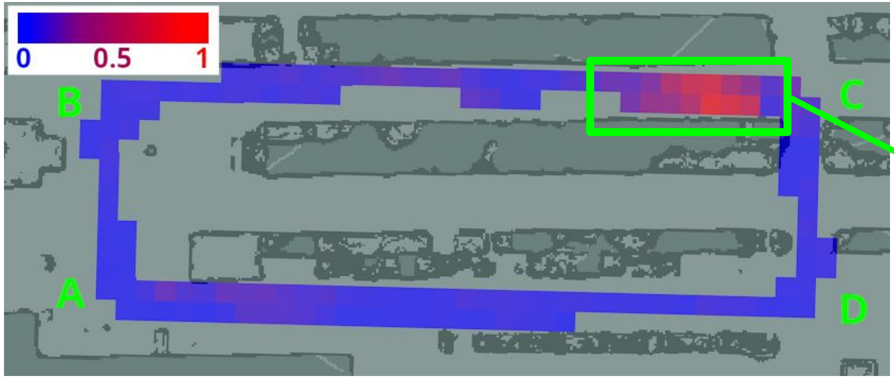
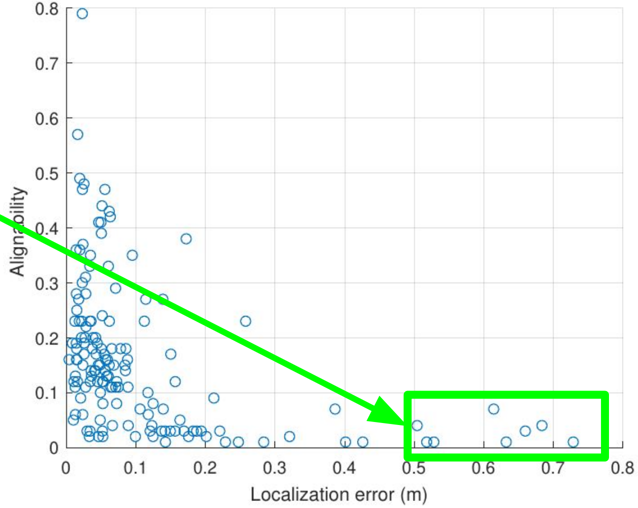


Error map



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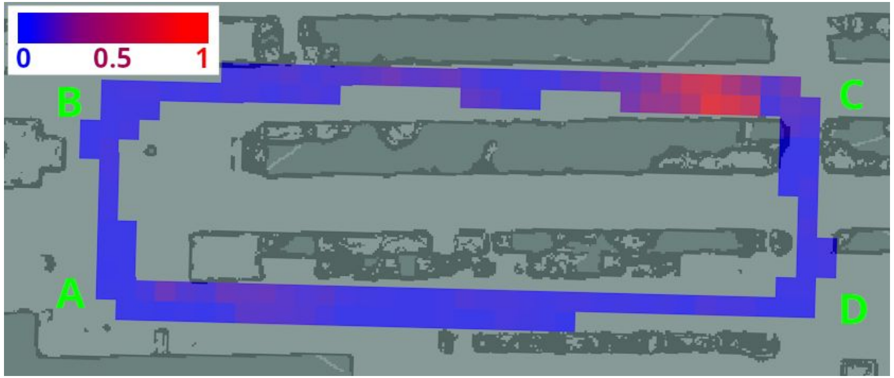

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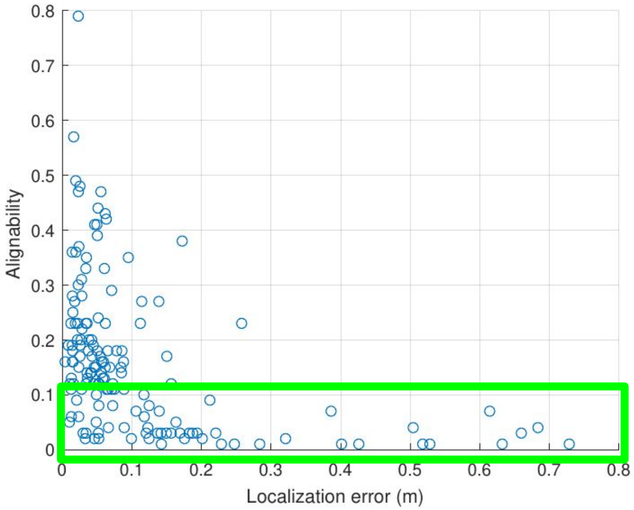

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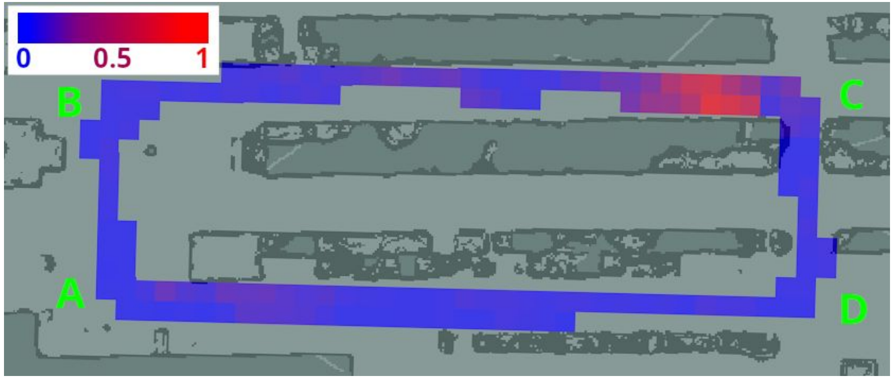

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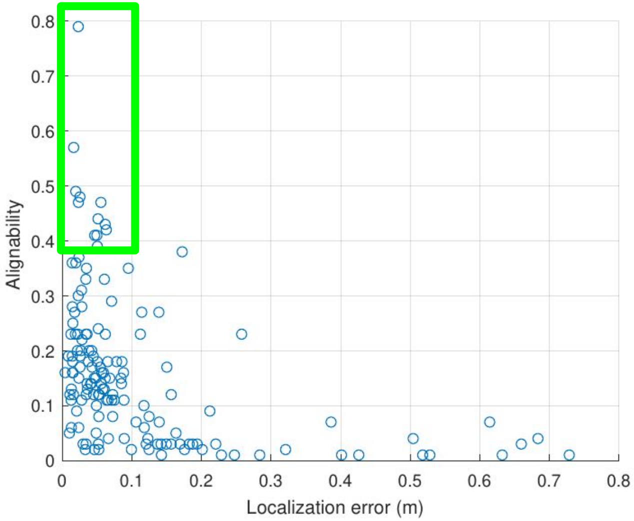


Correlation plot

Validation

Building of an alignability map

- Validation in real environment

- Experiment setup
  - Robotnik Kairos+ platform

Manipulation platform in a transport corridor system

Validation

Building of an alignability map

- Validation in real environment

- Experiment setup
  - Robotnik Kairos+ platform
  - Ouster OS0-128 lidar
    - 360º horizontal fov
    - 90º vertical fov

Manipulation platform in a transport corridor system

Validation

Building of an alignability map

- Validation in real environment

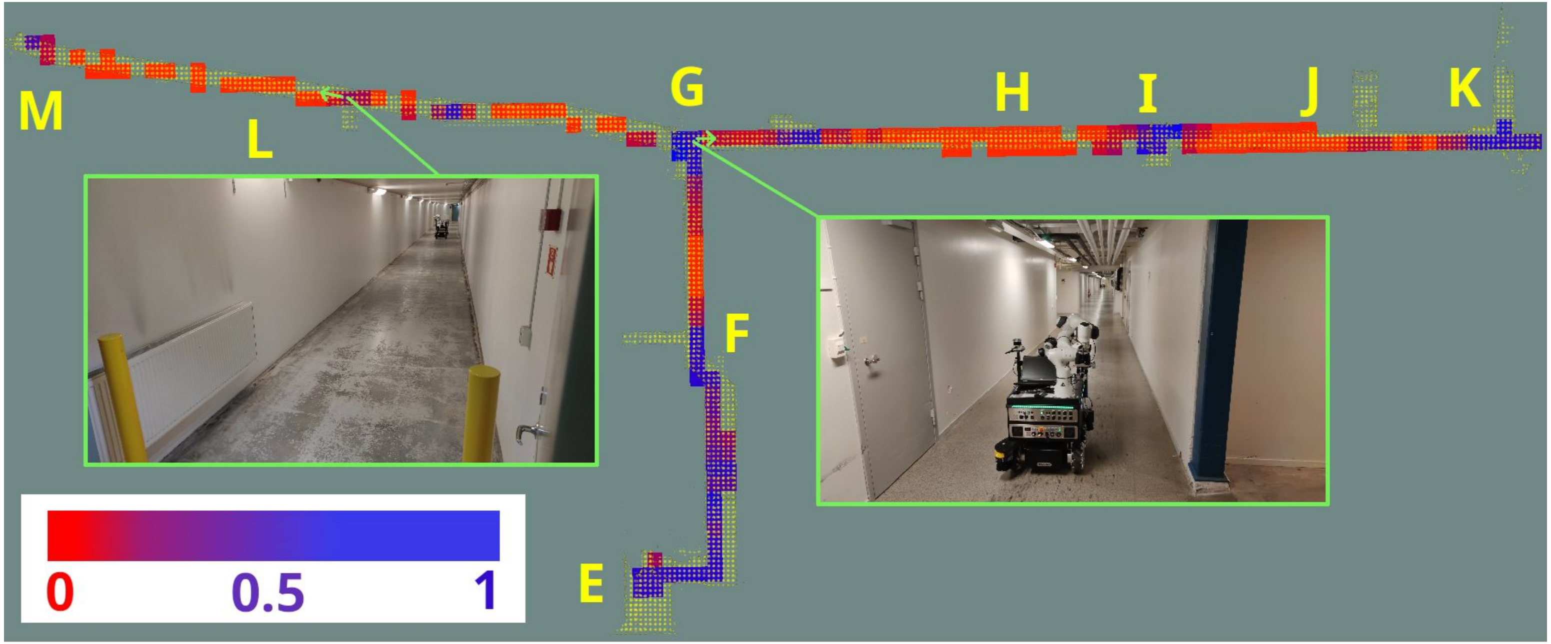
- Experiment setup
  - Robotnik Kairos+ platform
  - Ouster OS0-128 lidar
    - 360º horizontal fov
    - 90º vertical fov
  - Driving around underground transport corridors (very long)

Manipulation platform in a transport corridor system

Validation

Building of an alignability map

- Validation in real environment (results)



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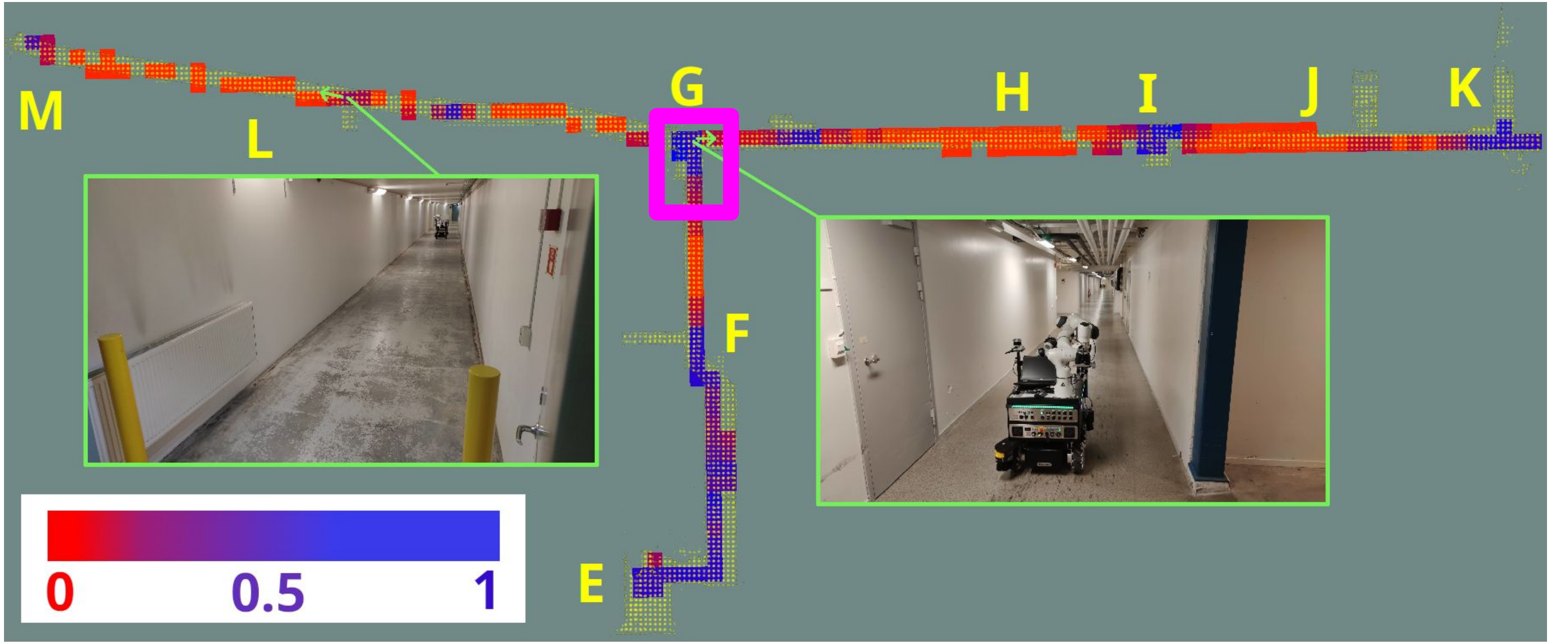

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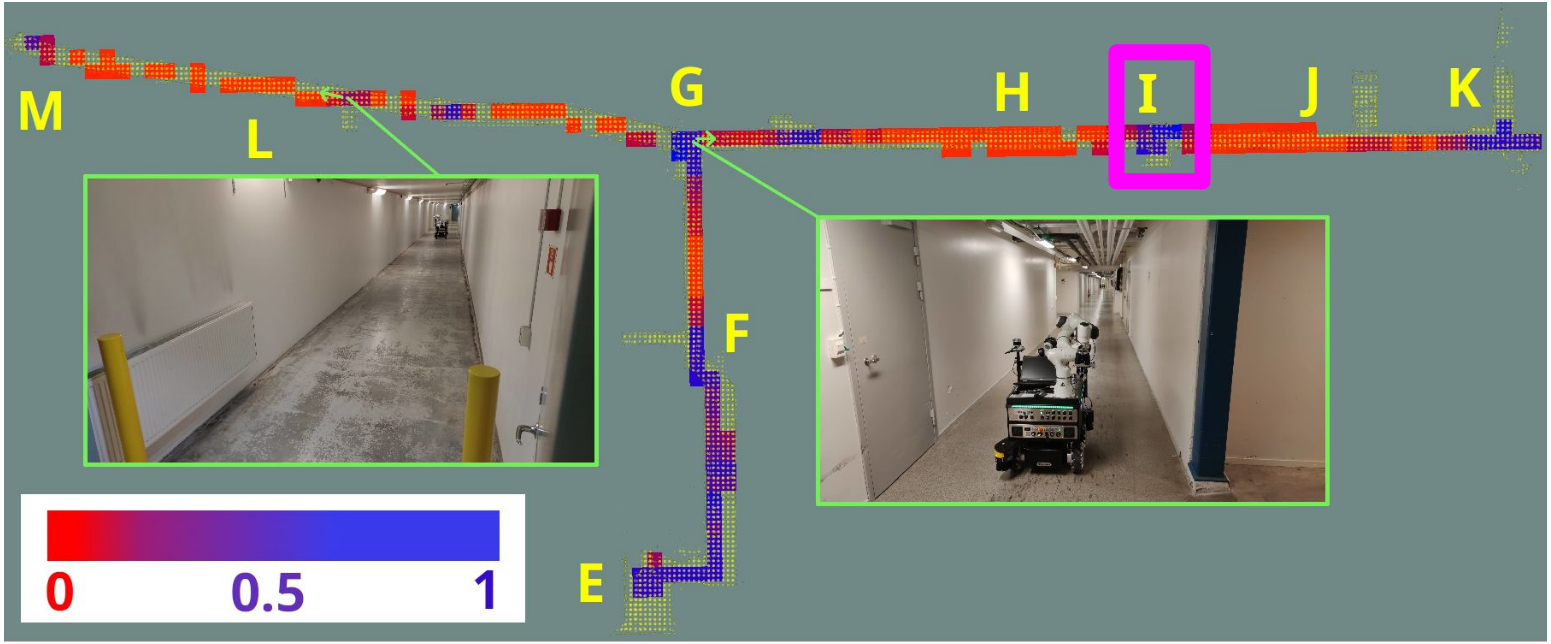

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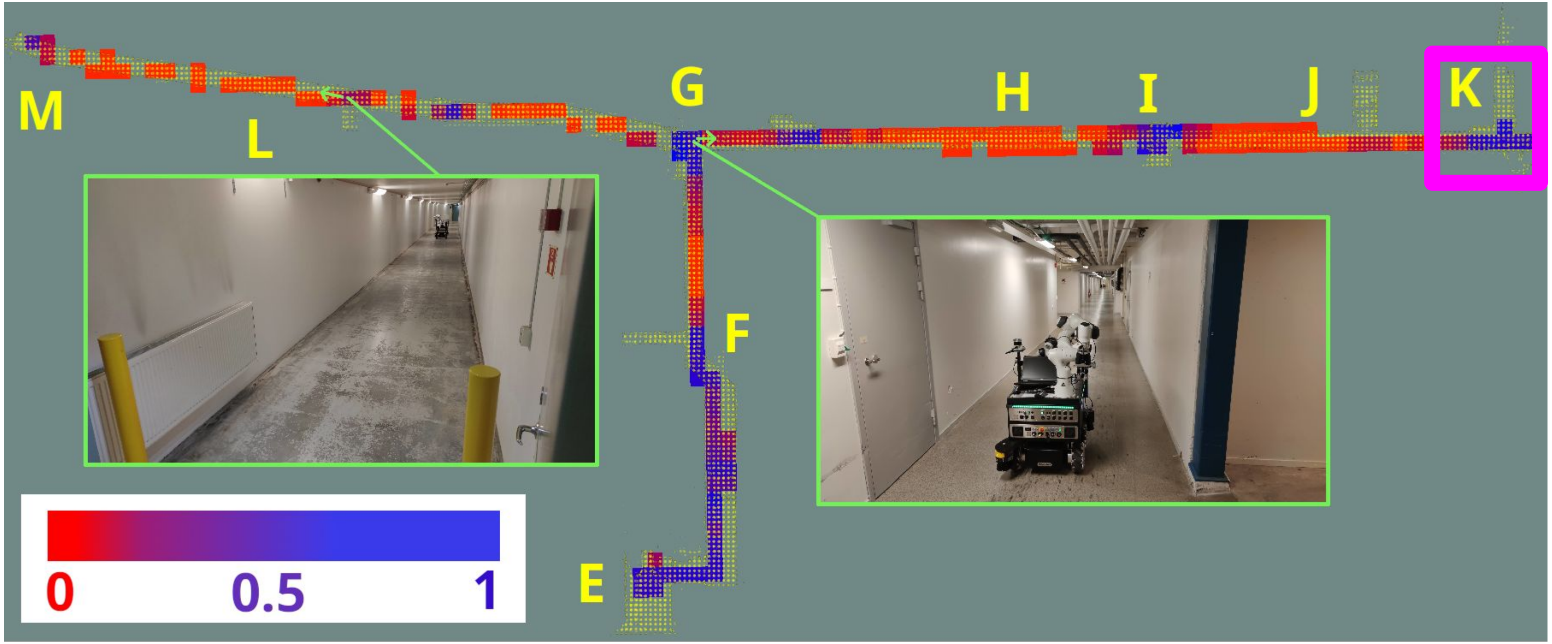

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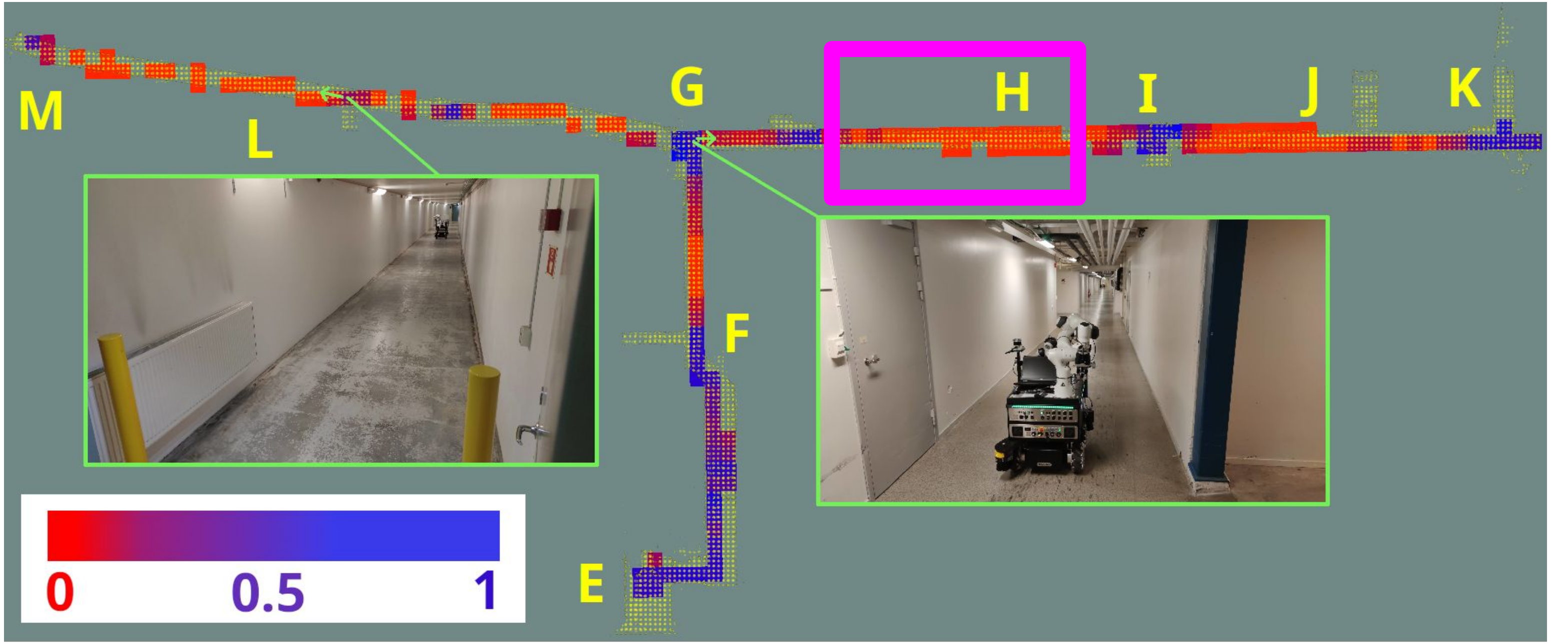

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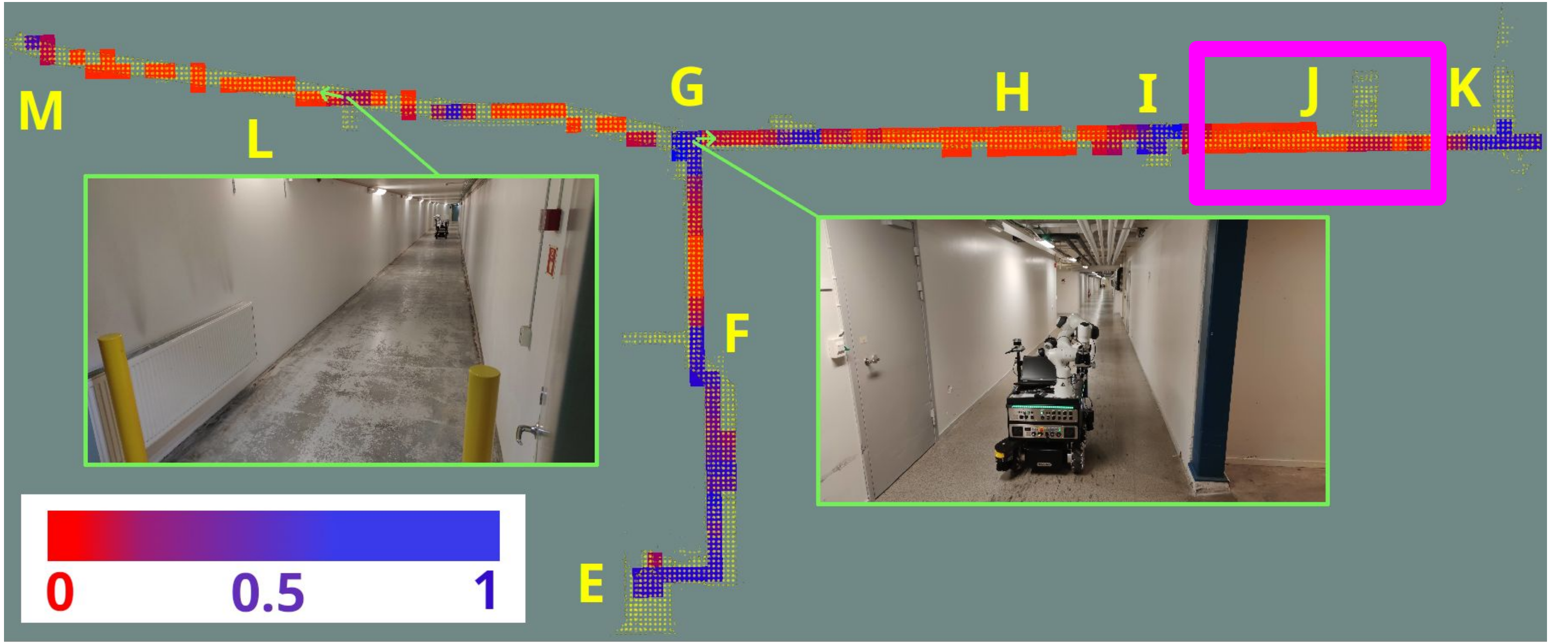

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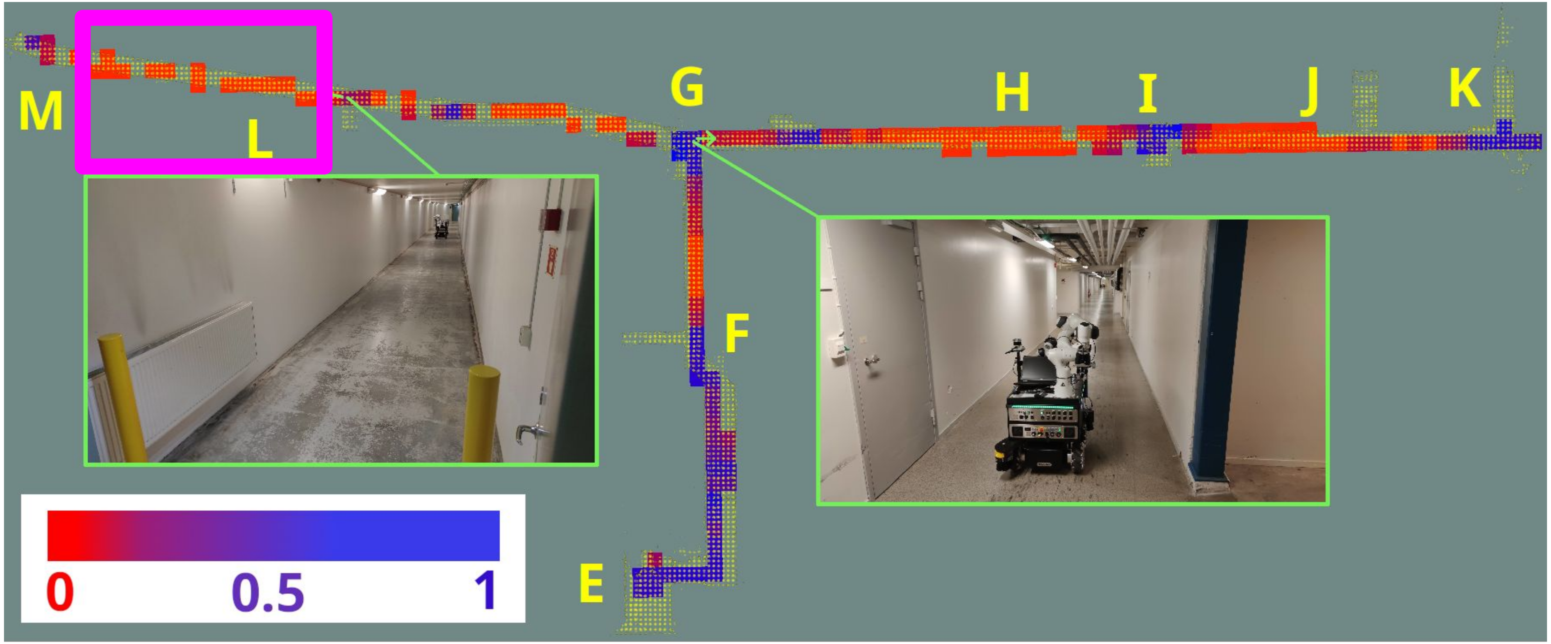

Application

Alignability in motion planning

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- Experimental setup
  - Alignability map used as a costmap for a motion planner (ROS `move_base`)

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  - Simulated experiments in our virtual environment

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Alignability in motion planning

- Experimental setup
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  - Simulated experiments in our virtual environment
    - Two waypoints

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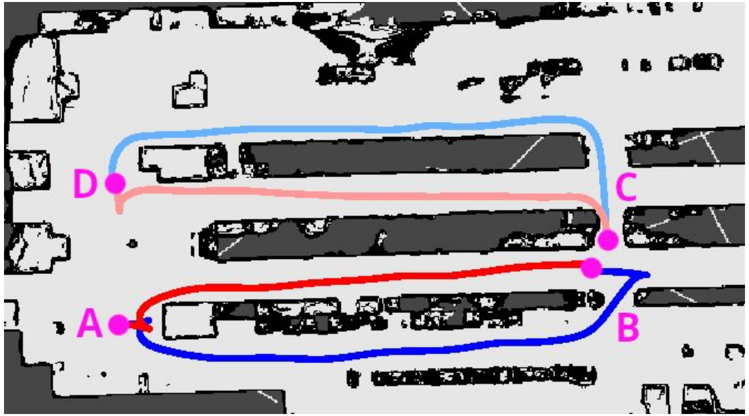

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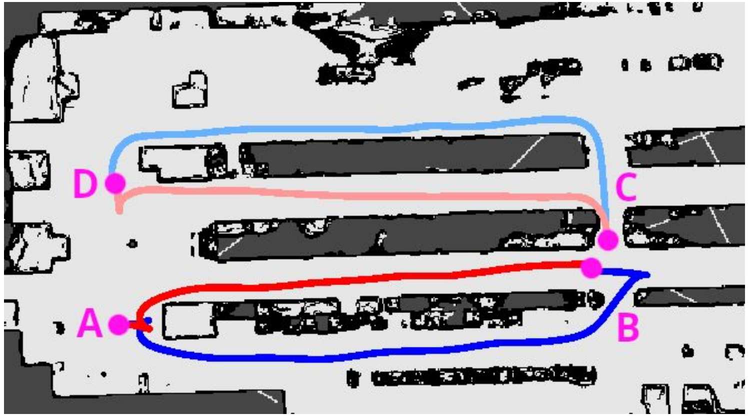

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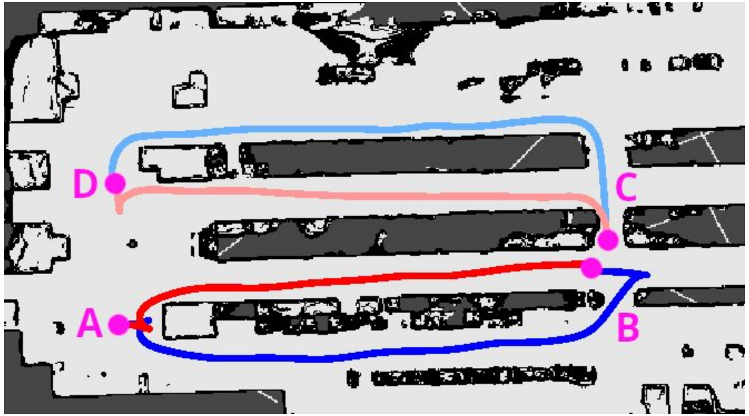
  - Simulated experiments in our virtual environment
    - Two waypoints
    - Red paths do not consider alignability (shortest)

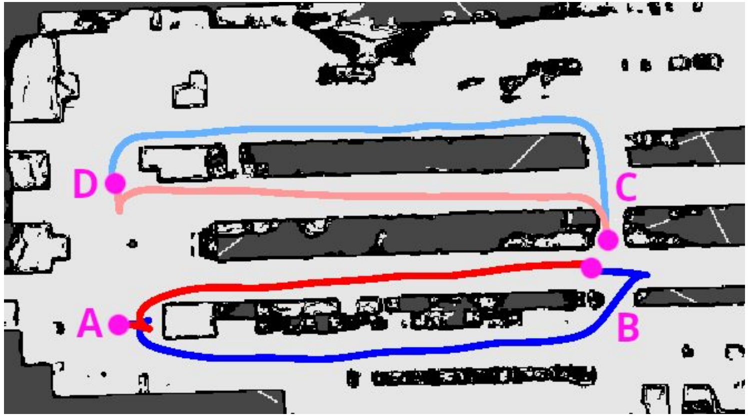


Application

Alignability in motion planning

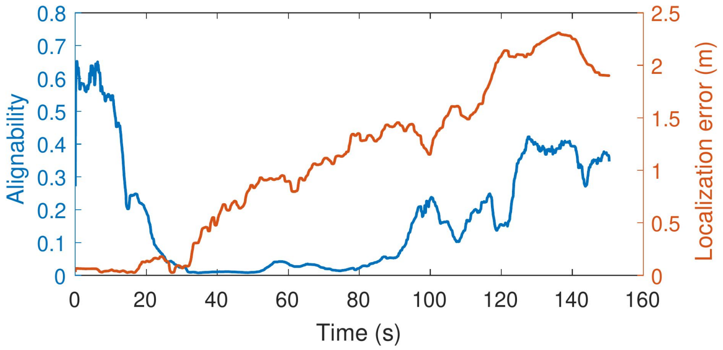
- Experimental setup
  - Alignability map used as a costmap for a motion planner (ROS `move_base`)

  - Simulated experiments in our virtual environment
    - Two waypoints
    - Red paths do not consider alignability (shortest)
    - Blue paths do (safest)

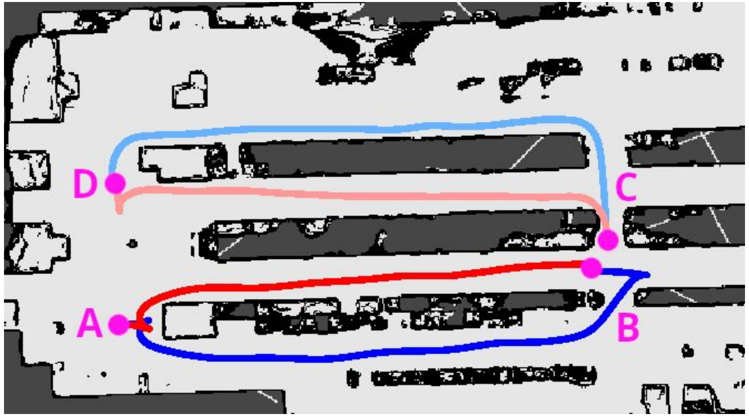


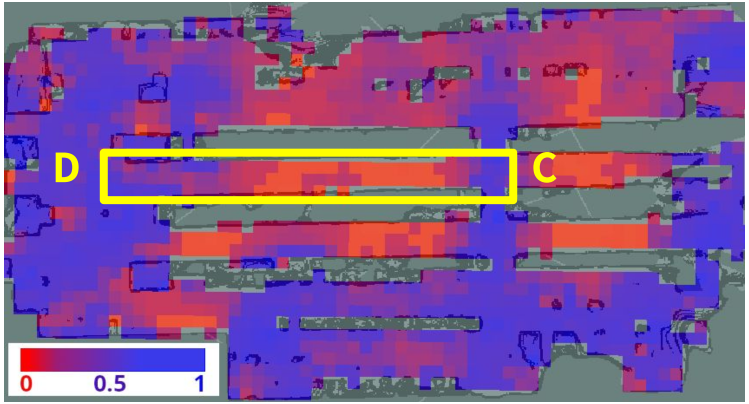
Application

Alignability in motion planning



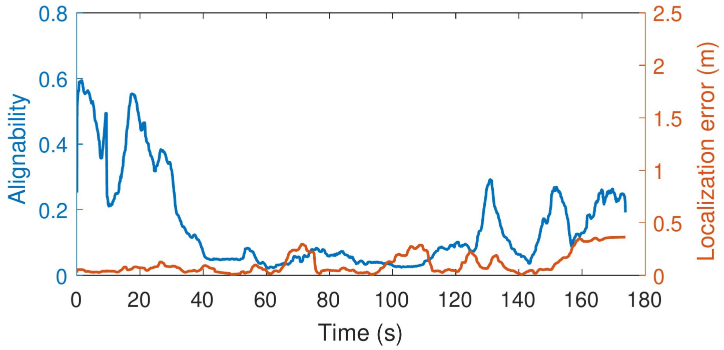
Experiment C-D (no alignability)



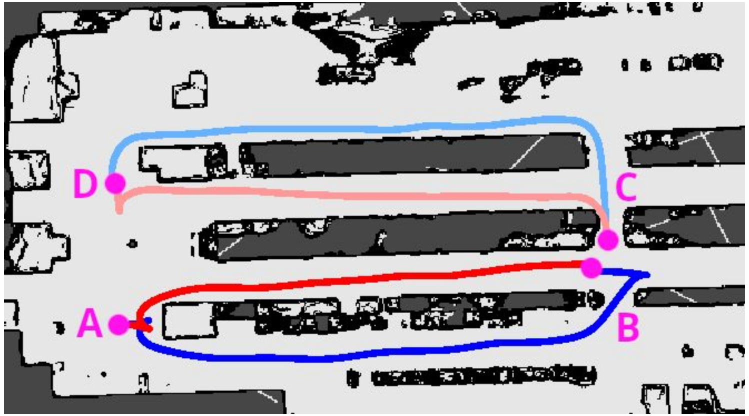


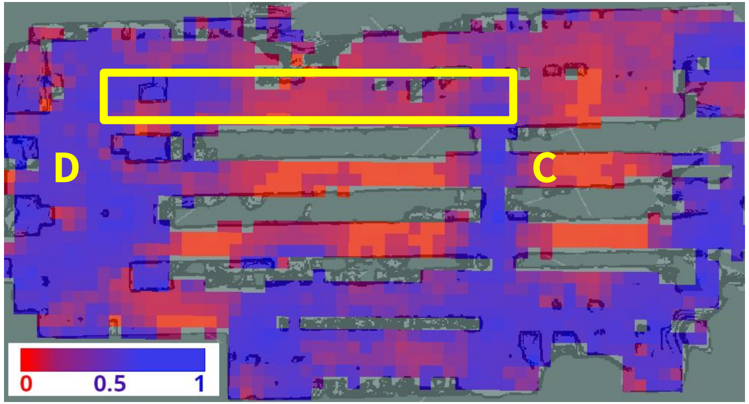
Application

Alignability in motion planning



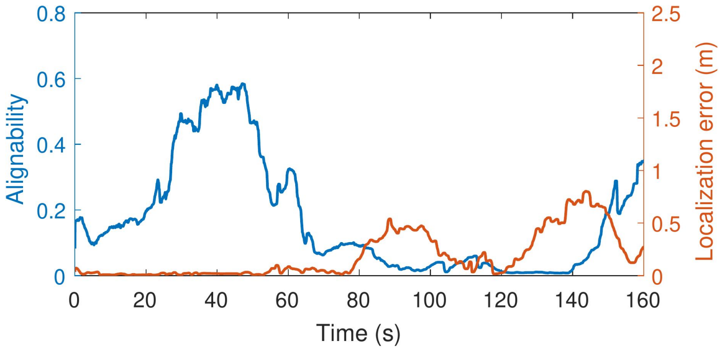
Experiment C-D (alignability)



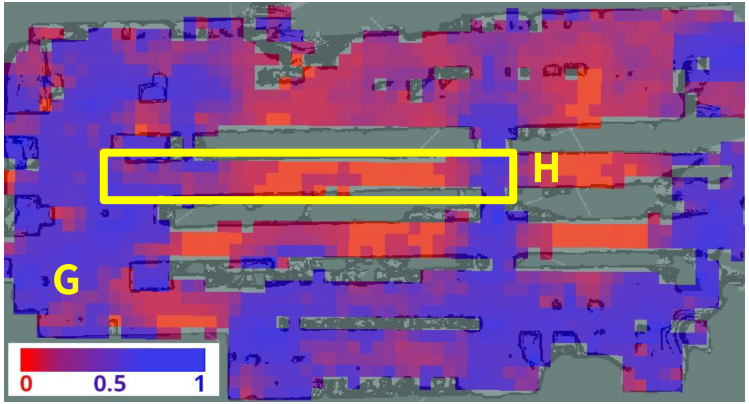


Application

Alignability in motion planning

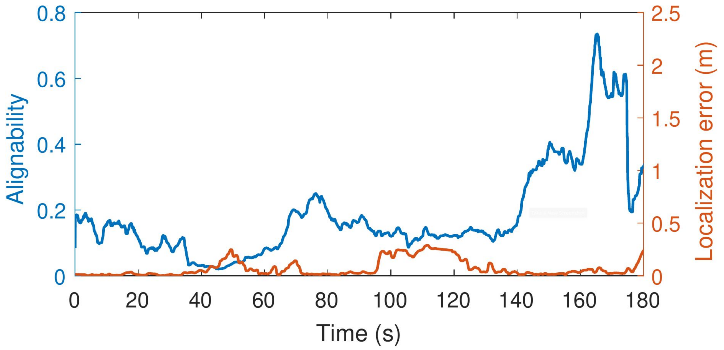


Experiment G-H (no alignability)

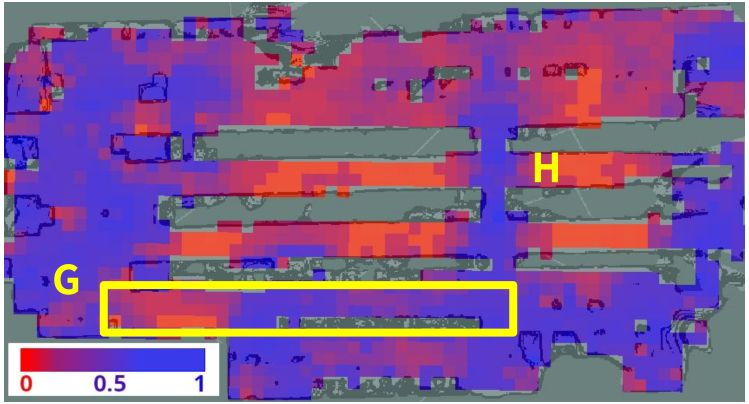


Application

Alignability in motion planning



Experiment G-H (alignability)



Conclusions

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- Alignability maps serve to capture the risk of localization error spatially
- We have demonstrated their utility in different environments
- They can be used to generate safer trajectories in motion planning

Alignability maps for ensuring high-precision localization

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IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2022)

October 23, 2022. Kyoto (Japan).

Alignability map

Alignability metric (Nobili et al., 2018)

- Informal definition
  - Variety of surfaces directions in a given scan, on a zero-to-one scale
  - The higher the value, the lower the risk of localization failure

- Computation
  - Segment point cloud into a set of planes
  - Compute all the normal directions in those planes (per-point)
  - Perform PCA analysis on those normals
    - Eigenvalues: $\lambda_a \geq \lambda_b \geq \lambda_c \geq 0$
    - Alignability:

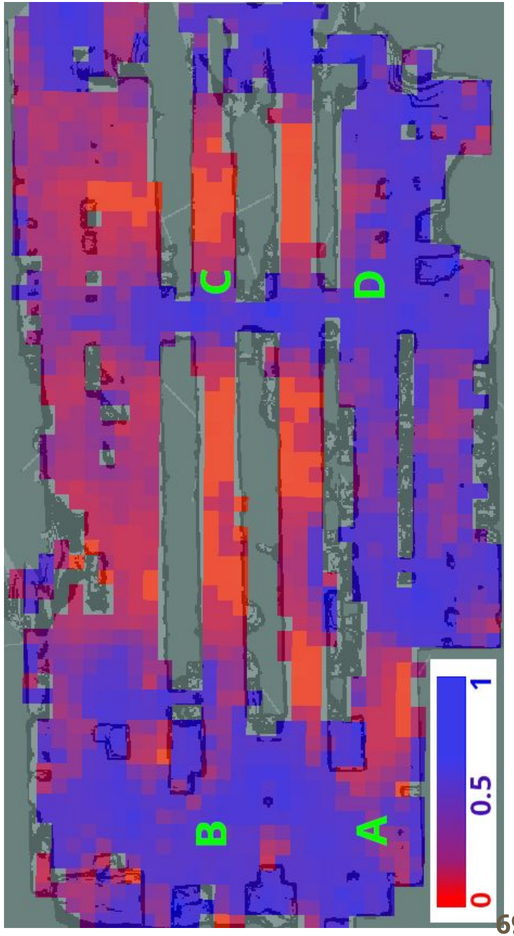
$$\alpha = \frac{\lambda_c}{\lambda_a} \quad \text{where } \alpha \in [0, 1] \subset \mathbb{R}$$

Introduction

Problems addressed and contributions

- Localization methods may still fail in real-world contexts
  - **Common issue**: scarcity of geometric features
  - Methods relying on **range-based** sensory information
  - How to quantify the **risk** of localization **failure**

- Proposed solutions
  - Spatial representation of risk based on ***alignability***
  - Building **alignability maps**
  - Validation for the prediction of localization errors
  - Application for motion planning



Alignability map

Implementation

- A 2D **grid map** that represents the **expected alignability** within a region of space
    - Each cell (i,j) is the **median** alignability of a set of *n* point clouds gathered in the region:

$$\mathcal{A}(i,j) = \text{median}(\mathbf{a})$$

$$\text{where } \mathbf{a} = (\alpha_1, \alpha_2, \ldots, \alpha_n)$$

- Alignability is only computed when the level of occupancy is lower than 50%

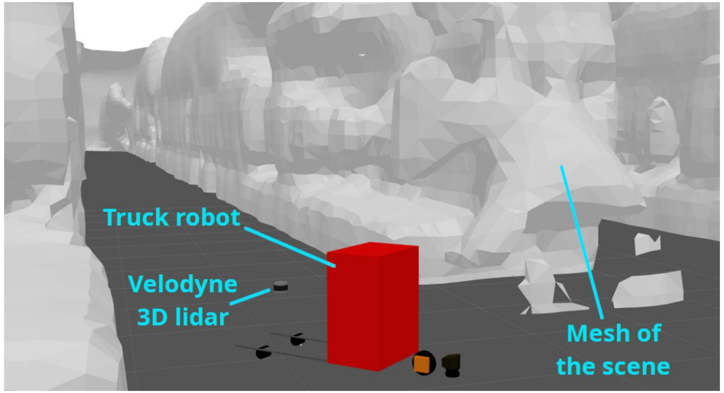
- We assume sensors with **360º field of view**
    - For more limited fov, we propose to define the map in different layers (future work)

Validation

Building of an alignability map

- Validation in virtual environment (built upon real data)

Warehouse environment



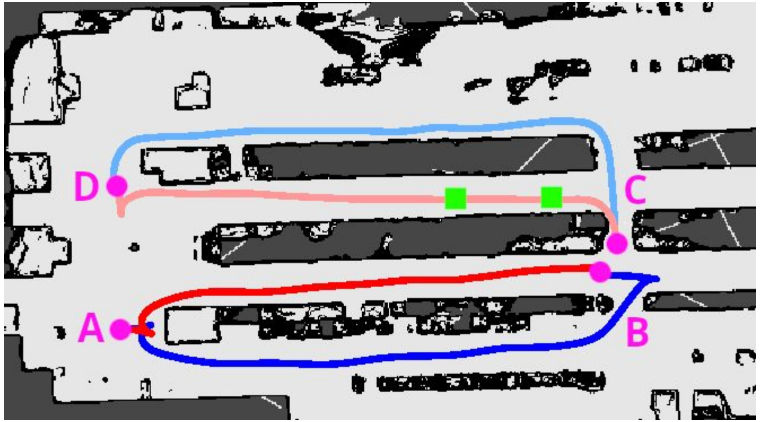
Virtual environment in Gazebo

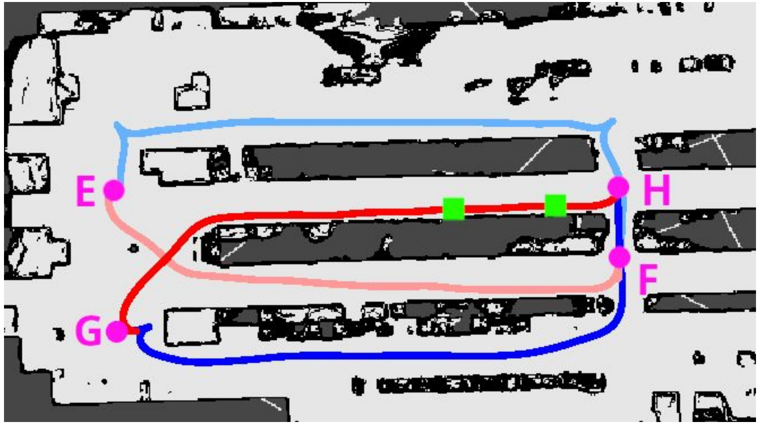
Validation

Application

Alignability in motion planning

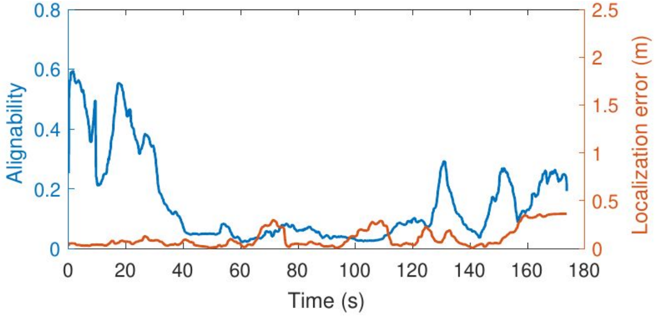
- Experimental setup
  - Our alignability map is used as a costmap for a motion planner (ROS `move_base`)
    - Alignability threshold of 0.02
    - Use of the maximum and minimum possible costs in the planner
  - Simulated experiments in the previous virtual environment
    - Complete a trajectory between two waypoints (considering and ignoring alignability costs for planning)



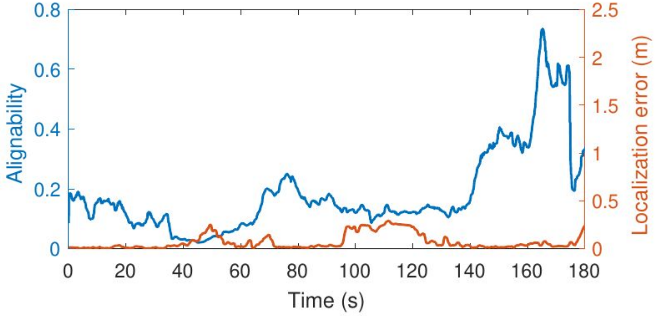


Validation

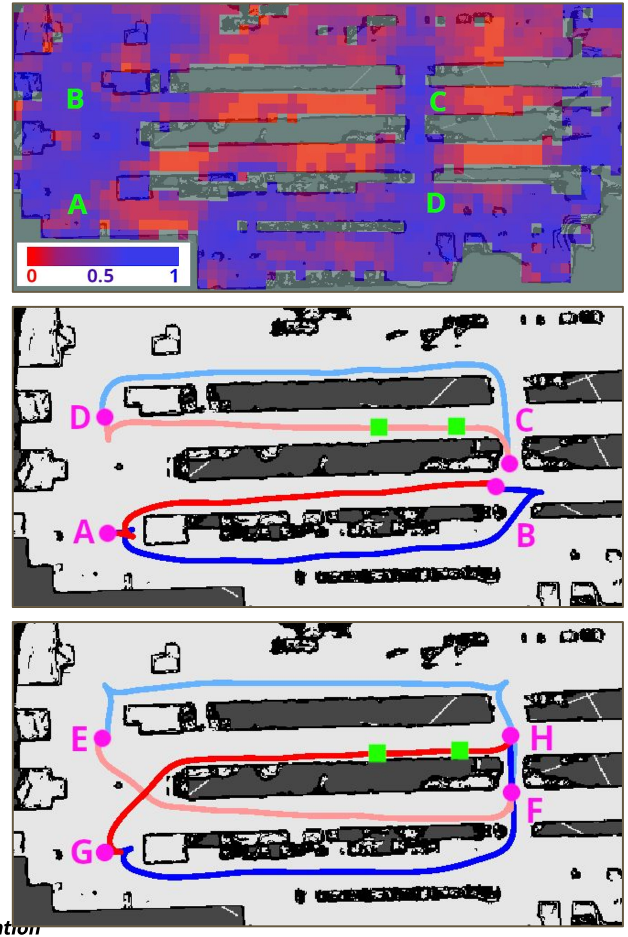
Alignability in motion planning



(c) Experiment C-D (alignability)



(d) Experiment G-H (alignability)



aps for ensuring high-precision localization

Speaker: Manuel Castellano Quero, Örebro University (Sweden)