Karlsruher Institut für Technologie

IFL

Towards Autonomous Navigation for Agile Production System

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- Intra-logistic environment
  - Automatically delivery item between stations
- Task-level navigation with objects
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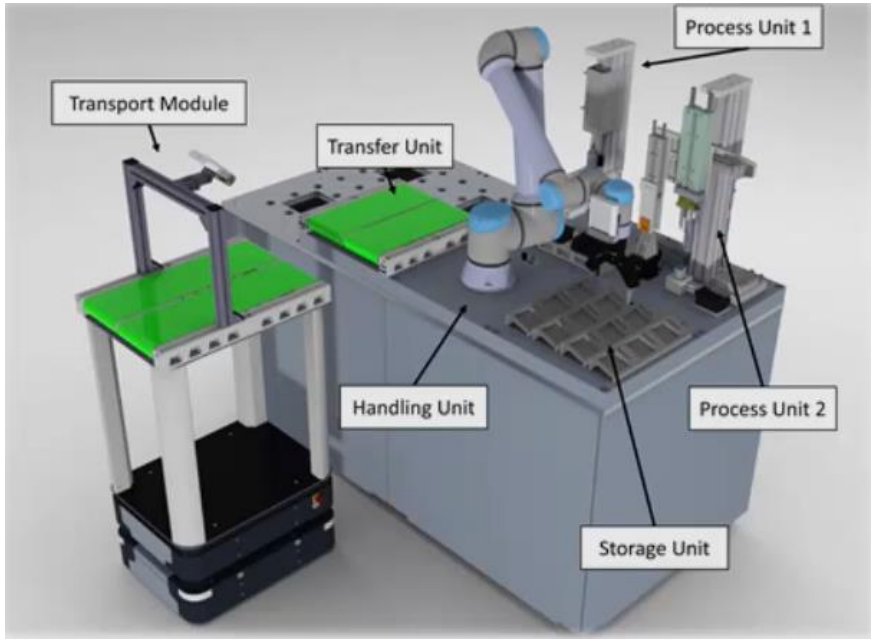
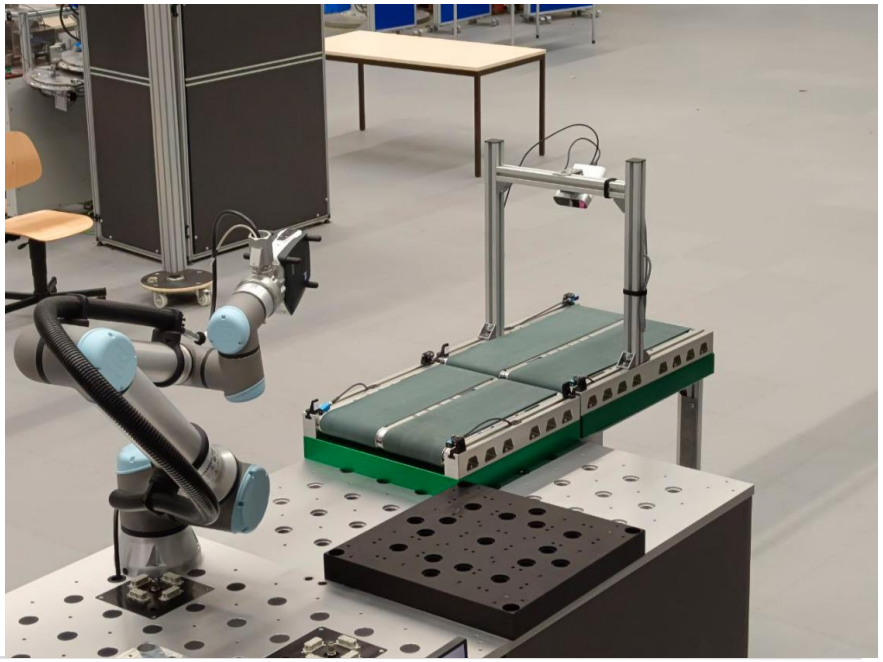
  - Hypermap with object information (hypermap)
- Fine-position navigation for docking
  - Global navigation with hypermap
  - Fine position navigation with laser-scanner

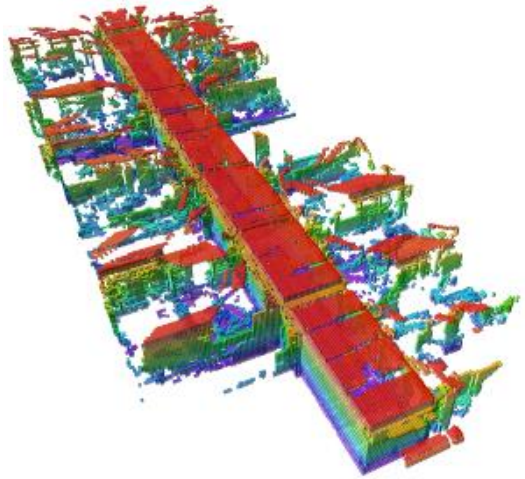


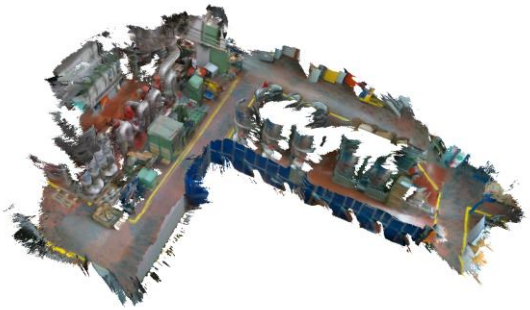


Literature Review

- Mapping

Method	Year	Sensors	Map Type	Map Feature	Usage
Grisetti et al Gmapping	2007	2D Laser scan	2D grid map	Occupancy info	Localization, Planar navigation
Hornung et al OctoMap	2013	3D laser scanner, RGB-D camera	3D voxel map	Occupancy info	Localization, Manipulation, 3D navigation
Oleynikova et al Voxblox	2017	RGB-D	3D voxel map	Occupancy info	3D navigation
Zaenker et al Hypermap	2020	2D laser scanner + RGB-D	Hypermap with occupancy, semantic and exploration layer	Occupancy info, semantic info, exploration infor	Planar navigation
Dengler et al Onlinr	2021	2D laser scanner + RGB-D	Hypermap with occupancy and object layer	Occupancy info, object info	Planar navigation
Sivananda et al Augment	2021	2D laser scanner + RGB-D	Hypermap with occupancy semantic, and object layer	Occupancy info, semantic info, object info	Planar navigation

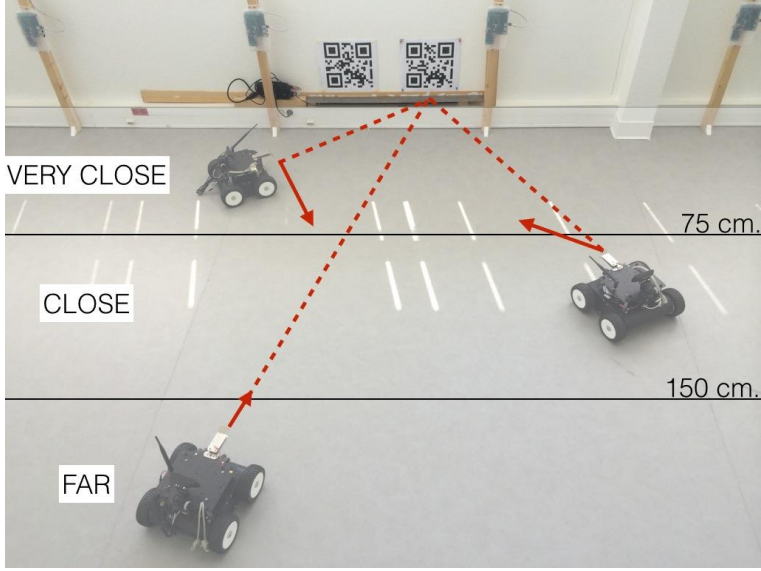


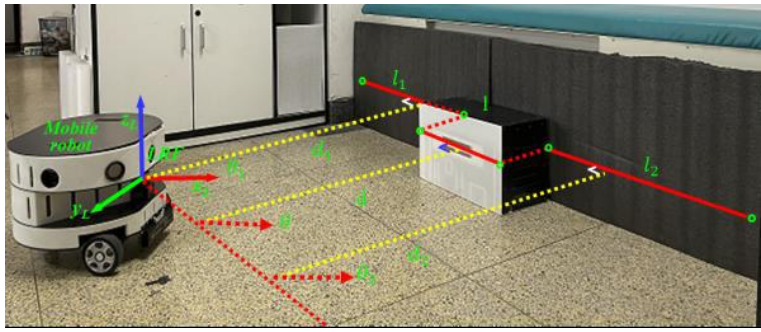


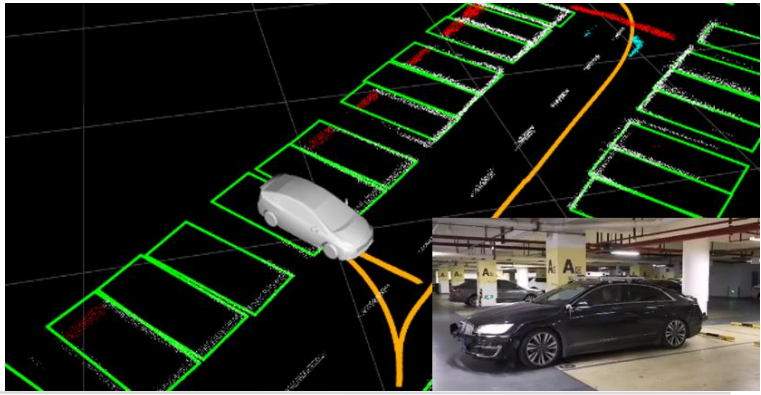
Literature Review

- Navigation (visual and laser based navigation)
- (fine-position navigation)

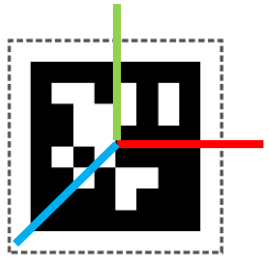
Method	Year	Sensors	Docking feature	Precision	Usage
Quile et al QR Code	2015	RGB camera	QR code	Not clear	
Fan et al AprilTag	2017	RGB camera	AprilTag	Not clear	warehouse
Zhang et al	2021	2D laser scanner	Line feature	e_pos < 2 cm e_angle < 3°	Indoor charging
Qin et al	2020	RGB, IMU	Semantic feature	e_pos < 36 cm	Parking lot







QR Code
Position Estimation



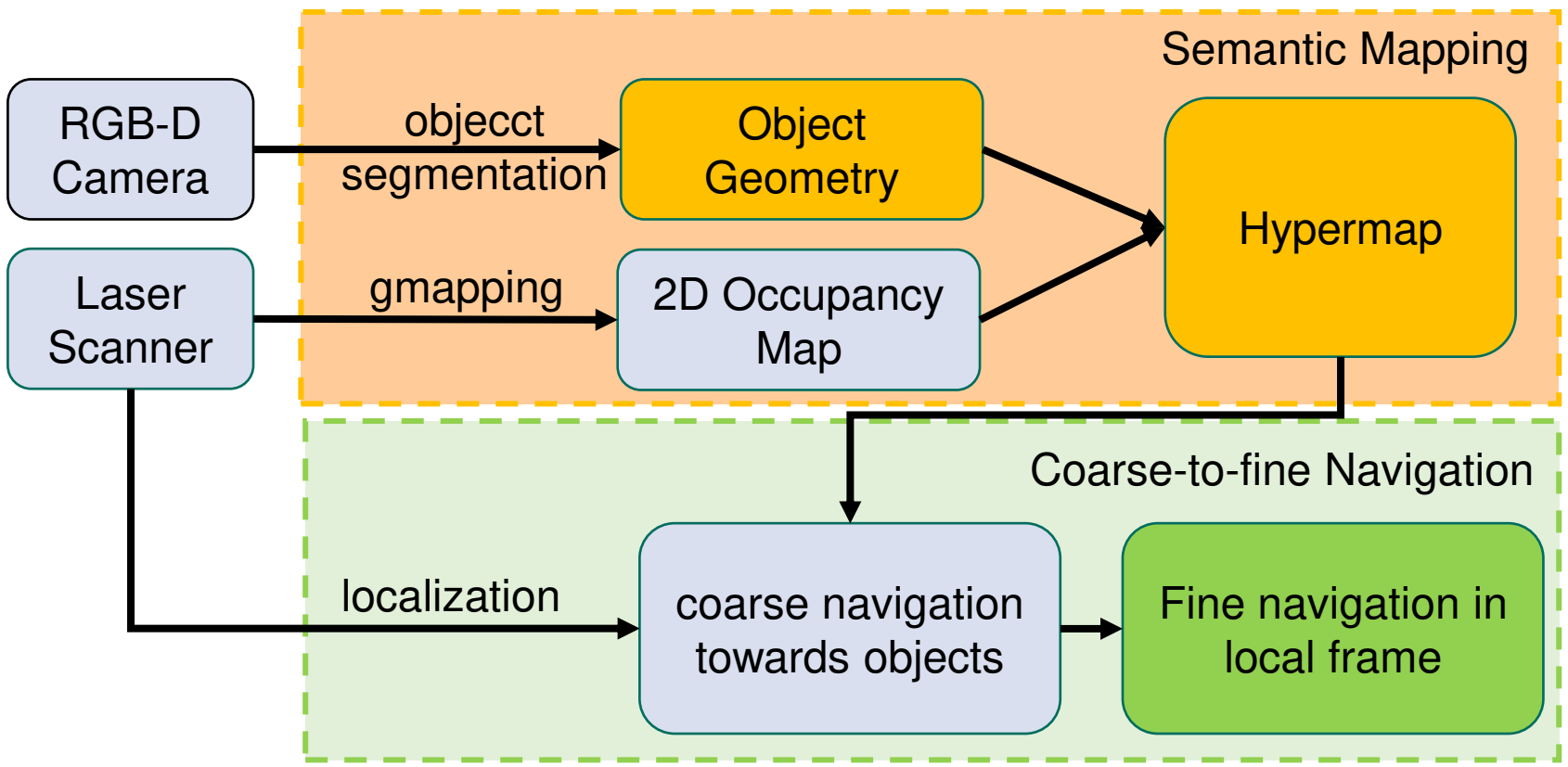
AprilTag
Pose Estimation

Laser scan
Pose Estimation

Contributions

- A semantic mapping system to efficient create a hypermap that appends semantic object information in the existing occupancy map.
- A coarse-to-fine navigation pipeline with hypermap to ensure a precise and safe navigation.
- A field experiment in an intra-logistic environment to demonstrate the efficiency of the whole system.

Method


Semantic Mapping
RGB-D Camera
objecct segmentation
Object Geometry
Hypermap
Laser Scanner
gmapping
2D Occupancy Map
Coarse-to-fine Navigation
localization
coarse navigation towards objects
Fine navigation in local frame

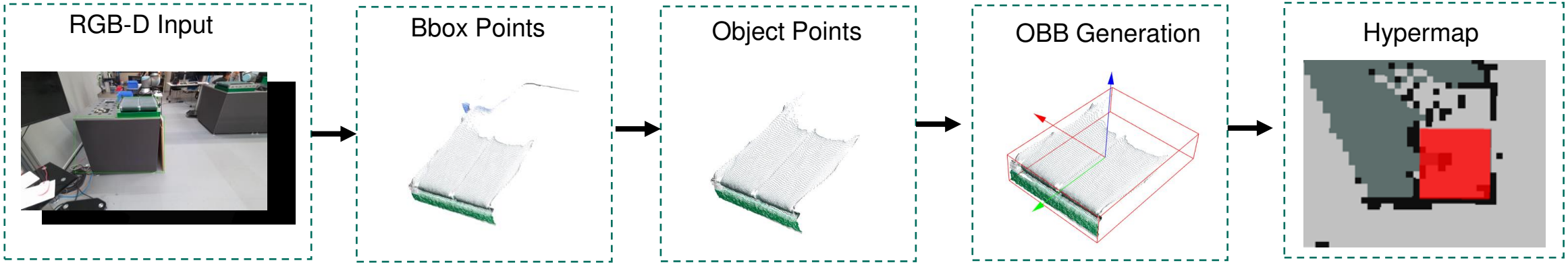

5cm

Method: Hypermap with object information

- Why mapping are two step
  - Not tightly coupled
  - 2d mapping is well studied and accurate, object detection is also accurate

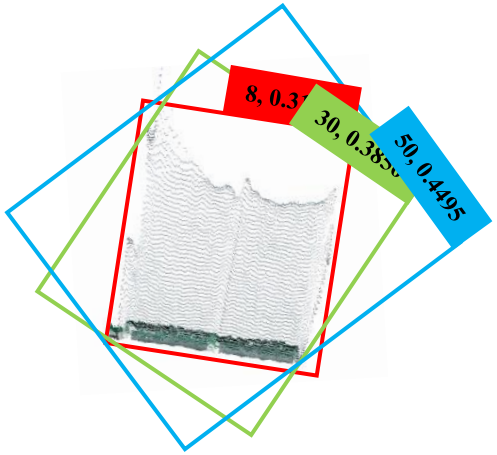
- 2D Occupancy Map -> gmapping package
  - REF: G. Grisetti, C. Stachniss, and W. Burgard, “Improved techniques for grid mapping with rao-blackwellized particle filters,” IEEE transactions on Robotics, vol. 23, no. 1, pp. 34–46, 2007.

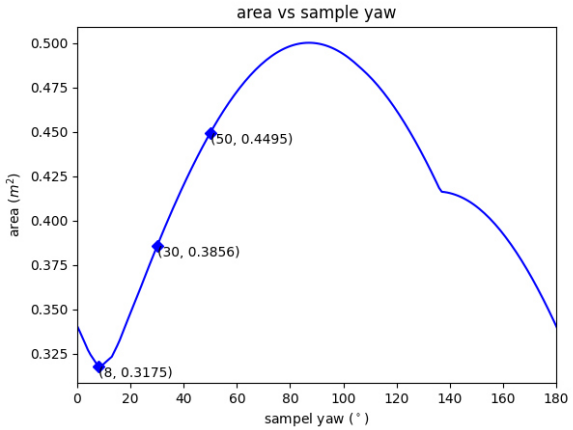
Method: Hypermap with object information



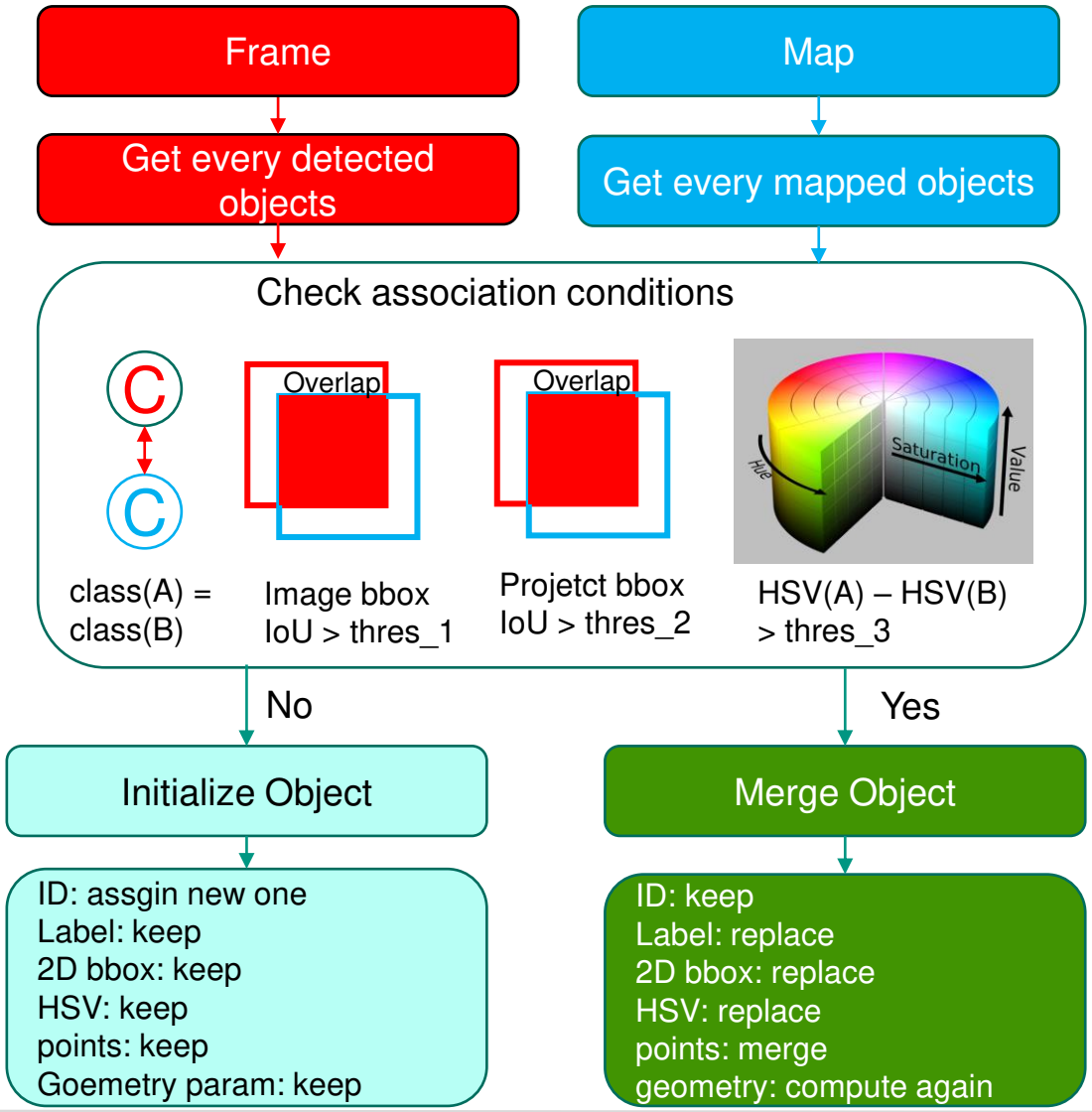
Object representation:

oriented object box, match objects to map



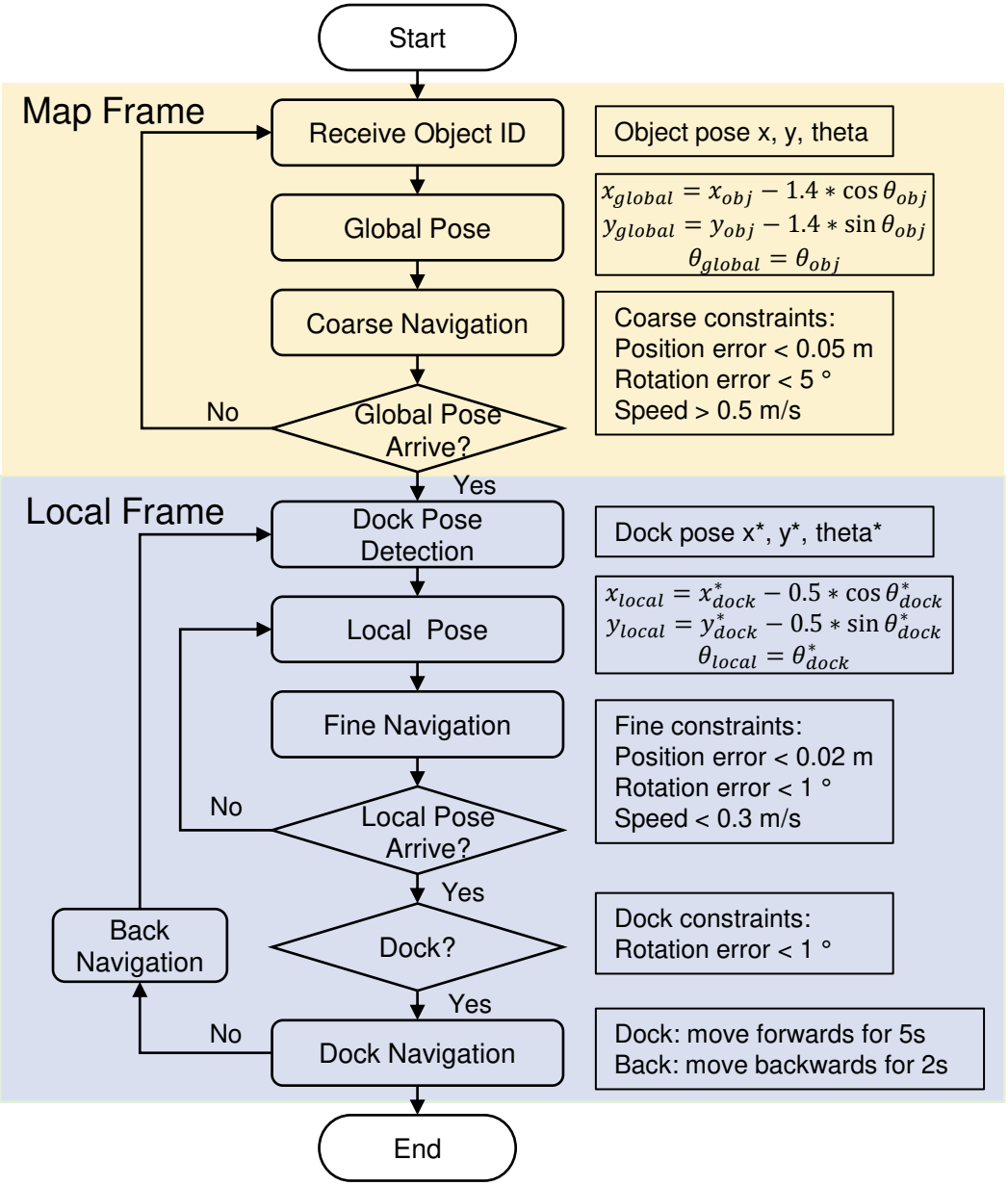


Method: Hypermap with object information

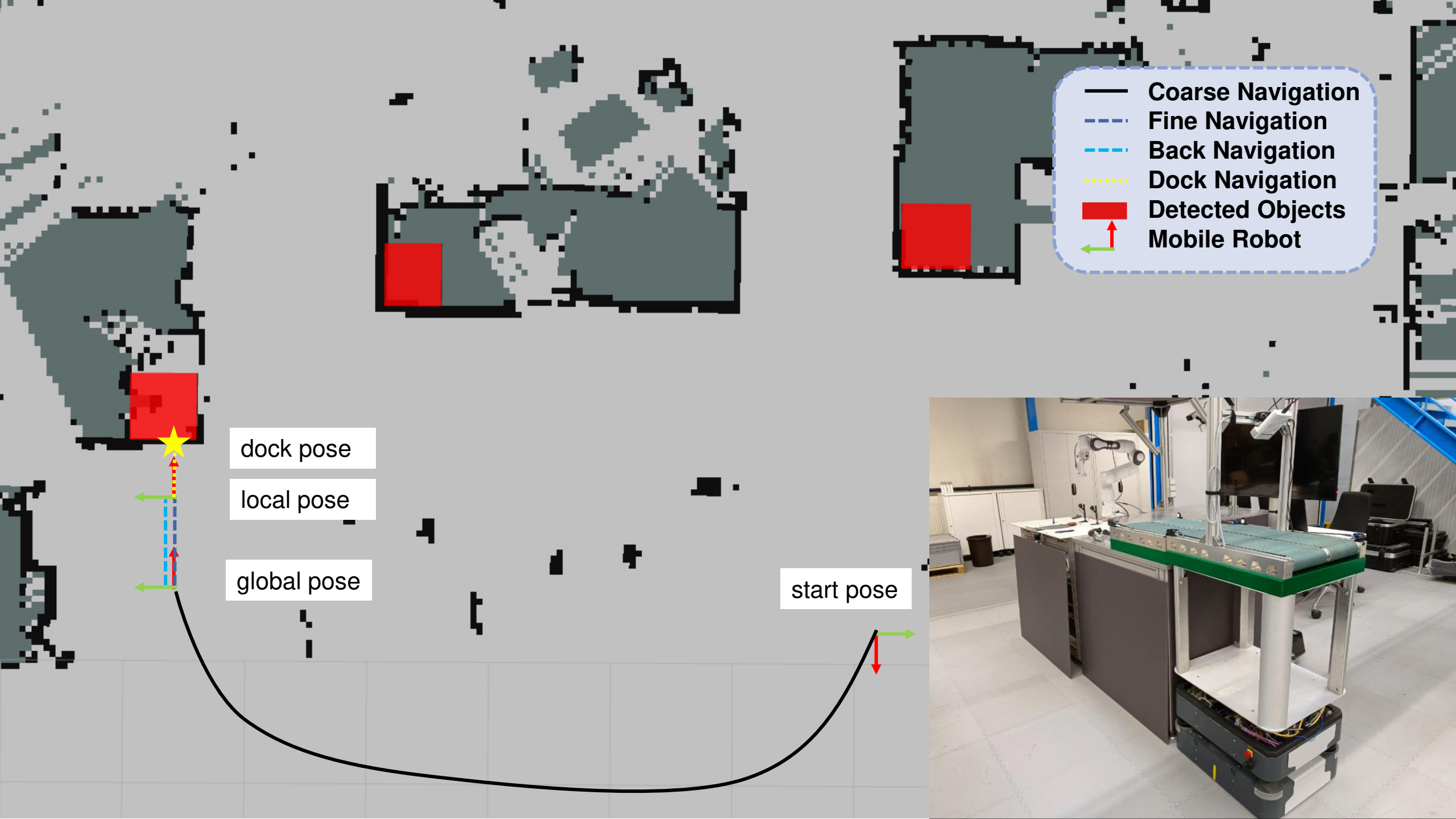


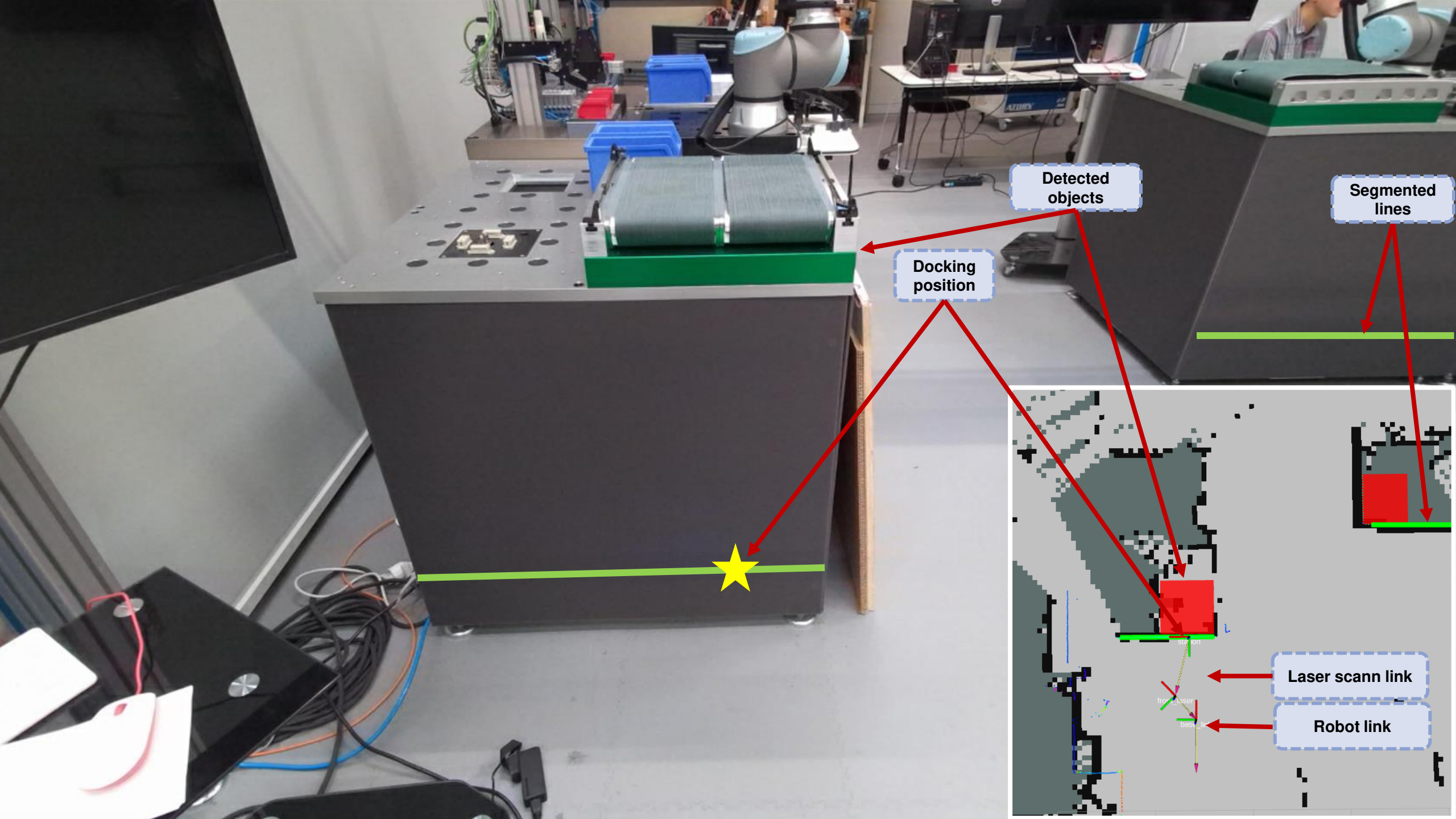
- Association: check frame detected objects match to mapped objects
- If they match, then, merge them
- If not, initiliaze a new object and add it to the map

Method: Coarse-to-fine navigation



- Global navigation with object info
  - how to define the nav goal
  - Constraints: speed, angle, map frame
- Fine postion navigation with laser scan
  - station feaure extraction
  - (project object to local frame, find associated line)
  - Constraints: speed, angle, local frame
- Docking and backwards navigation
  - Constraints: open controller
  - Backwards: adjust loop


Coarse Navigation
Fine Navigation
Back Navigation
Dock Navigation
Detected Objects
Mobile Robot
dock pose
local pose
global pose
start pose


Detected objects
Segmented lines
Docking position
Laser scann link
Robot link

Experiments

- Microsoft Azure RGB-D camera
- 2D SICK Laser Scan
- Camera-Laser Calibration

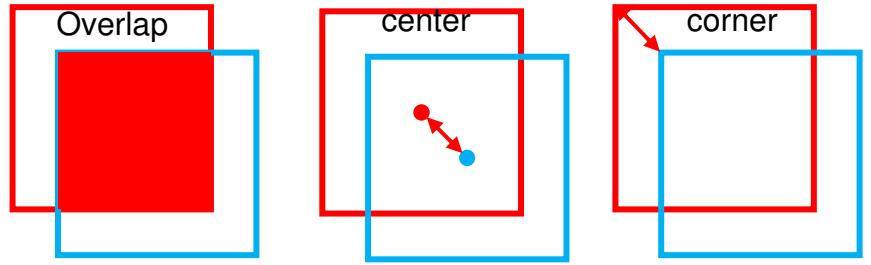
Experiments: Hypermap

- Object Intersection over Union
- Center of Mass distance (CoM-dist):
- Hausdorff distance (H-dist):

$$IoU = \frac{area(overlap)}{area(A) + area(B) - area(overlap)}$$

$$CoM\_dist = \sqrt{\|x_A - x_B\|^2 + \|y_A - y_B\|^2}$$

$$H\_dist = \max_i \sqrt{\|pi\_x_A - pi\_x_B\|^2 + \|pi\_y_A - pi\_y_B\|^2}$$



Conveyor	IoU	H-Dist	CoM-Dist
1	0.53	0.18	0.06
2	0.68	0.06	0.04
3	0.63	0.07	0.03
4	0.64	0.07	0.03

Experiments: Navigation

Task-level navigation
(delta x, delta y, delta theta)
(m, m, °)

Conveyor	Position (relative to station)	Position error	Ours
1	Left	(0.01, 0.008, 1)	(0.00, 0.01, 0)
2	Right	(0.01, 0.008, 1)	(0.00, 0.005, 1)
3	Left	(0.01, 0.008, 1)	(0.00, 0.02, 1)
4	Right	(0.01, 0.008, 1)	(0.02, 0.00, 0)

Runtime performance

Modules	Tasks	Runtime (mSec)
mapping	Occupancy mapping	
	Object mapping	
Navigation	Coarse navigation	
	Fine navigation	

Object mapping includes object detection, segmentation and updating.

Conclusion

- RQ4: How to navigate with object information and achieve a fine position docking process?
  - we presented an autonomous navigation pipeline that applied in real intra-logistic environment
  - an offline hypermap with occupancy and object layer is generated with laser scanner data
  - a coarse-to-fine navigation strategies is designed to ensure an autonomous task-level navigation.