Semantic Mapping and Autonomous Navigation for Agile Production System

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Introduction

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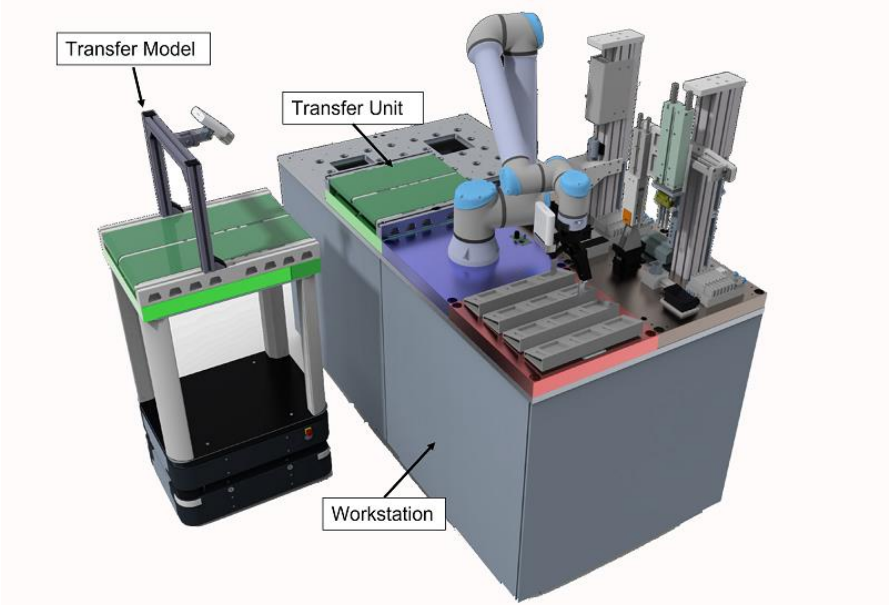
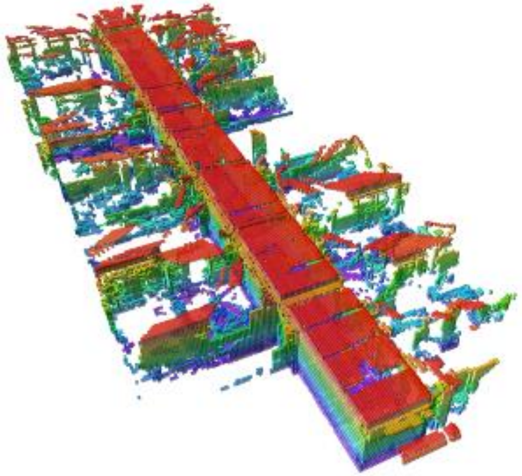
- Intra-logistic environment
  - Automatically delivery item between stations
- Task-level navigation with objects
  - Laser-based 2D mapping (gmapping)
  - Hypermap with object information (hypermap)
- Fine-position navigation for docking
  - Global navigation with hypermap
  - Fine position navigation with laser-scanner

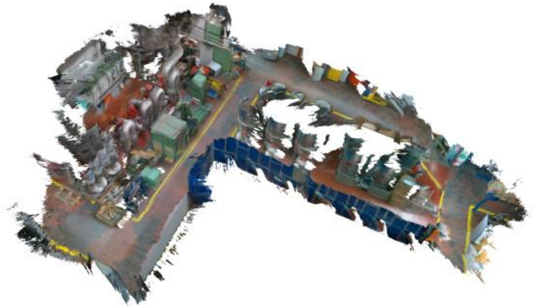


Literature Review

- Mapping

Method	Year	Sensors	Map Type	Map Feature	Features
Grisetti et al Gmapping	2007	2D Laser scan	2D grid map	Occupancy info	Probablistic occupancy map
Himstedt et al.	2017	RGB-D	2D grid map with labels	Occupancy info, semantic info	converted the labeled point cloud into annotated scan data
Pang et al	2019	2D laser scanner + RGB-D	2D grid map with labels	Occupancy info, semantic info	projected laser points into the images and assigned the corresponding classes to the laser points
Sivananda et al Augment	2022	2D laser scanner + RGB-D	Hypermap with occupancy semantic, and object layer	Occupancy info, semantic info, object info	searched for a corresponding object in a database
Zaenker et al Hypermap	2020	2D laser scanner + RGB-D	Hypermap with occupancy, semantic and exploration layer	Occupancy info, semantic info, exploration info	Multiply layers for different purposes
Dengler et al Onlinr	2021	2D laser scanner + RGB-D	Hypermap with occupancy and object layer	Occupancy info, object info	Online updating

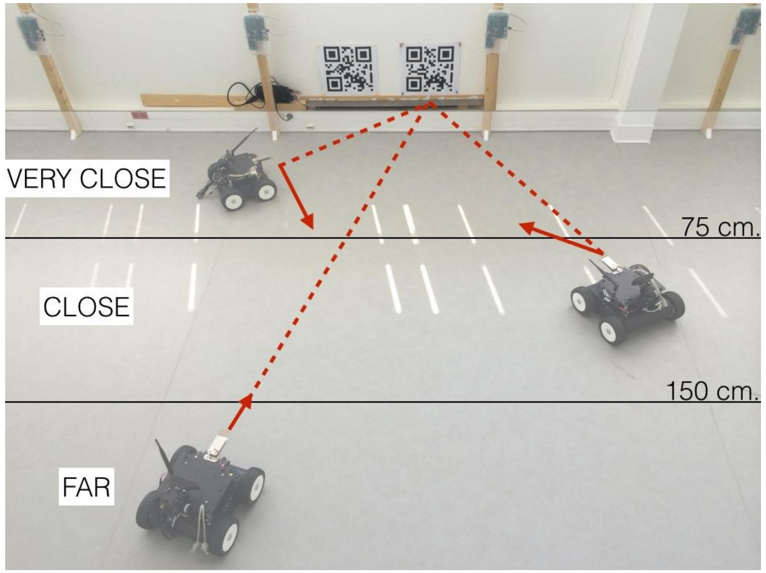




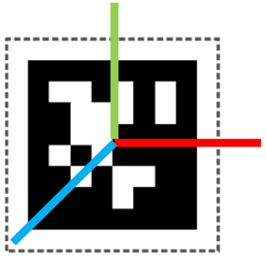
Literature Review

- 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

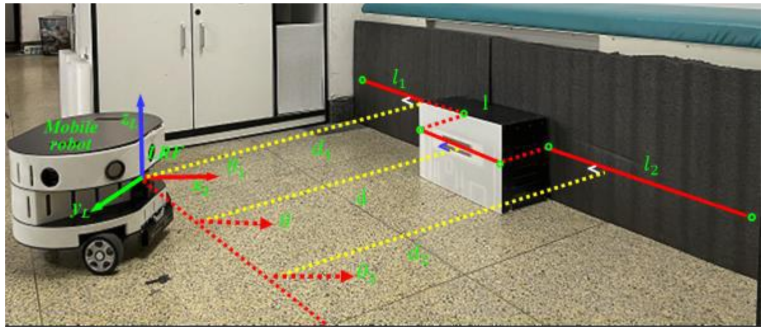


QR Code
Position Estimation



AprilTag
Pose Estimation

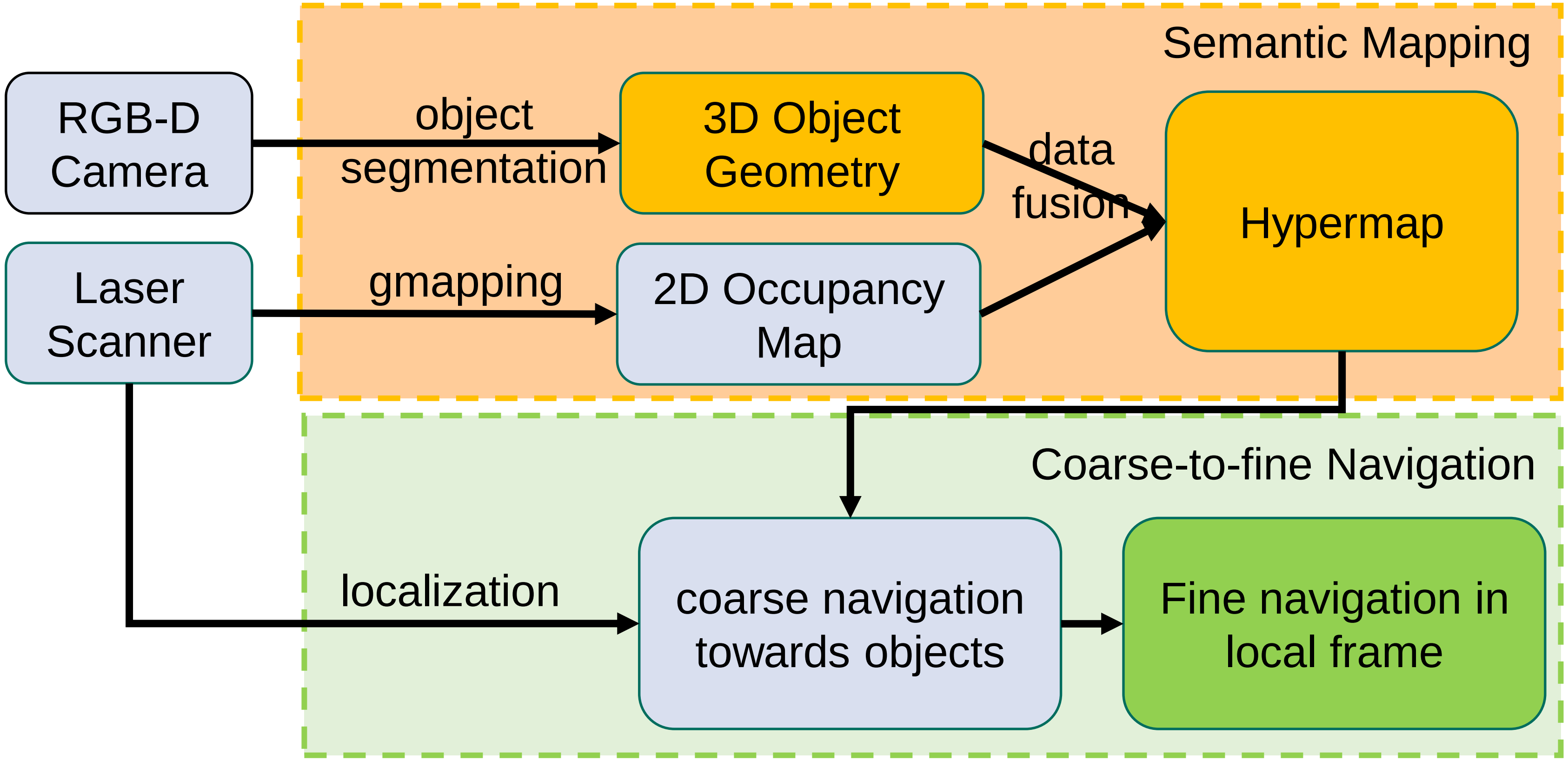
Laser scan
Pose Estimation



Contributions

- A semantic mapping system to efficiently create a hypermap that appends semantic objects to the existing occupancy map.
- A coarse-to-fine navigation pipeline which uses this hypermap to ensure safe and precise navigation.
- A field experiment in a production logistics environment to demonstrate the effectiveness of the entire system.

Method

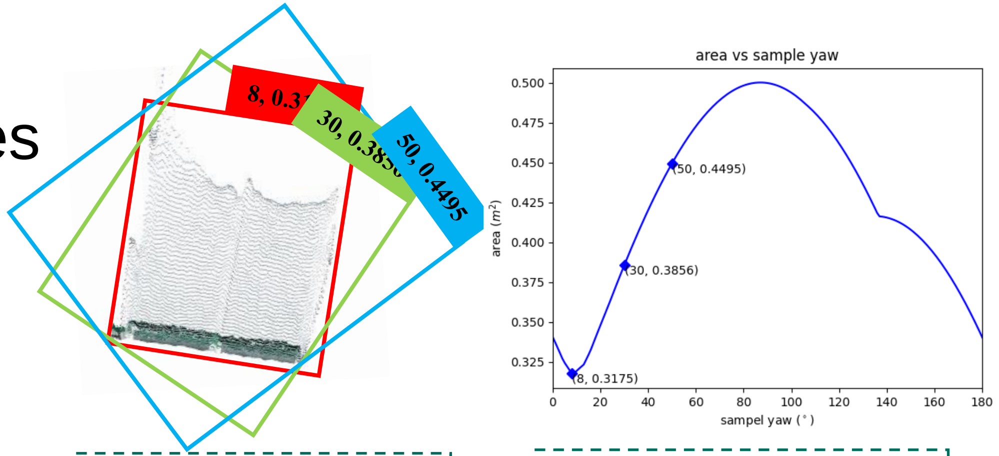

Semantic Mapping
RGB-D Camera
object segmentation
3D Object Geometry
data fusion
Hypermap
Laser Scanner
gmapping
2D Occupancy Map
Coarse-to-fine Navigation
localization
coarse navigation towards objects
Fine navigation in local frame

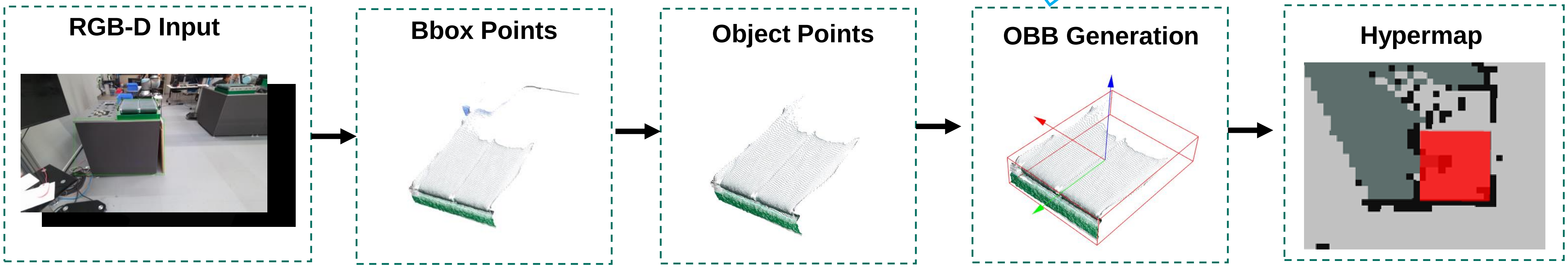

50cm

Method: Hypermap with object information

Object representation:
oriented object box,
match objects to map

- 2D Occupancy Map
  - Gmapping packages with laser scan data
- 3D Object Geometry
  - Object segmentation with RGB-D sequences





Method: Hypermap with object information

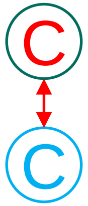
Frame

Get every detected objects

Map

Get every mapped objects

Check association conditions



class(A) = class(B)

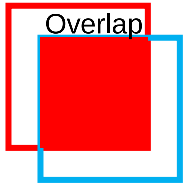
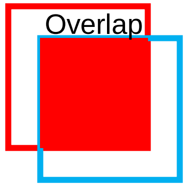
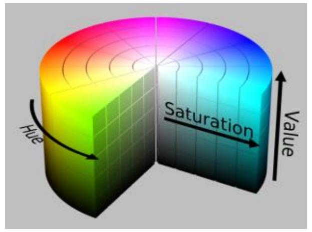


Image bbox IoU > thres_1



Projetct bbox IoU > thres_2



HSV(A) – HSV(B) > thres_3

No

Initialize Object

ID: assgin new one
Label: keep
2D bbox: keep
HSV: keep
points: keep
Goemetry param: keep

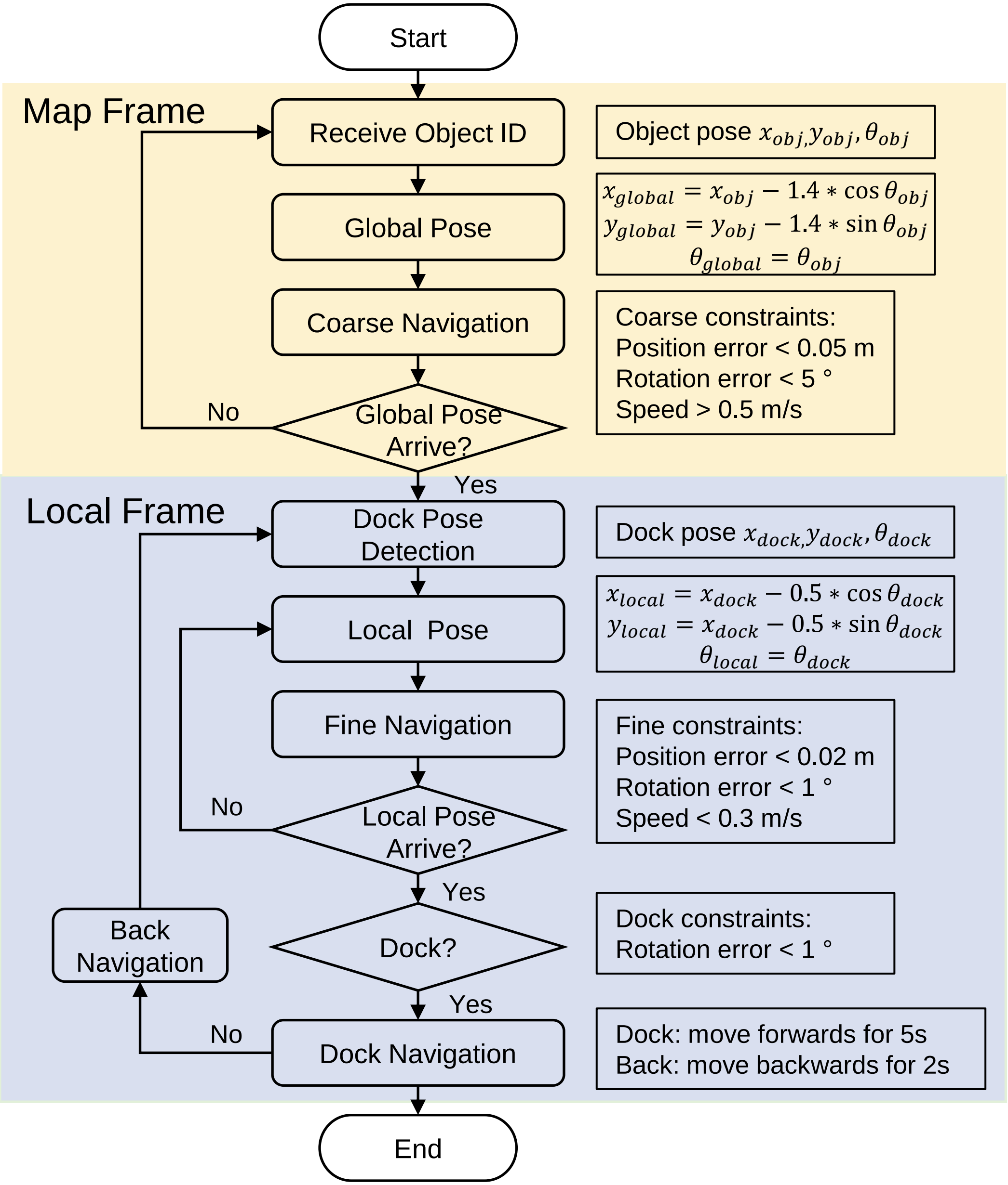
Yes

Merge Object

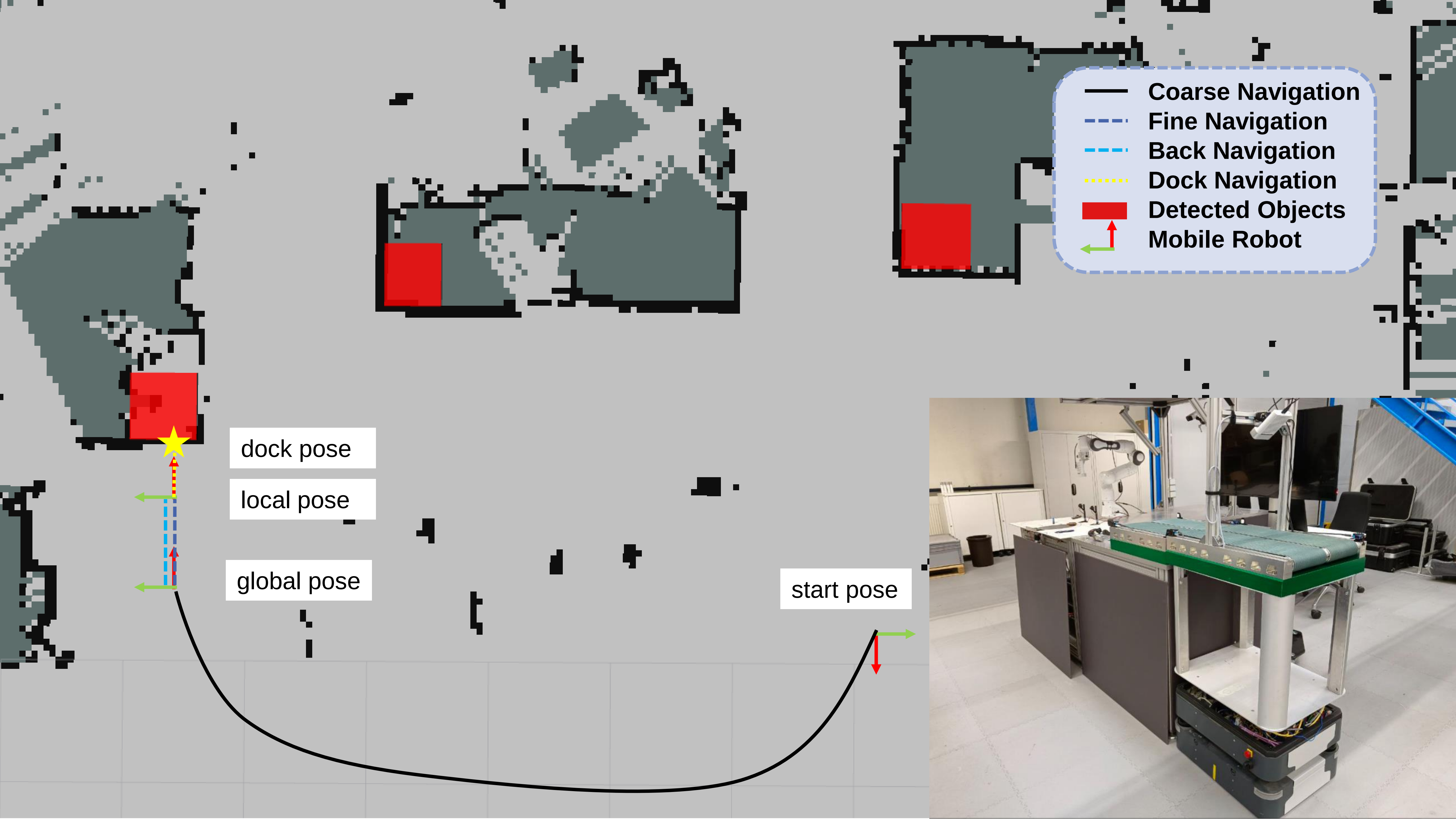
ID: keep
Label: replace
2D bbox: replace
HSV: replace
points: merge
geometry: compute again

- 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

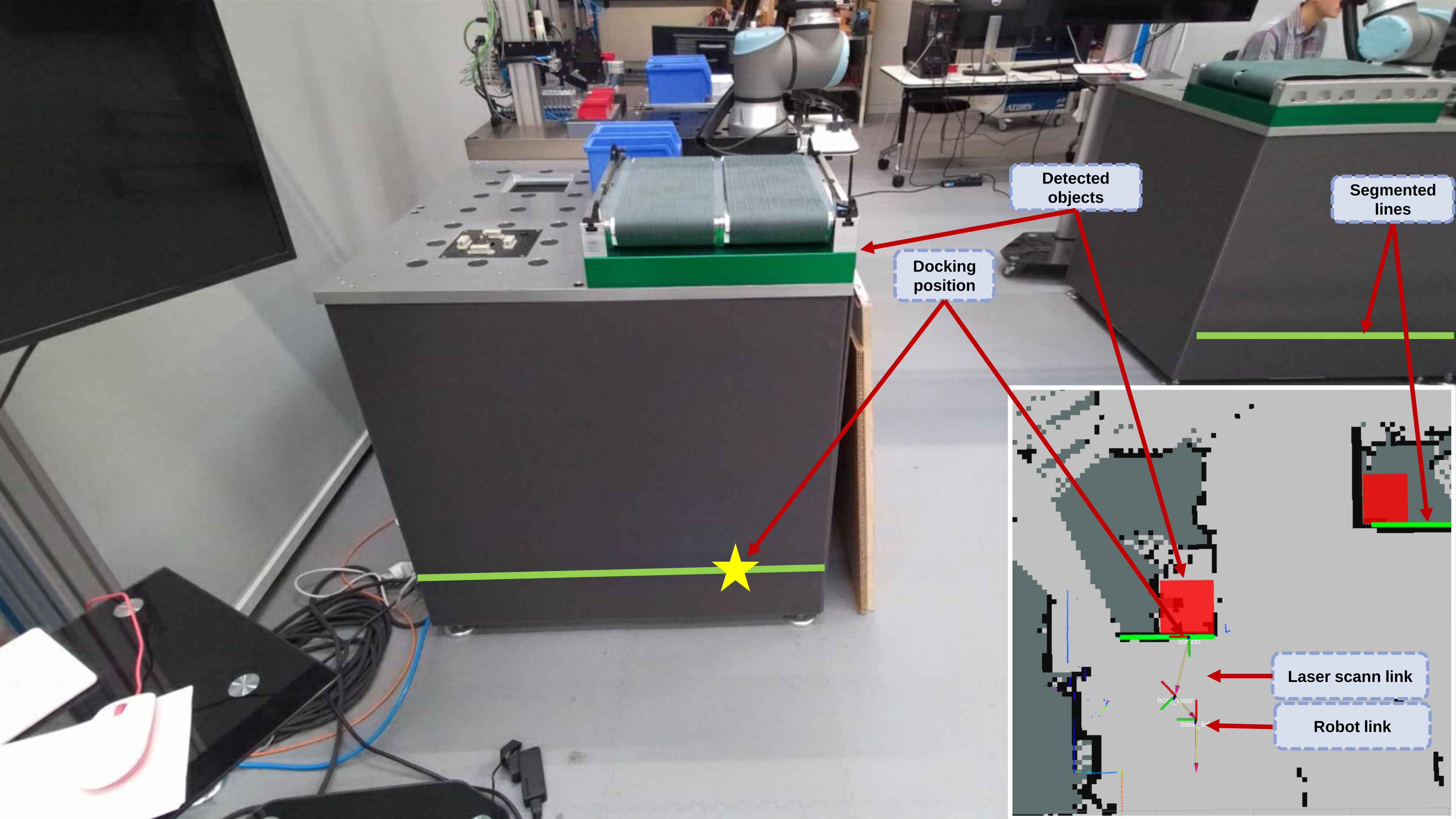
Method: Coarse-to-fine navigation



- 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

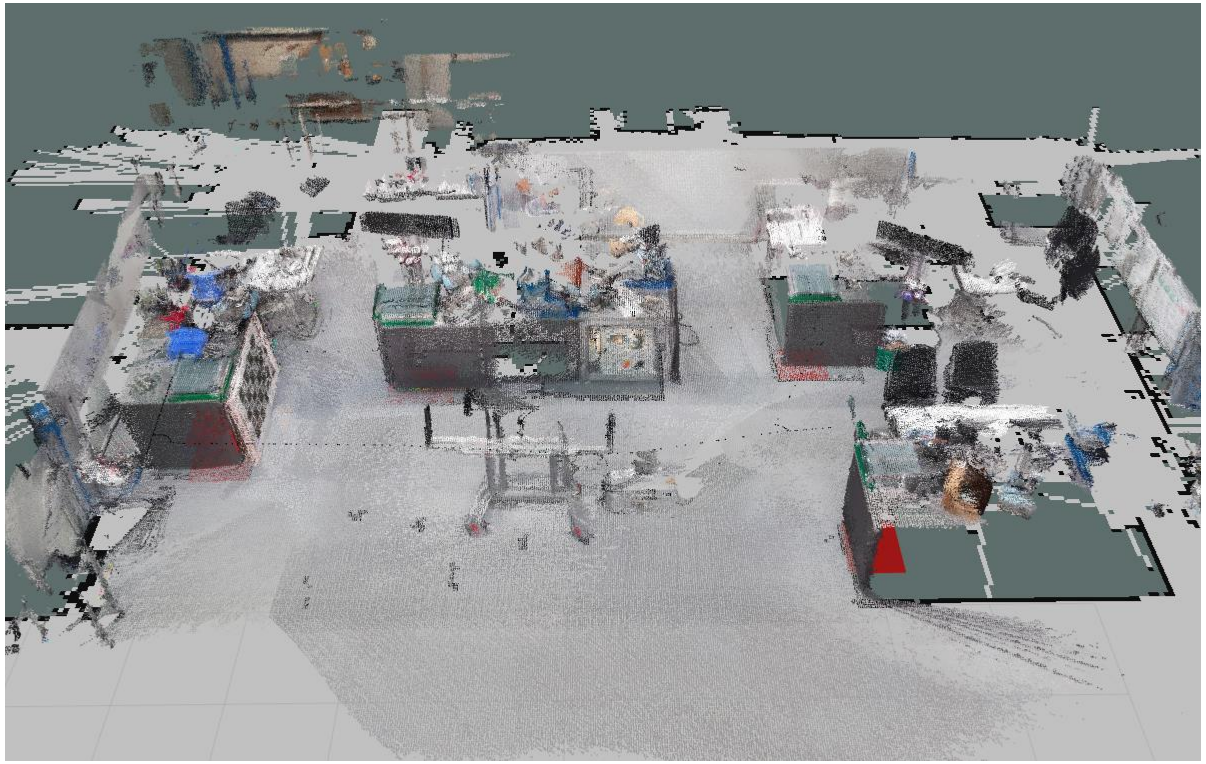


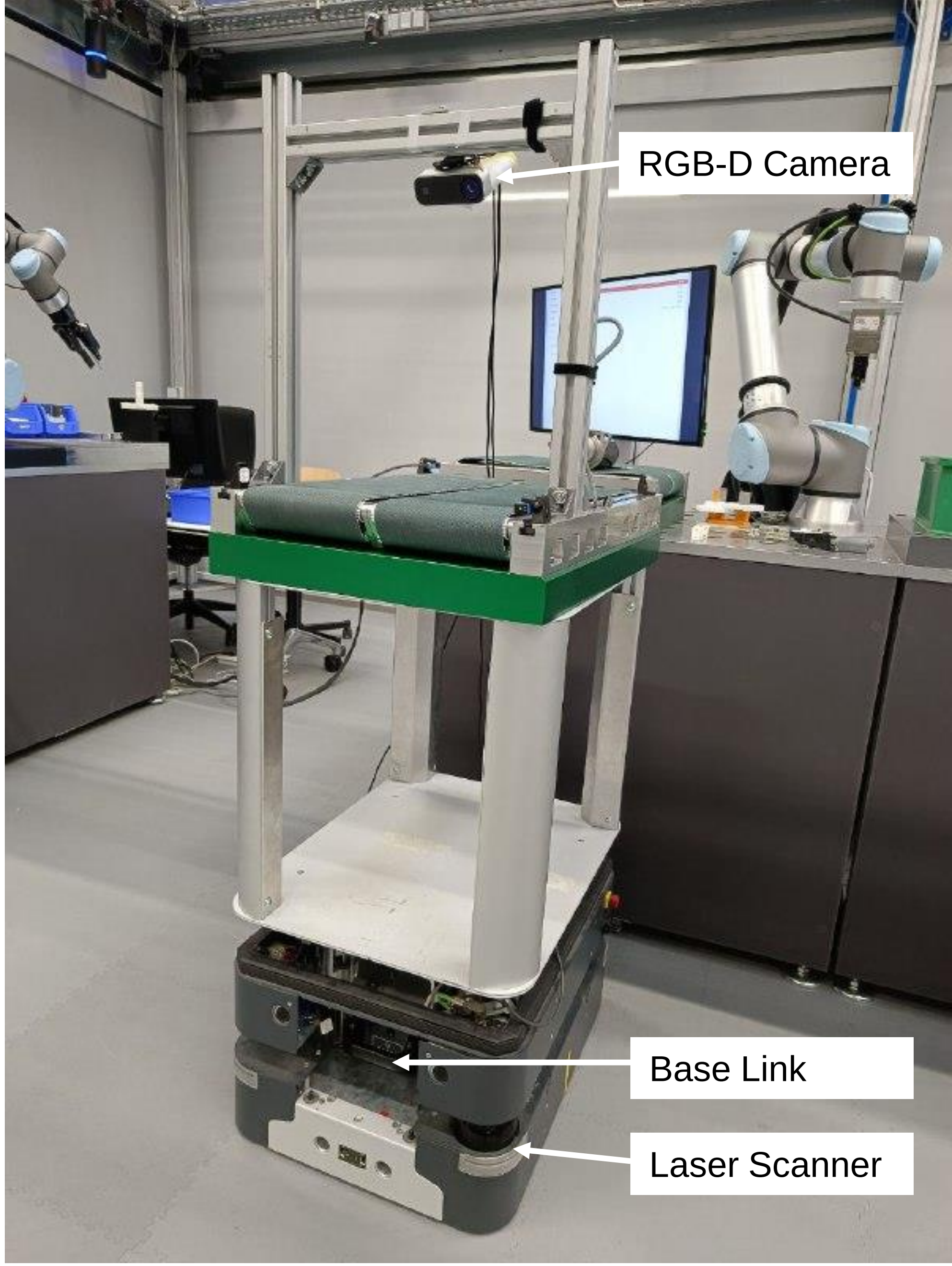
Coarse Navigation
Fine Navigation
Back Navigation
Dock Navigation
Detected Objects
Mobile Robot
dock pose
local pose
global pose
start pose


Detected objects
Segmented lines
Docking position
Laser scann link
Robot link

Experiments

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





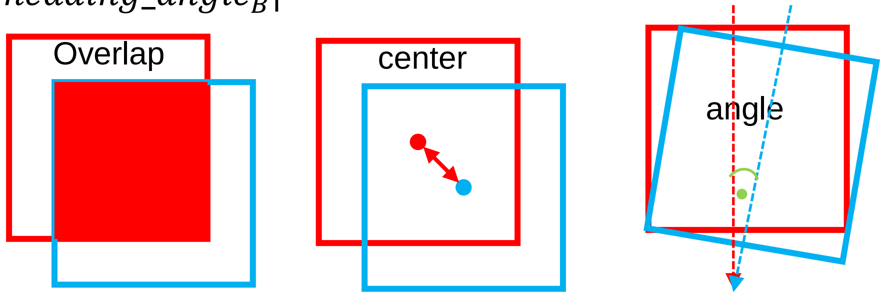
Experiments: Hypermap

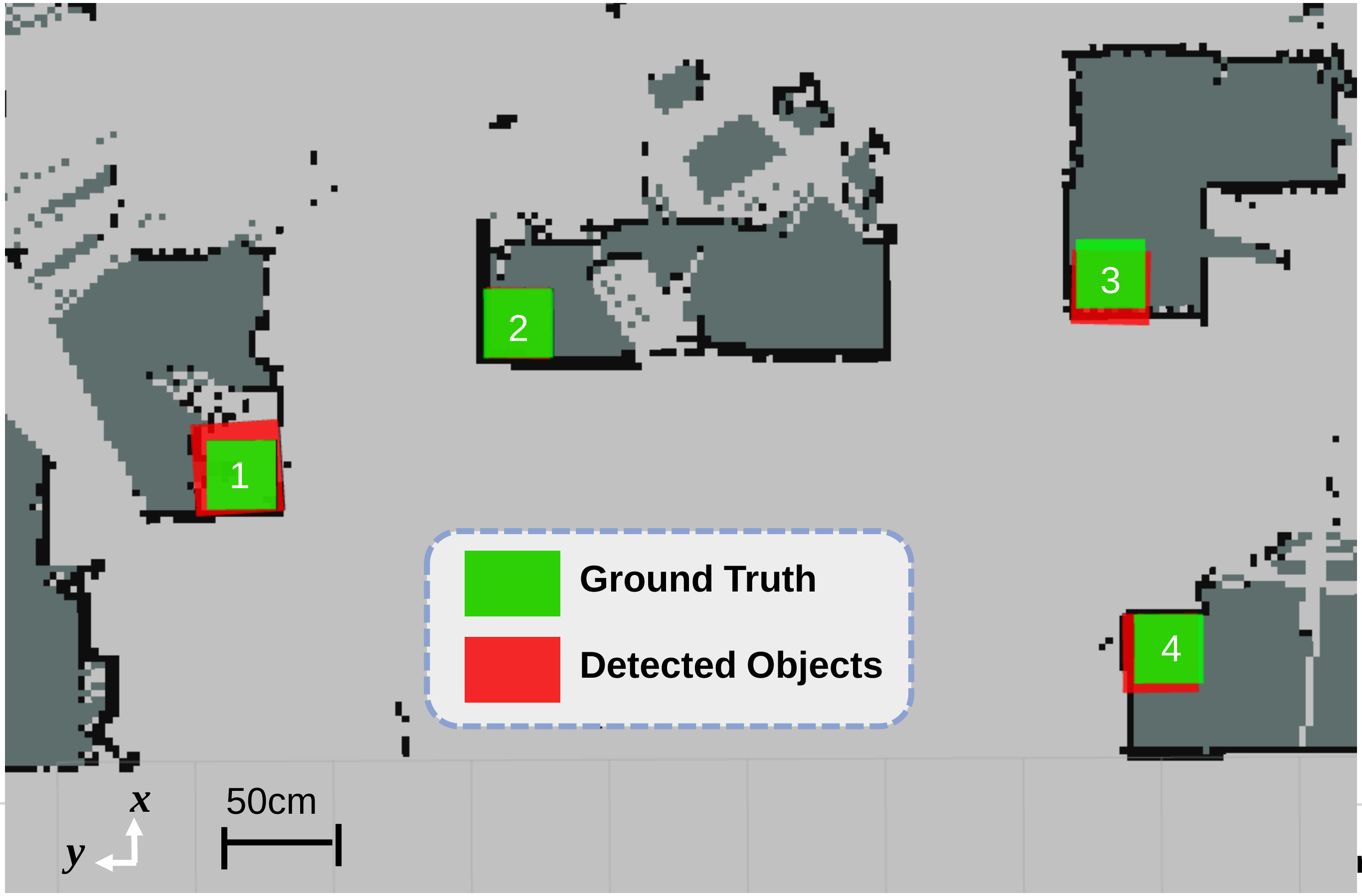
- Object Intersection over Union
- Translation error
- Rotation error

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

$$E\_trans = \sqrt{\|x_A - x_B\|^2 + \|y_A - y_B\|^2}$$

$$E\_rot = |heading\_angle_A - heading\_angle_B|$$



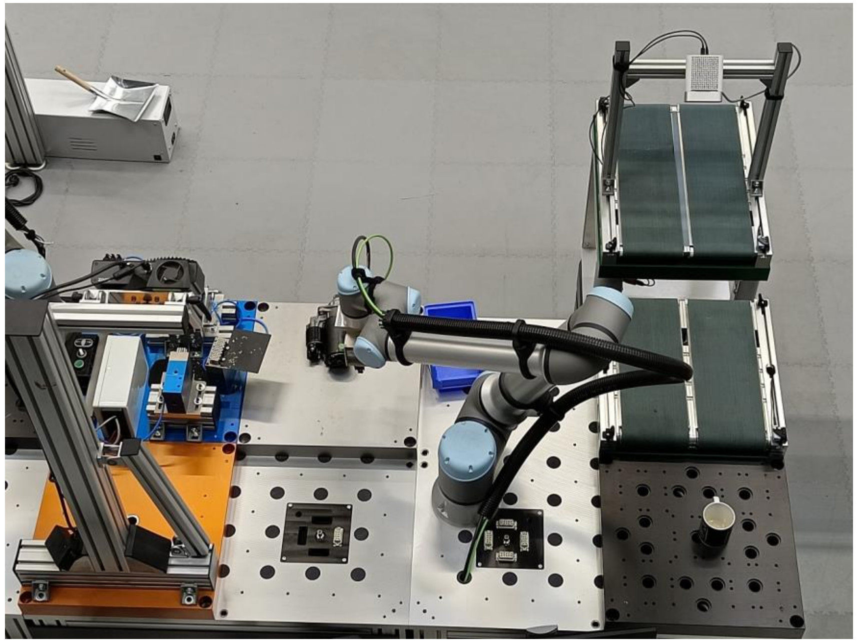


Conveyor	IoU	E_trans (m)	E_rot (°)
1	0.59	0.17	4
2	0.69	0.07	1
3	0.82	0.08	1
4	0.85	0.06	2
Acerage	0.7375	0.095	2

Experiments: Navigation

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

Conveyor	Position (relative to station)	ROS Navigation (m, m, °)	Ours (m, m, °)
1	Left	(0.01, 0.010, 2)	(0.00, 0.01, 0)
2	Right	(0.01, 0.020, 3)	(0.00, 0.005, 1)
3	Left	(0.01, 0.010, 3)	(0.00, 0.01, 1)
4	Right	(0.20, 0.010, 2)	(0.02, 0.00, 0)



Runtime performance

Modules	Tasks	Runtime (mSec)
mapping	Occupancy mapping	200
	Object mapping	135
Navigation	Coarse navigation	30
	Fine navigation	20

Object mapping includes object detection, segmentation and updating.

Conclusion

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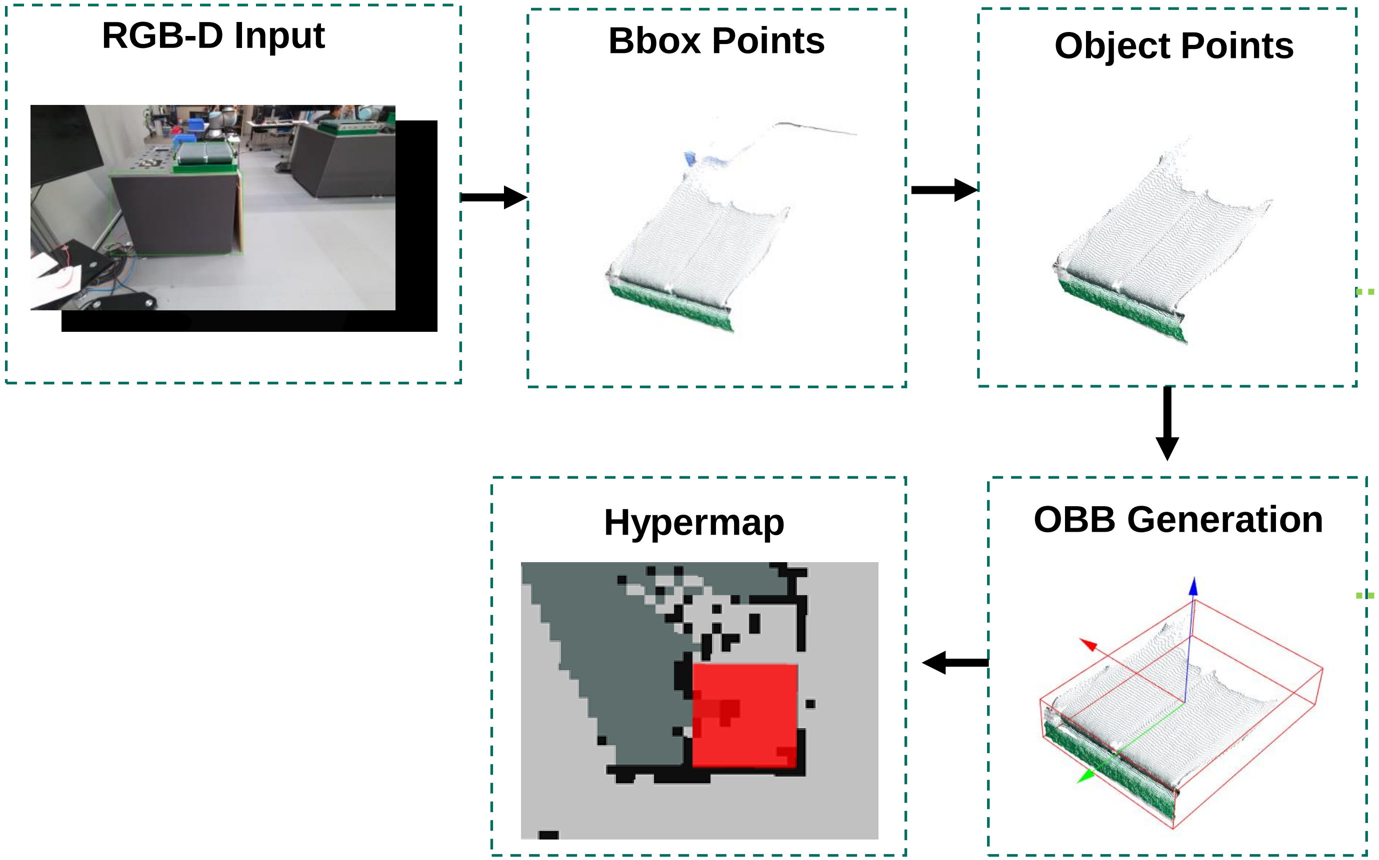
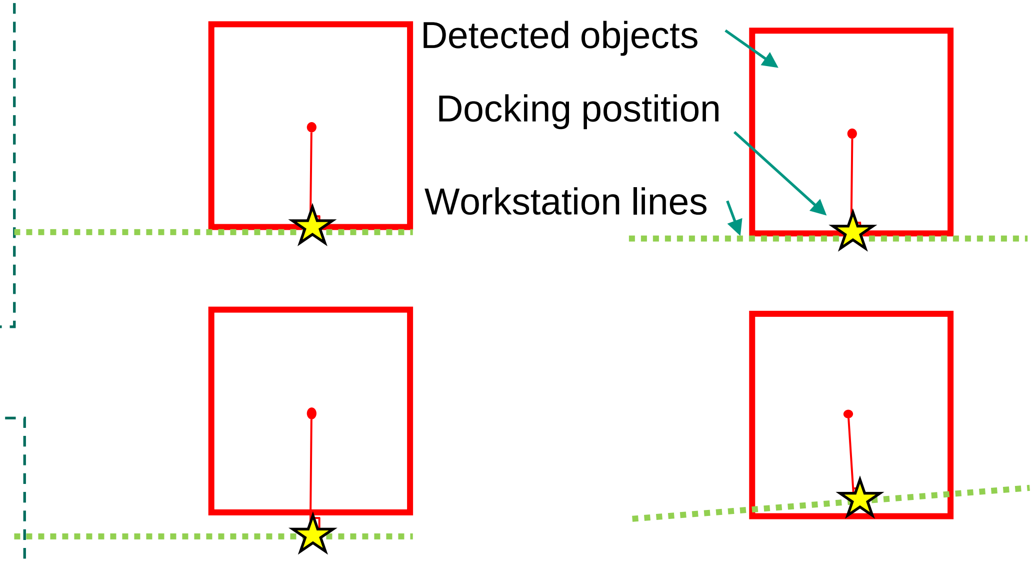
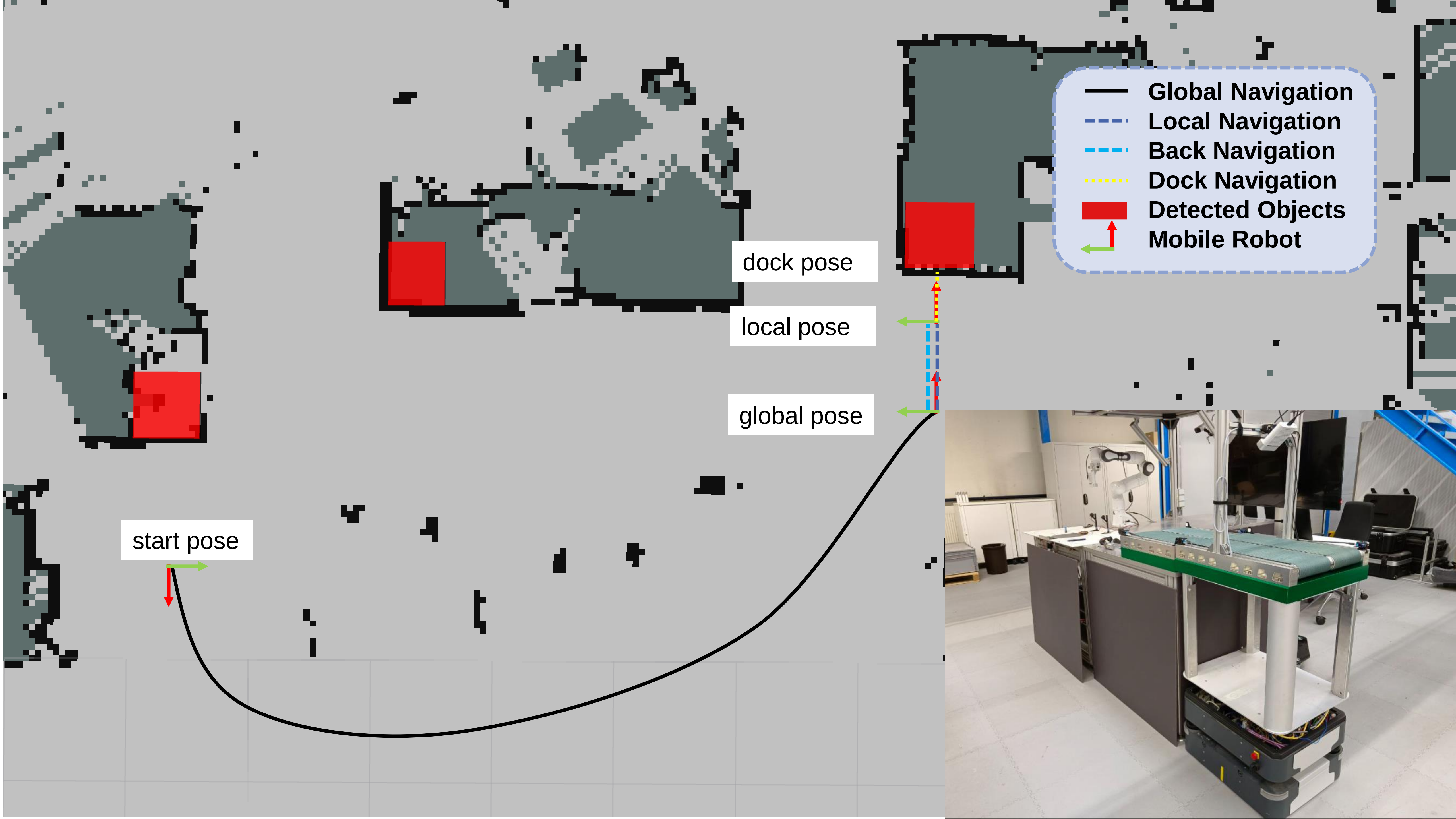
- RQ4: How to navigate with object information and achieve a fine position docking process?
  - We presented an autonomous navigation pipeline for the purpose of object-based mapping and navigation.
  - An offline hypermap with an occupancy and object layer is created, where the occupancy layer is generated using laser scan data, while the objects are segmented from RGB-D sequences and projected on the top of the 2D grid map.
  - A coarse-to-fine navigation strategy is designed to achieve task-level navigation. The coarse navigation takes object information as input to design a global path, while the fine navigation defines a dock pose in the local frame to ensure a precise dock.
  - We evaluate our system on the AgiProbot project, and the results demonstrate that our system can successfully dock to the workstation with high performances and achieve a flexible material handling process.

Extend Figures



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