

TOWARDS PLUG & PLAY SOLUTIONS FOR AUTONOMOUS NAVIGATION OF MOBILE ROBOTS AND AGV

Fraunhofer IPA - Department Robot and Assistive Systems

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Outline

- Plug & Play Navigation Solutions – Characteristics and keys
- IPA Navigation Stack
 - Concept and core components
 - Application on Smart Transport Robot at BMW
 - Potentials and Limitations
- NODE – Navigation on Demand
 - Concept
 - Experience-/Learning-based Navigation

Plug & Play Navigation Solutions

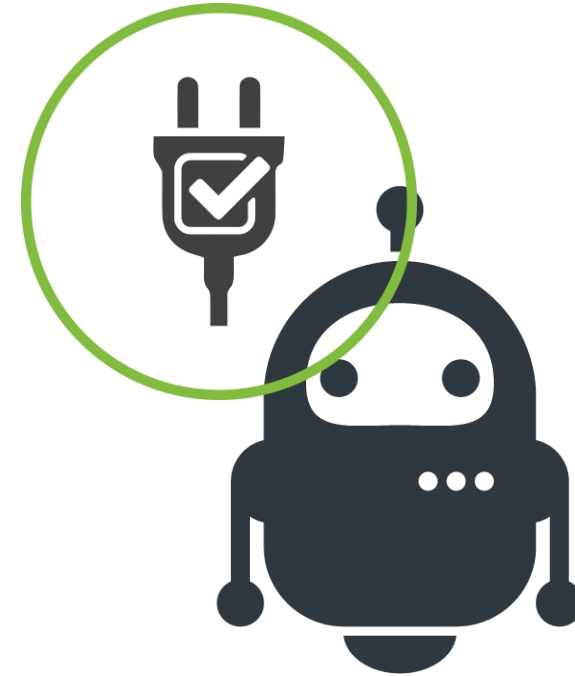
Key to the widespread of mobile robots/AGVs in industry

Features for Plug & Play:

- Minimum commissioning / maintenance efforts
- Ease of use and monitoring
- No expert knowledge necessary
- Versatile applicability:
 - Varying environmental conditions
 - Different applications/navigation behaviors
- Open, standardized interfaces

Key: High autonomy capabilities

- Infrastructureless/markerless localization
- Interaction/adaptation to dynamic and changing environments



IPA Navigation Stack

Autonomous navigation for mobile robots

- Versatile navigation stack for autonomous navigation in dynamic and changing environments
 - No markers or additional navigation infrastructure necessary
 - Mostly platform-/HW- and sensor-independent
 - Based on the Robot Operating System (ROS)
- Core components:
 - Long-Term SLAM
 - Zone-based global route planning
 - Dynamic, local path and trajectory optimization



Source: Alfred Kärcher GmbH



Source: Fraunhofer IPA



Source: Bär Automation GmbH



Source: BMW AG



Source: Fraunhofer IPA

IPA Navigation Stack

Application on Smart Transport Robot (STR) at BMW production plants

Task:

- Autonomous navigation for transport of coasters in BMW production halls
 - Markerless/infrastructure-less Localization
 - Dynamic path planning and obstacle avoidance

Challenges:

- Sparse sensor data (180° FOV 2D safety laser scan data + wheel odometry)
- Highly variable environment, hardly any static structures
- Interaction with forklifts, trugger trains, persons, etc.
- Large environments ($> 100,000 \text{ m}^2$)
- Limited maneuverability with variable footprint and speed-dependent safety fields

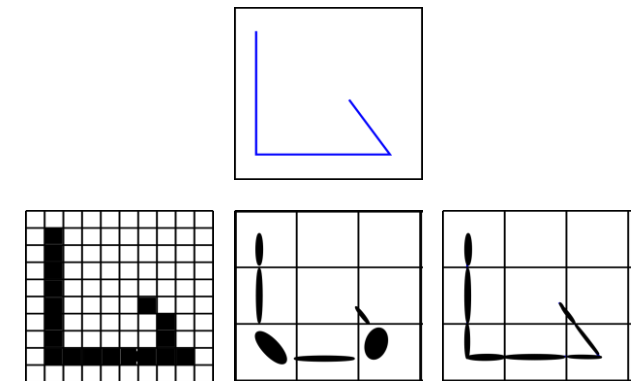
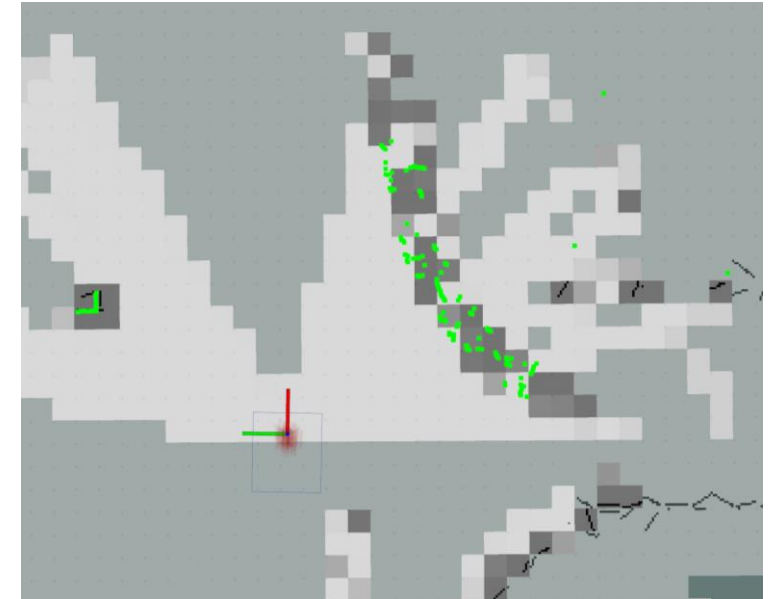


Source: BMW AG

IPA Long Term SLAM

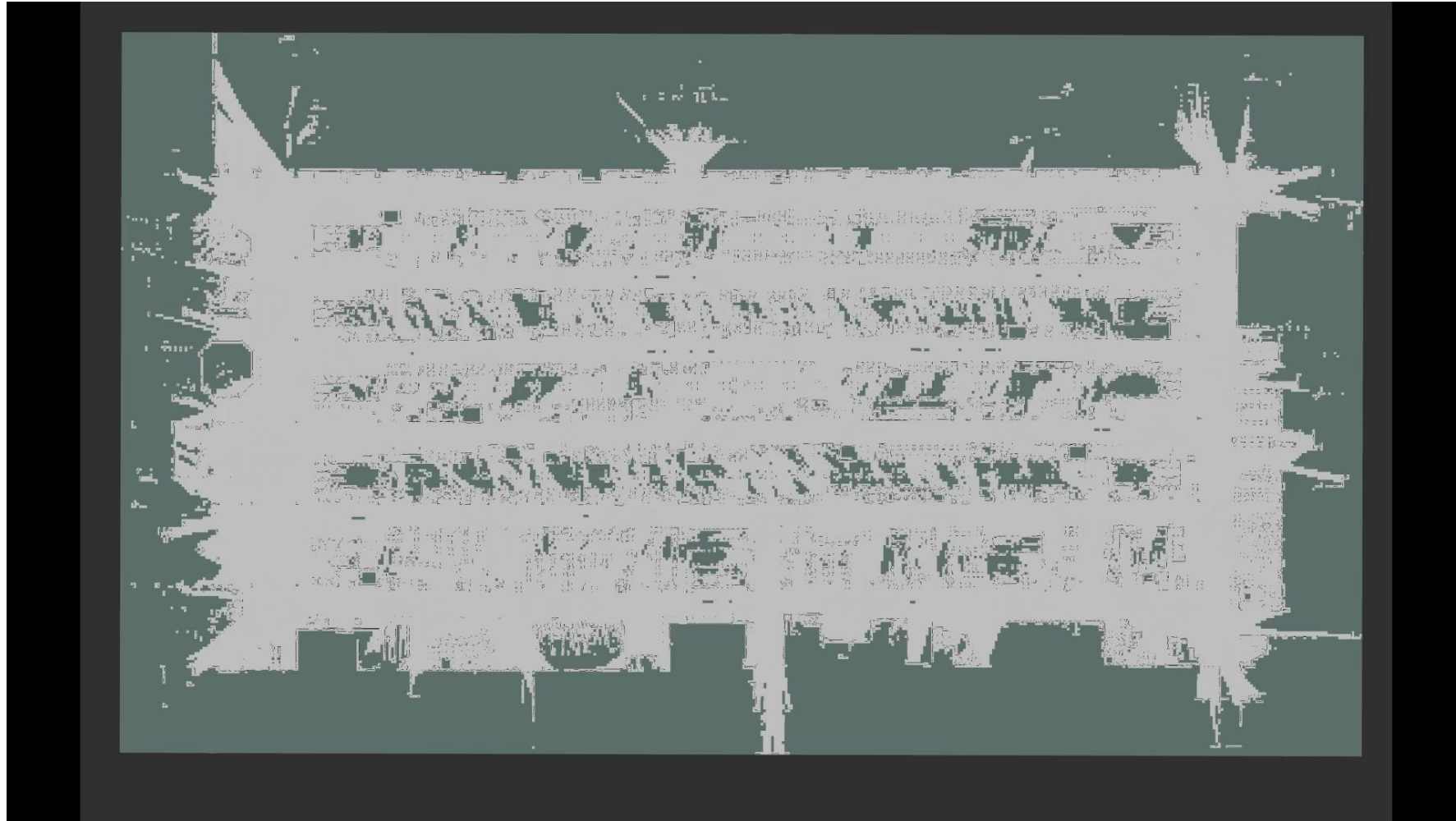
Continuous localization & mapping in changing environments

- Particle filter-based localization on changing map
 - High-frequency, robust and precise ego pose estimation
 - 2D laser scan and odometry as primary input
 - Further sensors can be integrated via plug-ins
- Continuous updating of the map
 - Initialization with Occupancy Grid Map from Offline SLAM
 - Continuous estimation of the contour + dynamics of the environment
 - Multiple map layers for handling uncertainty in mapping process
 - Precise + performant map representation
 - Interface to path planner
- Work in progress:
 - Support of 3D point clouds & RGBD data



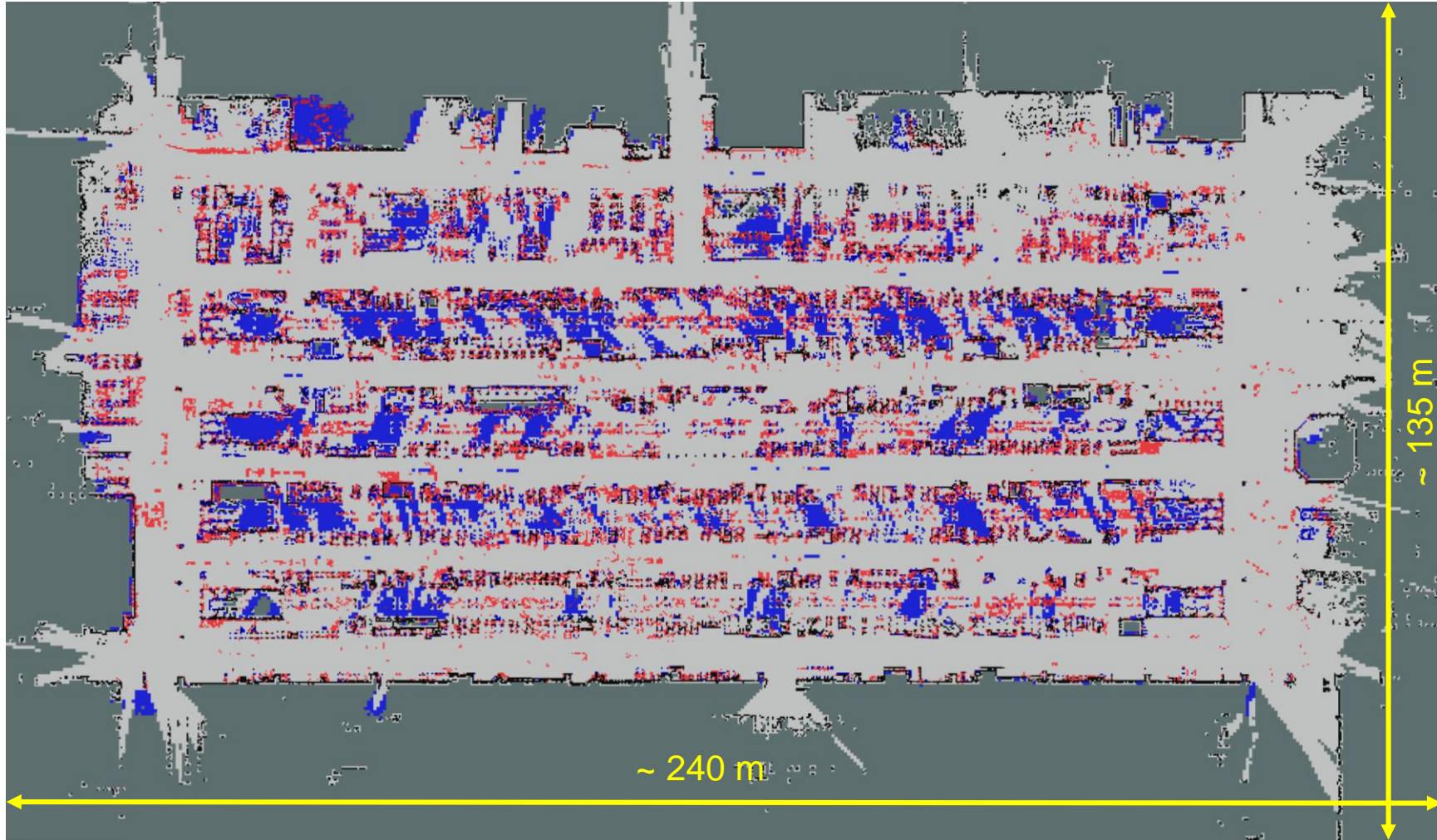
IPA Long Term SLAM

Application on Smart Transport Robot (STR) at BMW production plants



IPA Long Term SLAM

Application on Smart Transport Robot (STR) at BMW production plants



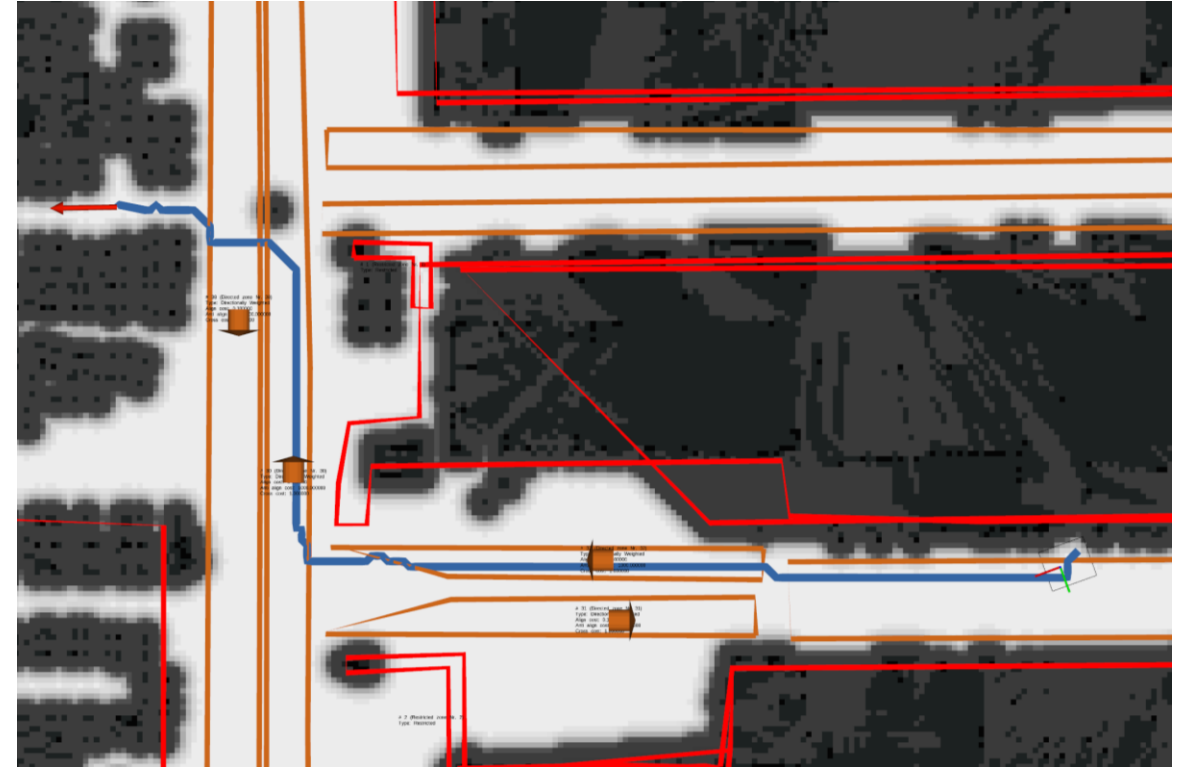
After 2 months ...

- New free cells
- New occupied cells

IPA Zone Based Route Planner

Online route planning in changing environments

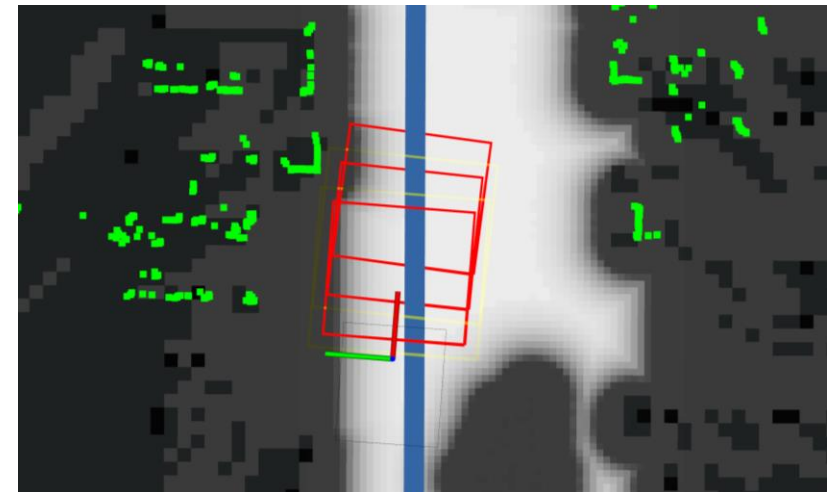
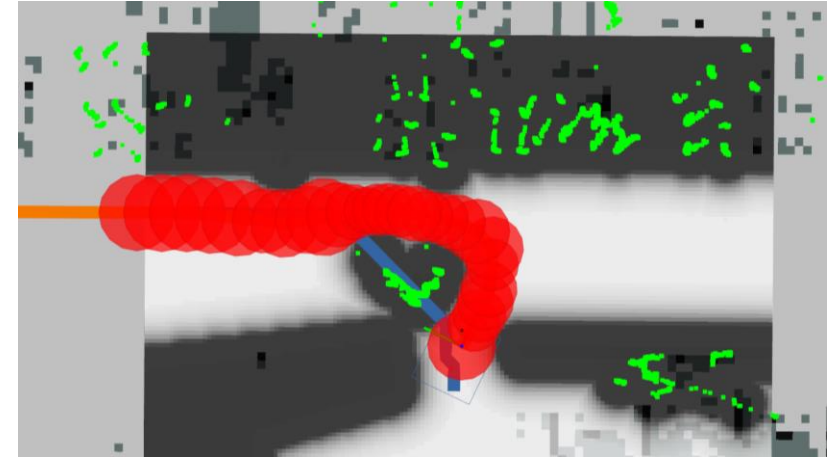
- Online route planning on costmaps & navigation zones
 - Incorporation of kinematic boundary conditions & dynamic environment
- Zone model for manual adjustment of the desired path planning behavior
 - No manual configuration of routes required
 - Generic zone model for application-specific requirements
- Work in progress:
 - Improved consideration of non-circular footprints and speed-dependent safety fields
 - Automated generation of roadmap graphs for better performance in large-scale environments



IPA Eband Local Planner + Path Control

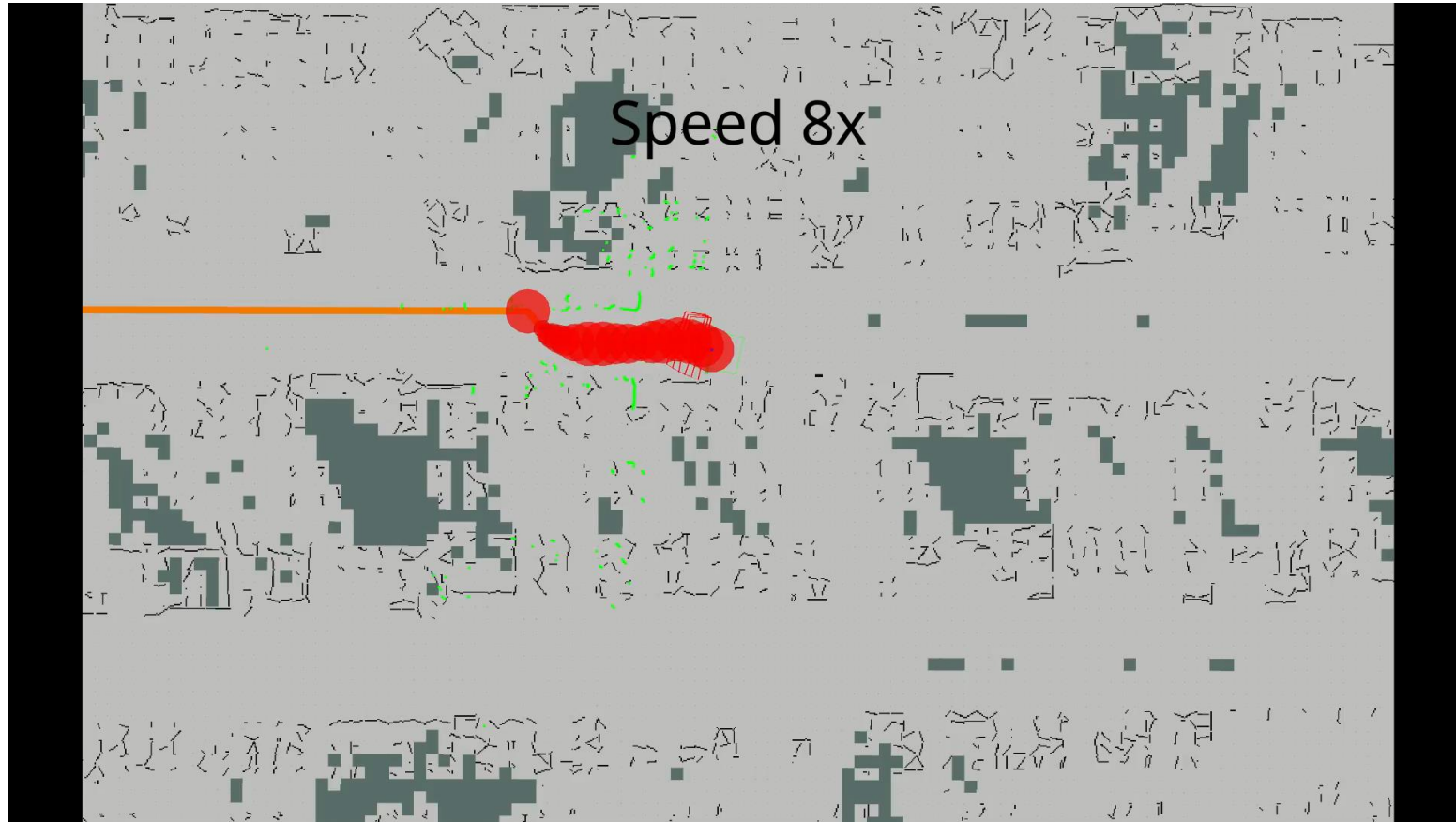
Dynamic path optimization and obstacle avoidance

- Dynamic path optimization and trajectory planning for collision avoidance based on the elastic band method
- Prediction of footprint and safety fields to avoid collisions and safety field violations
- Consideration of kinematic/kinodynamic boundary conditions
- Input: 2D/3D point clouds + global route, output: Twist
- Work in progress:
 - Safety field-optimal local path planning
 - Simplified configuration of the desired, application-specific planning behavior



IPA Eband Local Planner + Path Control

Application on Smart Transport Robot (STR) at BMW production plants



IPA Navigation Stack

Potentials and limitations

Potentials:

- Versatile applicability proven - from cleaning robots to heavy goods vehicles
- Low commissioning costs
 - New robot type (ROS enabled): approx. 1 day
 - New environments: approx. 2-3 hours
- Application on STR shows robustness and efficiency in complex, industrial environment
 - Long-term autonomy in changing environments
 - Enlargement of sensor FOV for further increase of robustness and path planning view
- Camera/point-cloud sensors for classification of dynamic objects and adaptation of navigation behavior

Limitations:

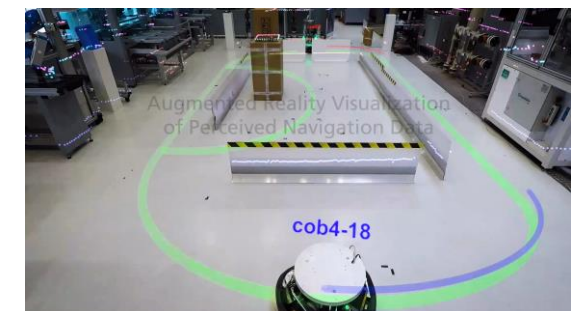
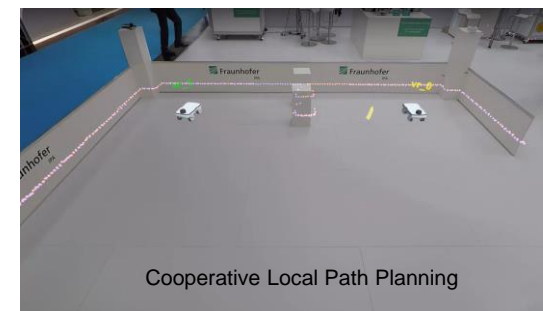
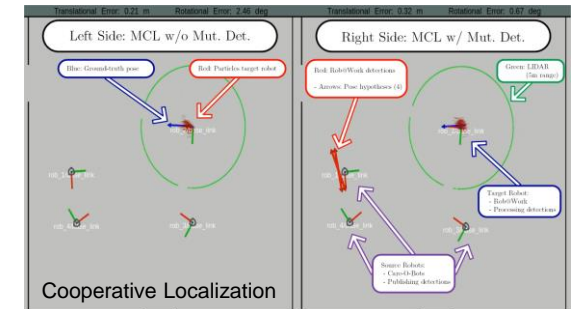
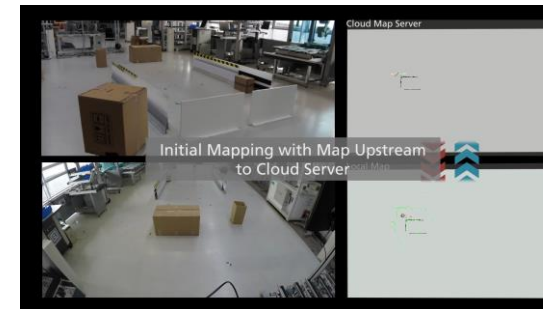
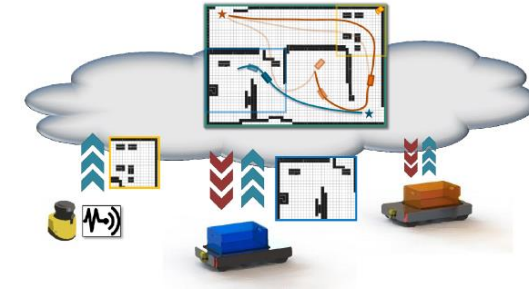
- Robustness/accuracy of localization decreases in highly changing areas
- Reactive behavior without communication with dynamic objects leads to inefficiencies up to mutual deadlocks.
- Restriction to local horizon of vision does not allow for predictive driving
- Increased configuration effort for applications with special navigation requirements

NODE - Navigation on Demand

Networking, Cooperation, Cloud-/Edge-Computing and Machine Learning

- Resolution of local limitations through networking
- Building Holistic Environment/State Models
- Outsourcing of computational intensive processes to cloud/edge servers
- More efficient and robust navigation through cooperation
- Optimal orchestration of (also heterogeneous) fleets
- Experience/learning-based self-configuration and self-optimization

➞ Autonomy and optimal navigation of the entire fleet!



Experience/learning-based Navigation

Combined local path optimization, trajectory planning/control

■ Problem:

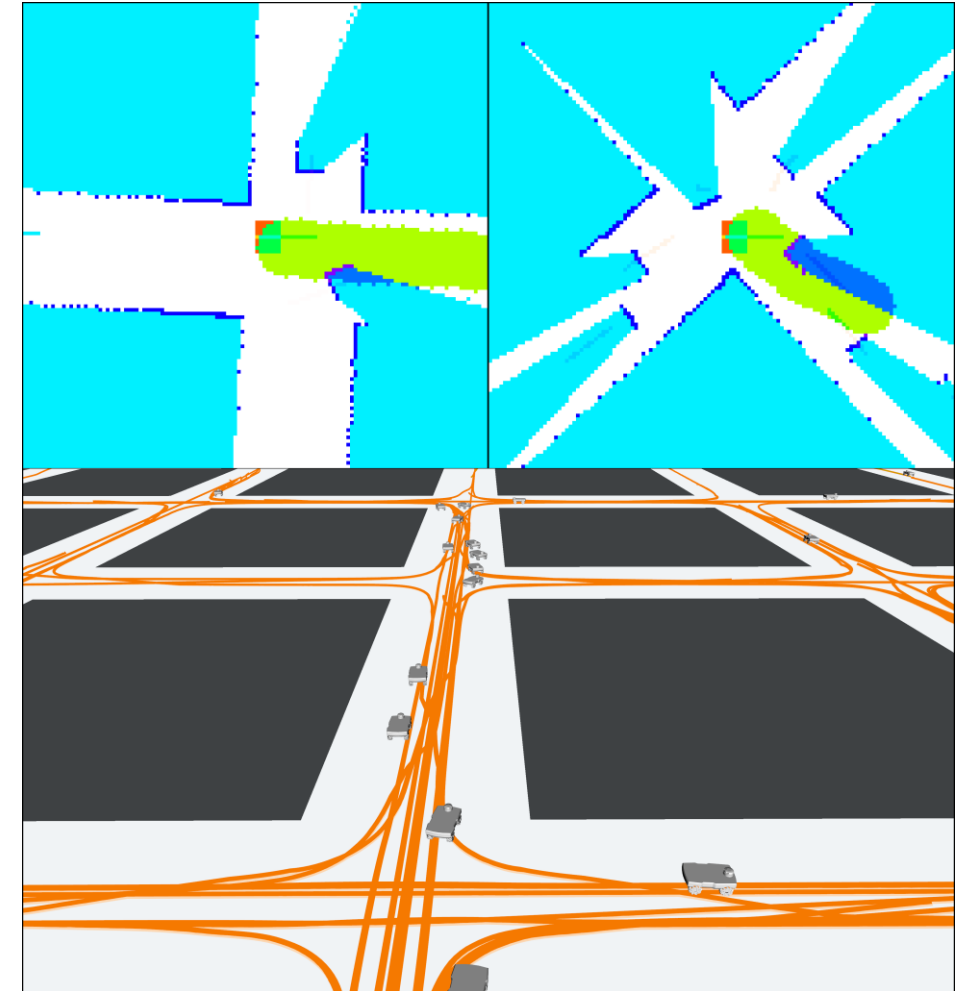
- Generation of driving behavior under various restrictions (kinematics, protective fields, static + dynamic obstacles, etc.)
- Current potential field/sample-based approaches require a lot of model knowledge and are complex to configure/test.

■ Approach:

- Deep Reinforcement Learning to learn suitable driving behavior
- Input: global path + laser scan, output: twist
- Training in simulation, optimization on real vehicles

■ Status:

- Promising performance in simulation, test on real vehicle still pending



Erfahrungs-/Lernbasierte Navigation

Combined local path optimization, trajectory planning/control

Path following
with reinforcement learning

Experience/learning-based Navigation

Optimized global routing

■ Problem:

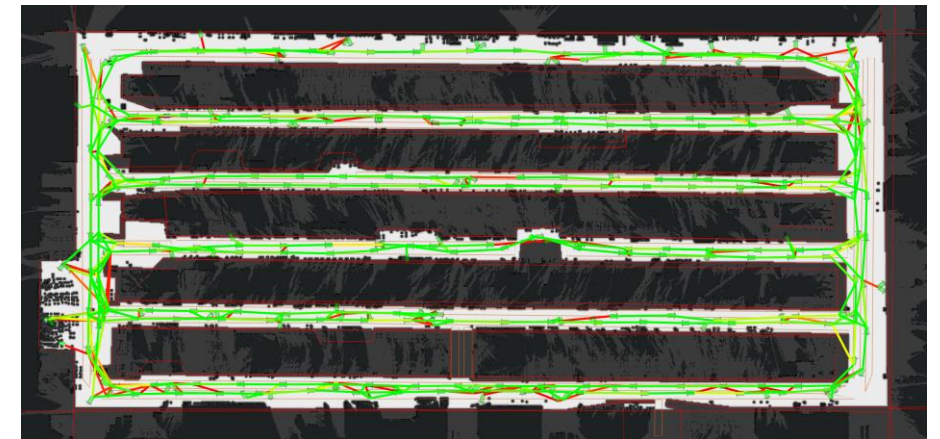
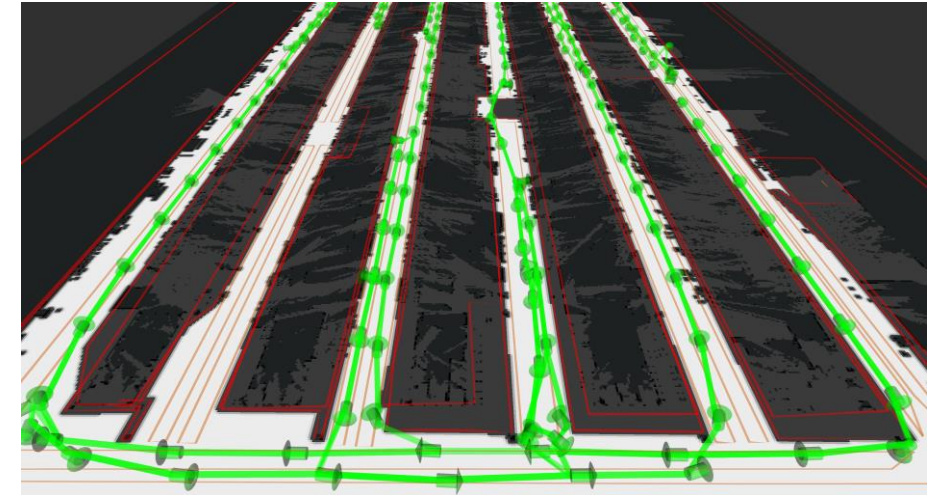
- Dynamic (geometric, kinematic, ...) route planning for large-area environments computational intensive
- Calculation of shortest paths on rigid models with partly significant divergence to operation times

■ Approach:

- Offline generation of an initial route graph on initial (occupancy grid) map using the "Growing Neuronal Gas" approach
- Learning real route section costs by integrating the operating data of the fleet in live operation

■ Status:

- Graph generation and update implemented
- Integration in global route planner and real-life test pending



Experience/learning-based Navigation

Optimized global routing

Experience-based Path Planning

Unsupervised learning of an experience roadmap
for path planning in mobile robotics

THANKS FOR YOUR ATTENTION!



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