



Safe Autonomous Navigation for Long-term Operation of Industrial Vehicles

**ERF WS "Autonomous Vehicles for Long-Term Operation
in Industrial Environments"**



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<p>1</p> <p>Mobile Robotics & Olfaction Lab Profile</p> <p>AASS</p> <p>Cognitive Robotics Systems (CRS) Lab (Alessandro Saffioti)</p> <p>Mobile Robotics & Olfaction (MR&O) Lab (Achim J. Lilienthal)</p>	<p>2</p> <p>Mobile Robotics & Olfaction Lab Projects</p>	<p>3</p> <p>Flash Camera People Tracking</p> <p>Rafael Mosberger, Henrik Andreasson and Achim J. Lilienthal</p>	<p>4</p> <p>Highly Accurate Navigation in Dynamic Environments</p> <p>Henrik Andreasson, Marcello Cirillo, Tom Duckett, Achim J. Lilienthal, Martin Magnusson, Jari Saarinen, Todor Stoyanov</p>	<p>5</p> <p>Summary</p>
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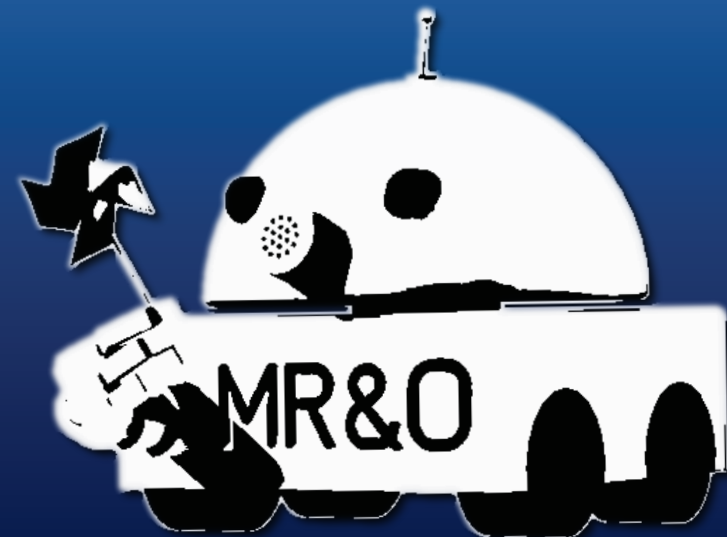
Mobile Robotics & Olfaction Lab

Profile

AASS

Cognitive Robotic
Systems (CRS) Lab
(Alessandro Saffiotti)

Mobile Robotics &
Olfaction (MR&O) Lab
(Achim J. Lilienthal)





The AASS Mobile Robotics & Olfaction Lab in 2013*

- 15 Ph.D. students, 12 senior researchers
- 8 ongoing projects, funding > 1.2M€/y



Research Area 1:

Mobile Transport Robots for Industrial Applications

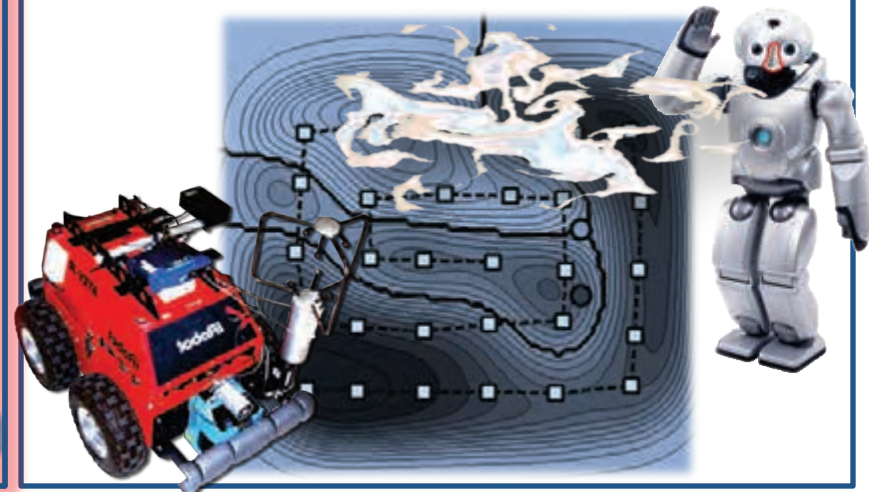
- 3D perception, robot vision and navigation
- autonomous and safe long-term operation in the real world
- extensive technology transfer through collaborative projects with industrial partners
- autonomous forklifts, wheel loaders, mining vehicles, service robots on airports, in hospitals and for cleaning
- leader in Europe, key player world-wide



Research Area 2:

Mobile Robot Olfaction

- gas sensing with sensor systems in open sampling configuration (from electronic to mobile nose)
- gas sensor networks for air pollution monitoring, mobile robots for surveillance of landfill sites, gas leak localization, gas-sensitive flying robots
- world-leading in mobile robot olfaction



■ General Focus ...

- perception systems for mobile robots (fundamentals of autonomous operation and environmental monitoring)

■ Objective ...

- theoretical and practical foundations of long-term operation of mobile robots in **unconstrained, dynamic environments**



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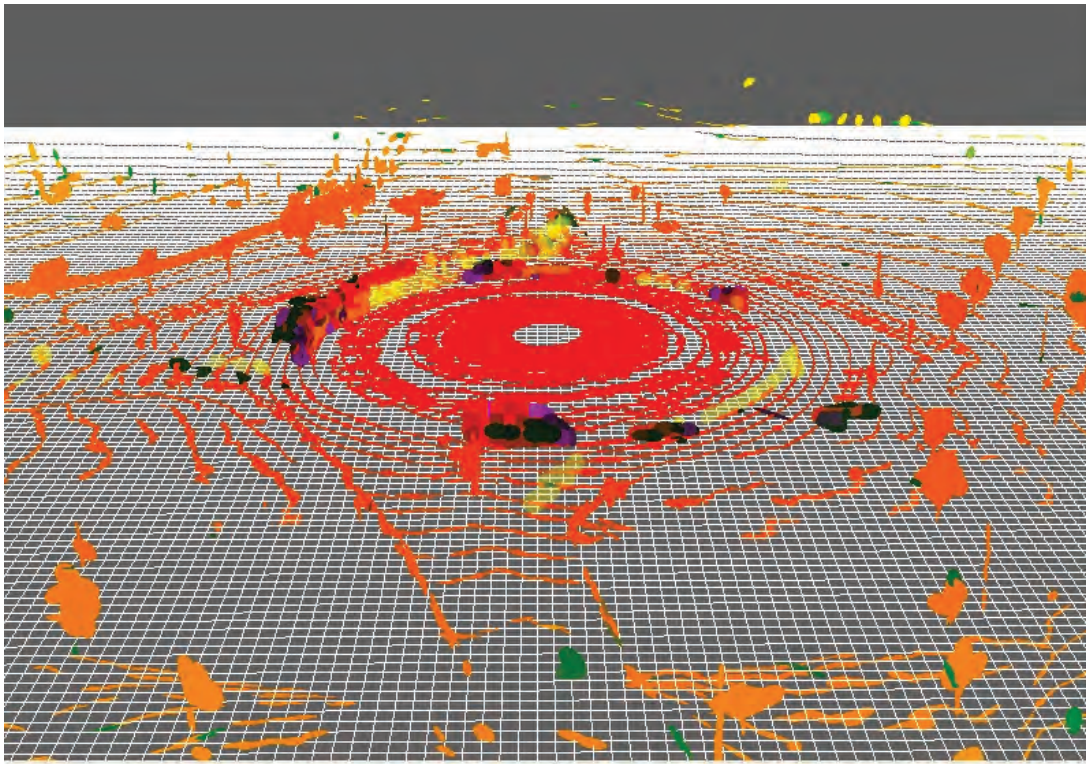


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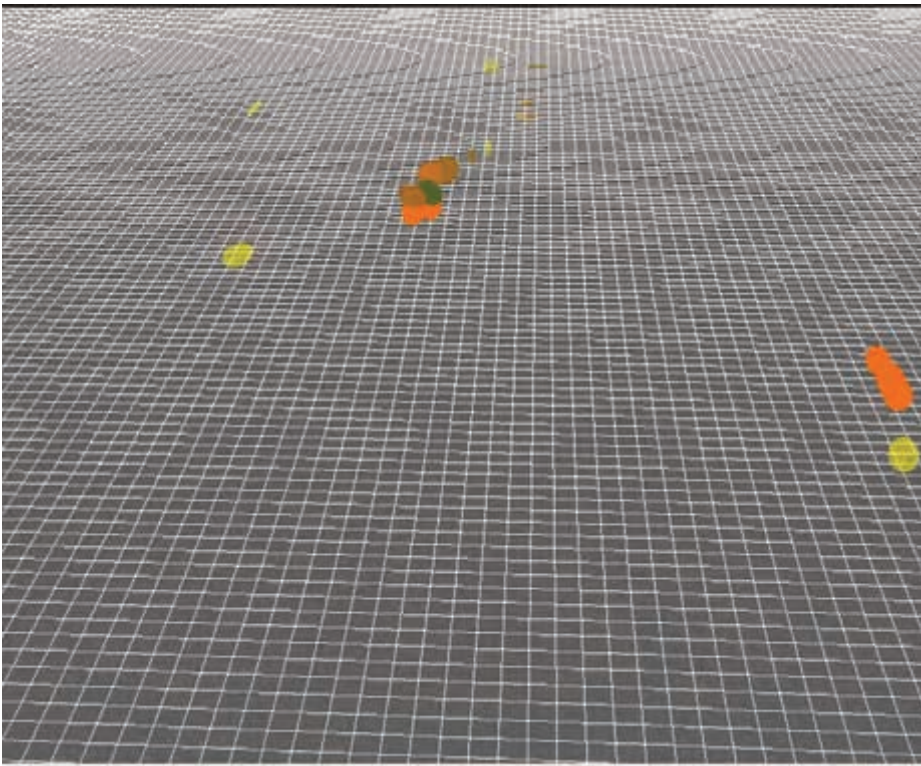


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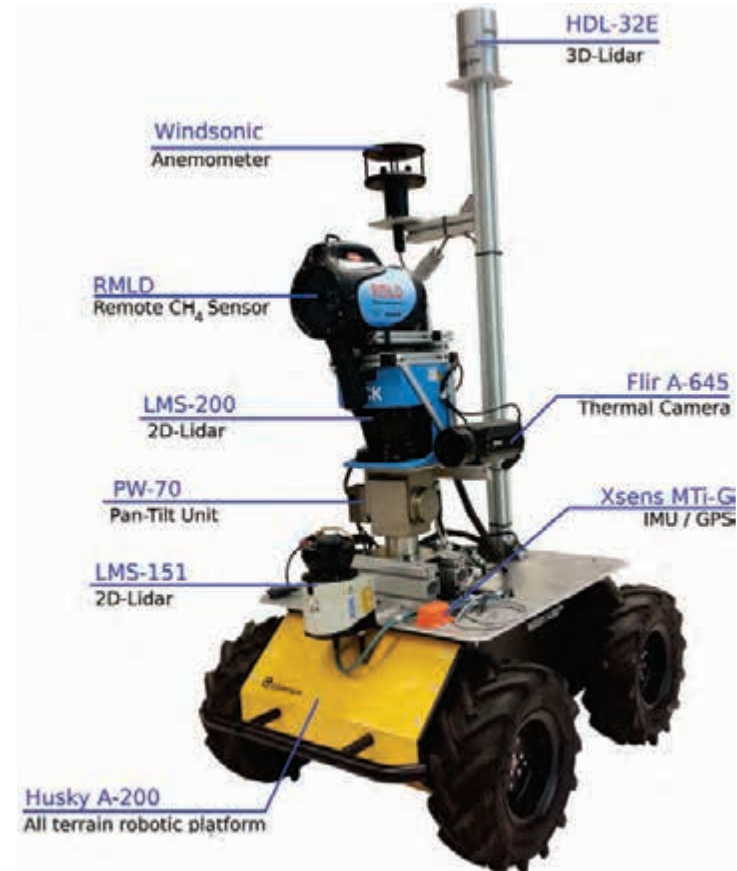
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■ Approaches are Characterized by ...

- fusion of different sensor modalities



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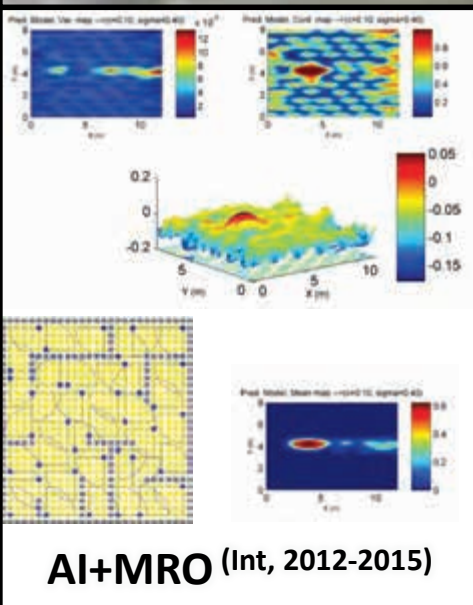
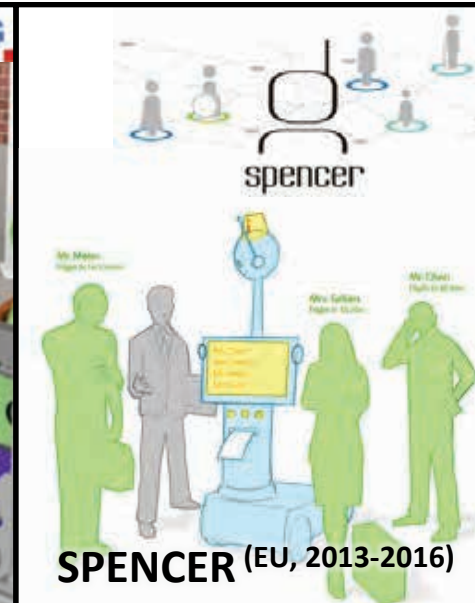
- fusion of different sensor modalities
- timely integration into industrial demonstrators



Mobile Robotics & Olfaction Lab

Projects









Flash Camera People Tracking

Rafael Mosberger, Henrik Andreasson and Achim J. Lilienthal



■ People Tracking with the Stereo-Flash Camera

- Rafael Mosberger, Henrik Andreasson and Achim J. Lilienthal.
Multi-human Tracking using High-visibility Clothing for Industrial Safety.
Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS), 2013, pp. 638 – 644.



■ People Tracking with the Stereo-Flash Camera

- highly reliable detection and tracking of humans is required
- robust performance is key
 - » under different weather/illumination conditions
 - » independent of body pose
- industrial work sites allow to make specific assumptions



■ People Tracking with the Stereo-Flash Camera

○ Camera Setup



NIR Camera



Wide-angle Lens



Bandpass Filter

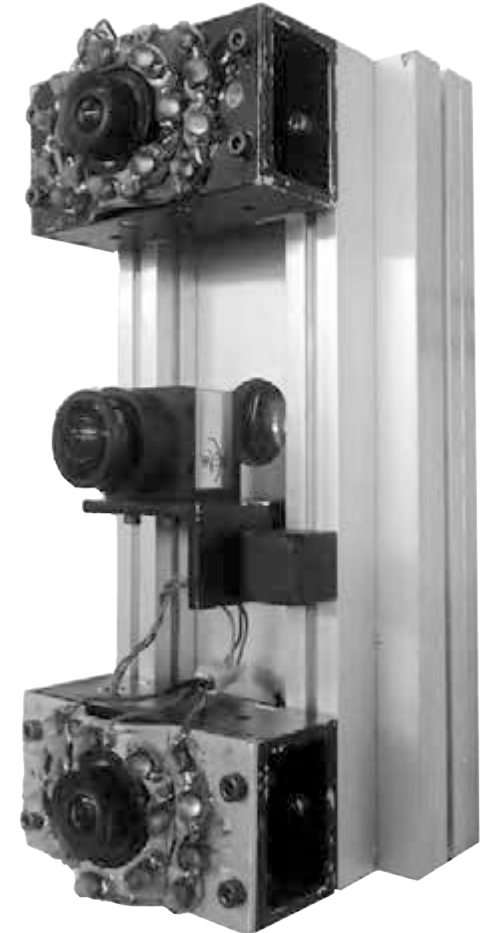


16 x NIR LEDs

1 Color Camera

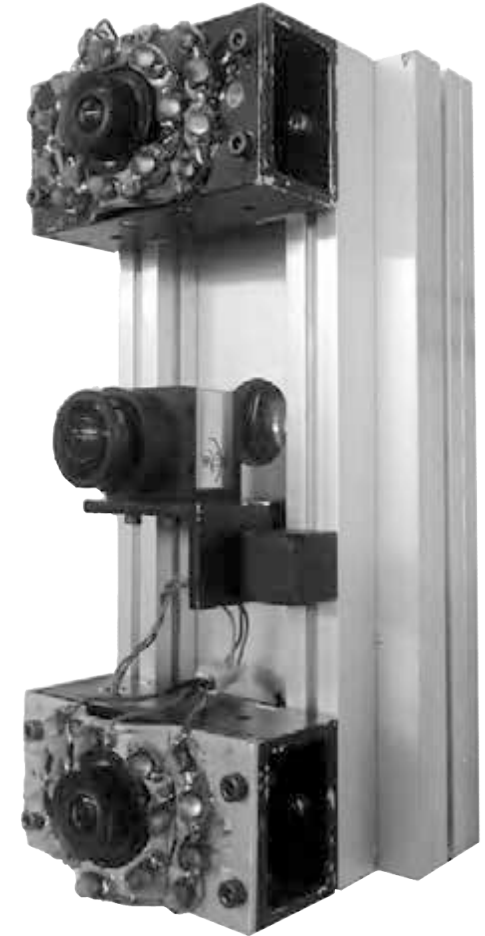
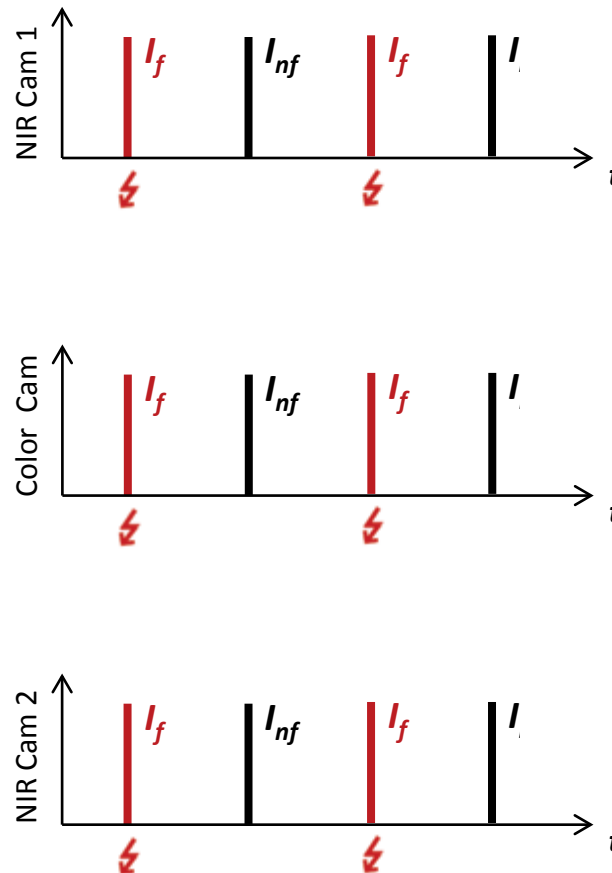
For visualization purposes

2 NIR Camera Units



■ People Tracking with the Stereo-Flash Camera

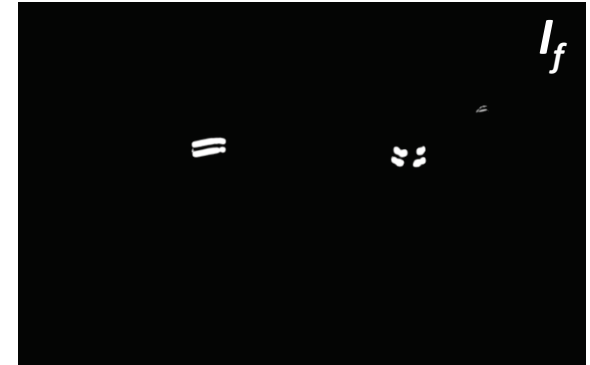
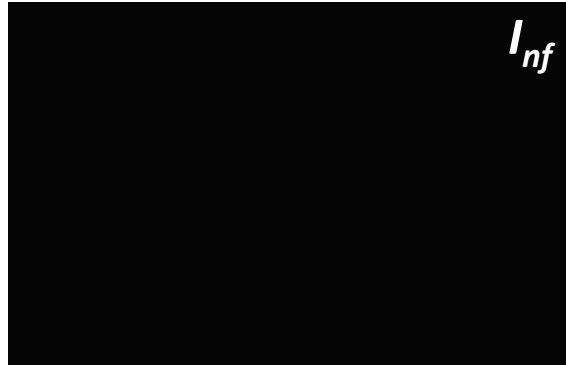
- Camera Setup
- Image Acquisition



■ People Tracking with the Stereo-Flash Camera

- Camera Setup
- Image Acquisition

The ideal case: no secondary NIR light sources



The non-ideal case: secondary NIR light sources cause background illumination



■ People Tracking with the Stereo-Flash Camera, Algorithm

Image Segmentation

- Detect image regions containing reflectors

Localization

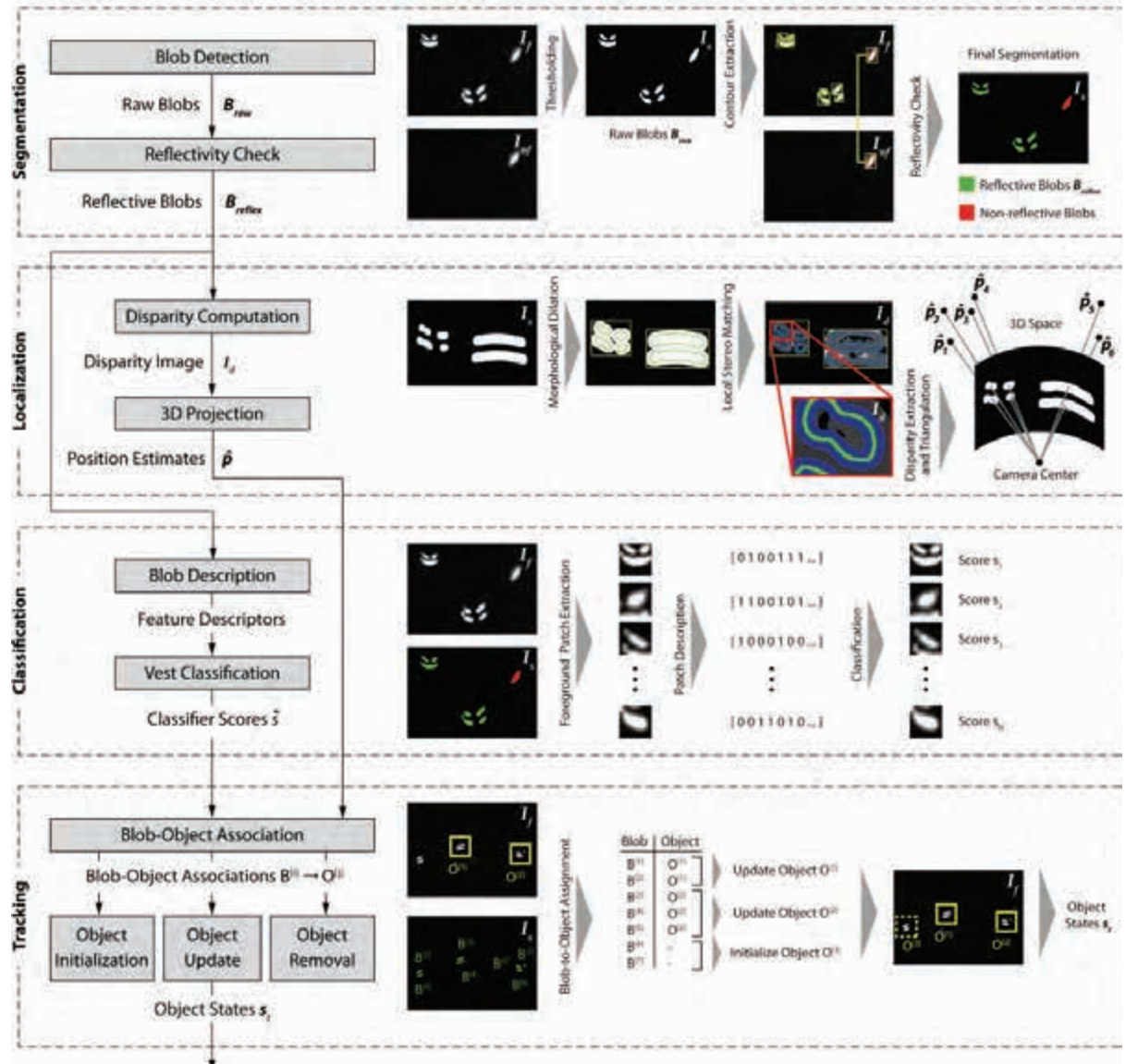
- Obtain a 3D position estimate for each detected reflector

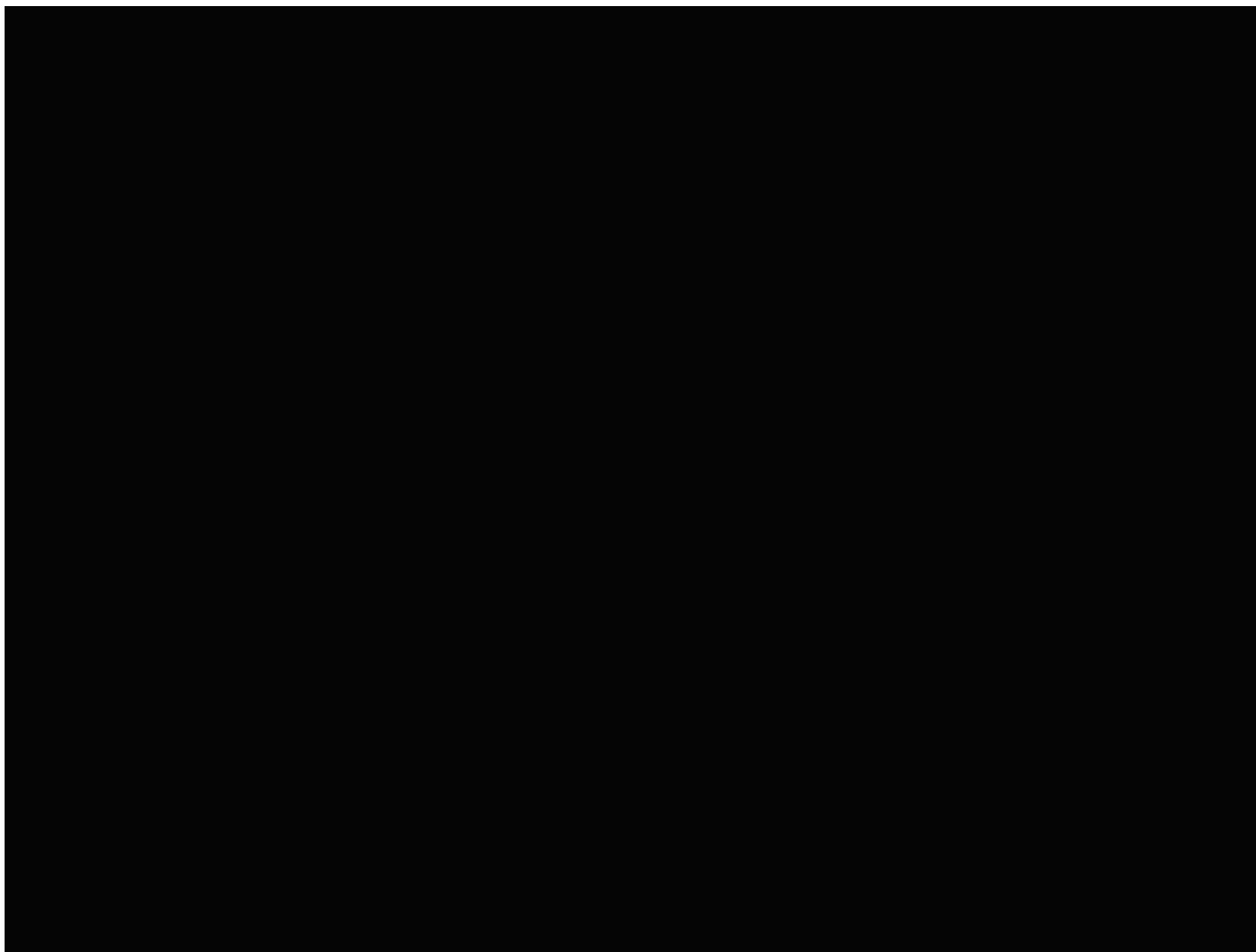
Classification

- Discriminate reflectors of safety clothing from arbitrary other reflectors

Tracking

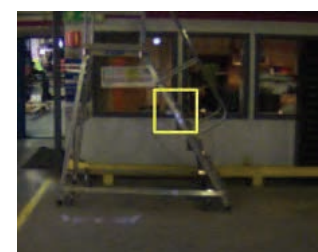
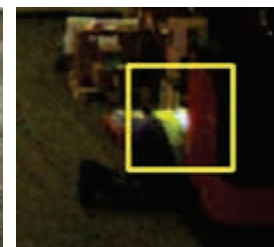
- Assign individual reflectors to tracked persons and maintain a filtered state for position and speed





■ People Tracking with the Stereo-Flash Camera

- Advantages of the flash camera approach
 - » High robustness to various illumination conditions
 - » Accurate detection under partial occlusion
 - » Robust towards body pose variation
- Current Limitations
 - » Tracking performance decreases under frequent interaction between persons
 - » Algorithm allows to detect reflective safety vests but not specifically humans
- Future Work
 - » Refine detections by using information from the color camera

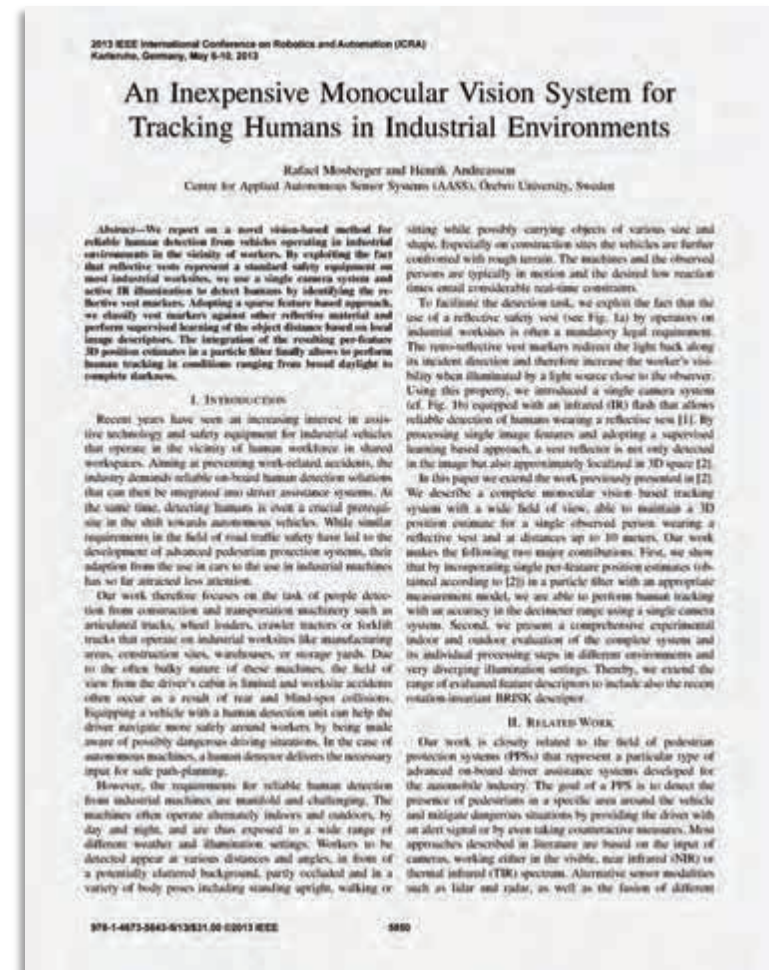


■ People Tracking with the Mono-Flash Camera

- Rafael Mosberger and Henrik Andreasson.

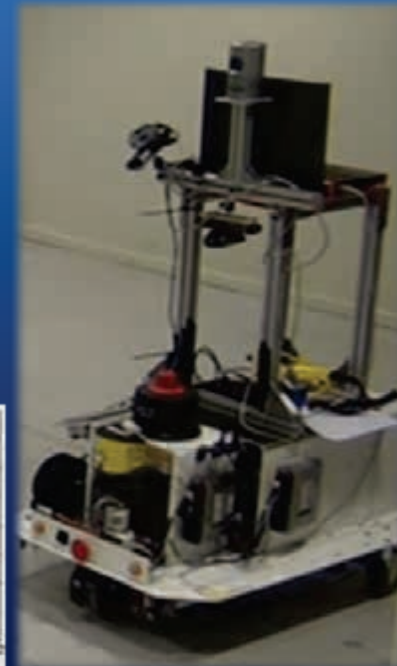
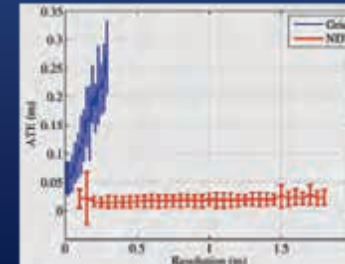
An Inexpensive Monocular Vision System for Tracking Humans in Industrial Environments.

Proc. Int. Conf. on Robotics and Automation (ICRA), 2013, pp. 5850 – 5857.



Highly Accurate Navigation in Dynamic Environments

Henrik Andreasson, Marcello Cirillo, Tom Duckett, Achim J. Lilienthal, Martin Magnusson, Jari Saarinen, Todor Stoyanov



- **Autonomous Navigation in Industrial Environments**
 - key challenge: infrastructure-free localization



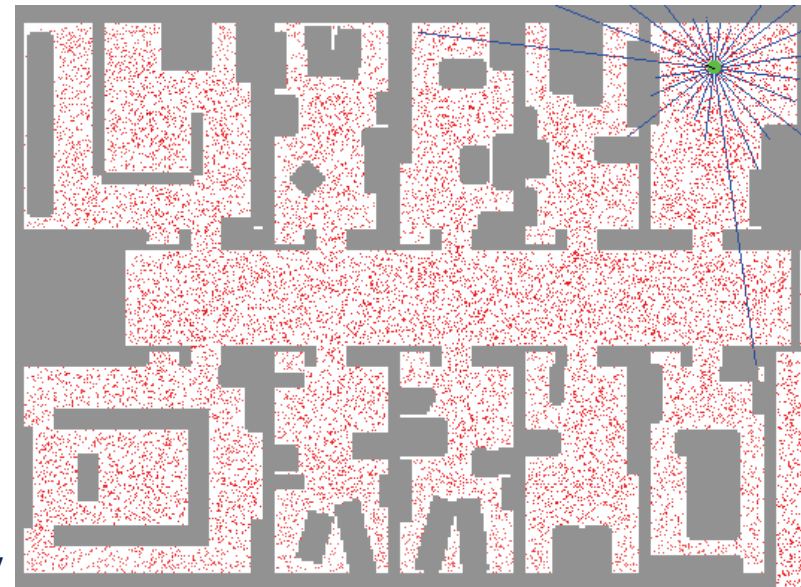
■ Autonomous Navigation in Industrial Environments

- key challenge: infrastructure-free localization
- key challenge: fast planning and execution of trajectories to reach arbitrary target positions and orientations
 - » with high accuracy and precision ($<0.03\text{m}$)
 - » taking into account non-holonomic vehicle constraints



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- state of the art solution not sufficient
 - » Monte-Carlo localization (MCL) against grid map

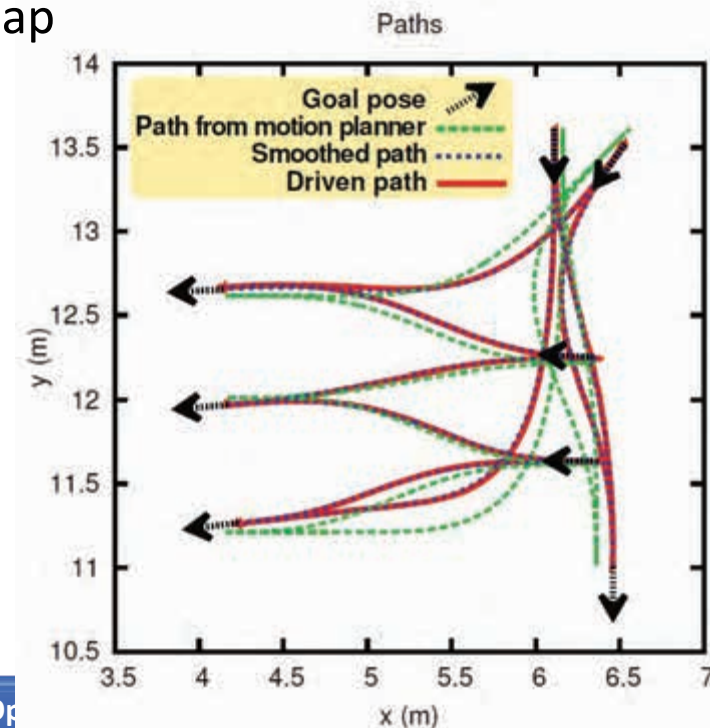


<http://www.cs.washington.edu/robotics/mcl/>



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 - → path smoothing



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Henrik Andreasson, Jari Saarinen, Marcello Cirillo, Todor Stoyanov and Achim J. Lilienthal.

Drive the Drive: from Discrete Motion Plans to Smooth Drivable Trajectories.

Submitted to IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS), 2014.



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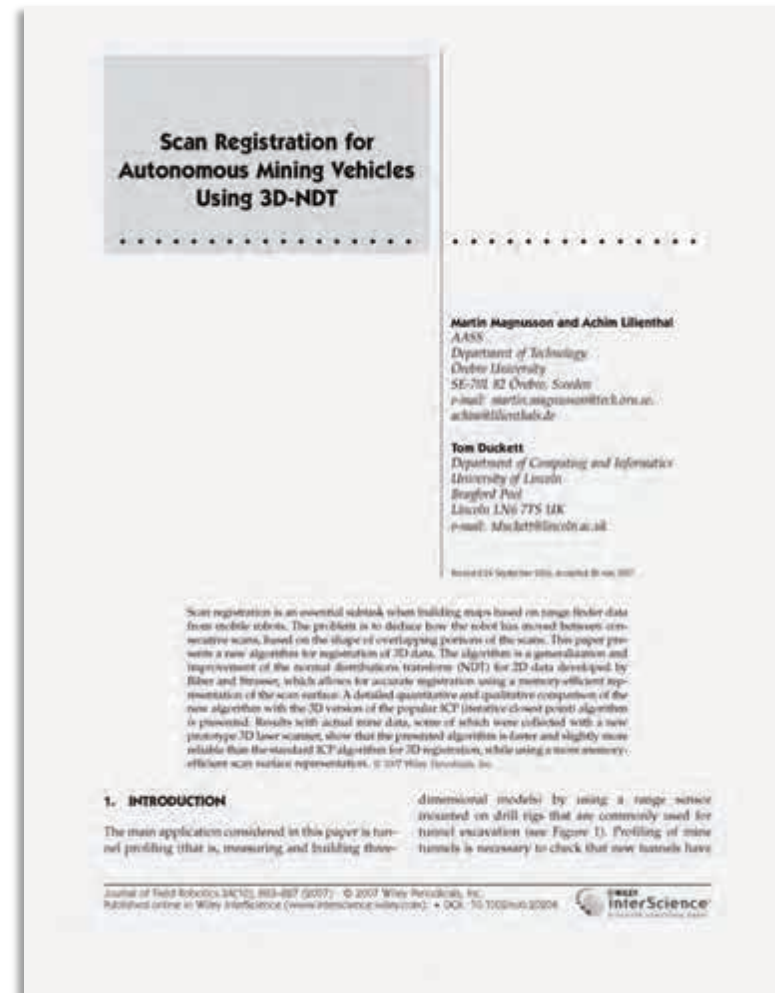
3D NDT-OM for Mapping

J. Saarinen, H. Andreasson, T. Stoyanov,
Martin Magnusson, Tom Duckett, and A. J. Lilienthal

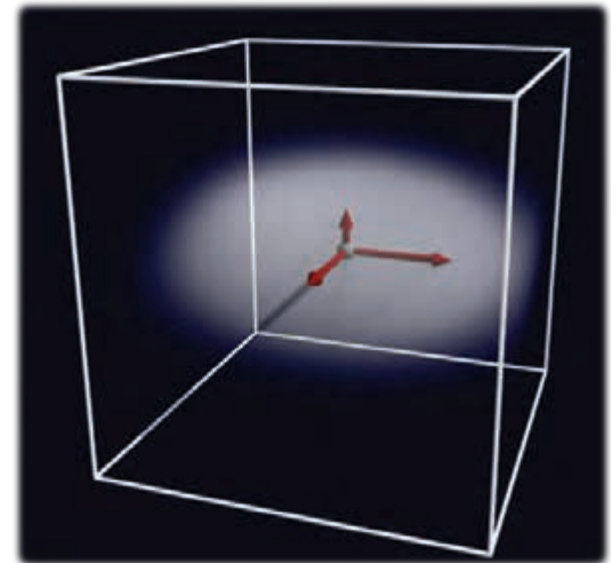
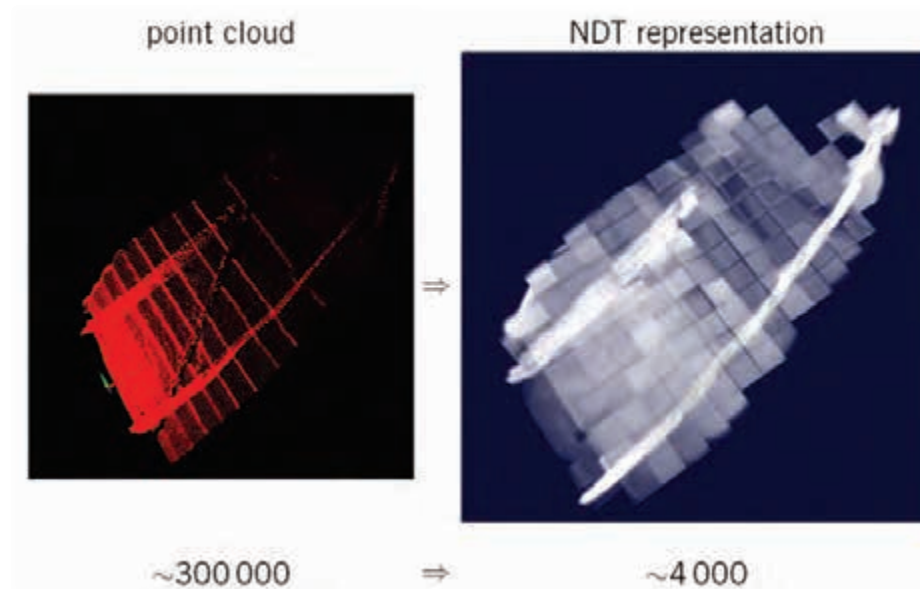


■ 3D NDT (Normal Distribution Transform)

- Martin Magnusson, Tom Duckett and Achim J. Lilienthal.
Scan Registration for Autonomous Mining Vehicles Using 3D-NDT.
Journal of Field Robotics, 24:10, 2007,
pp. 803-827.



■ 3D NDT (Normal Distribution Transform)



■ 3D NDT-OM Occupancy Mapping in Dynamic Environments

- Jari P. Saarinen, Henrik Andreasson, Todor Stoyanov and Achim J. Lilienthal.
3D Normal Distributions Transform Occupancy Maps: An Efficient Representation for Mapping in Dynamic Environments.
International Journal of Robotics Research (IJRR), 2013, pp. 1627 - 1644.
- Jari Saarinen, Henrik Andreasson, Todor Stoyanov and Achim J. Lilienthal.
Normal Distribution Transform Occupancy Maps: Application to Large-Scale Online 3D Mapping.
Proc. IEEE Int. Conf. on Robotics and Automation (ICRA), 2013, pp. 2225 - 2230.



Monte Carlo Localization with NDT

**Jari Saarinen, Henrik Andreasson, Todor Stoyanov,
and Achim J. Lilienthal**



■ Monte Carlo Localization with NDT-OM

- Jari Saarinen, Henrik Andreasson, Todor Stoyanov and Achim J. Lilienthal.
Normal Distributions Transform Monte-Carlo Localization (NDT-MCL).
Proc. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS), 2013, pp. 382 - 389.



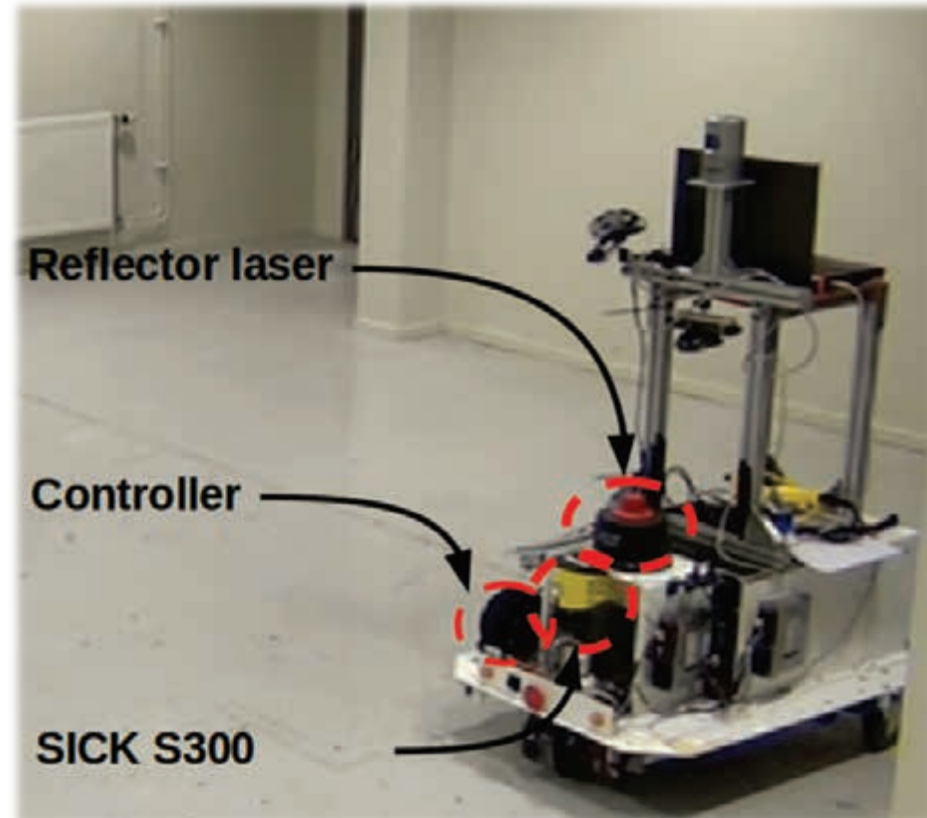
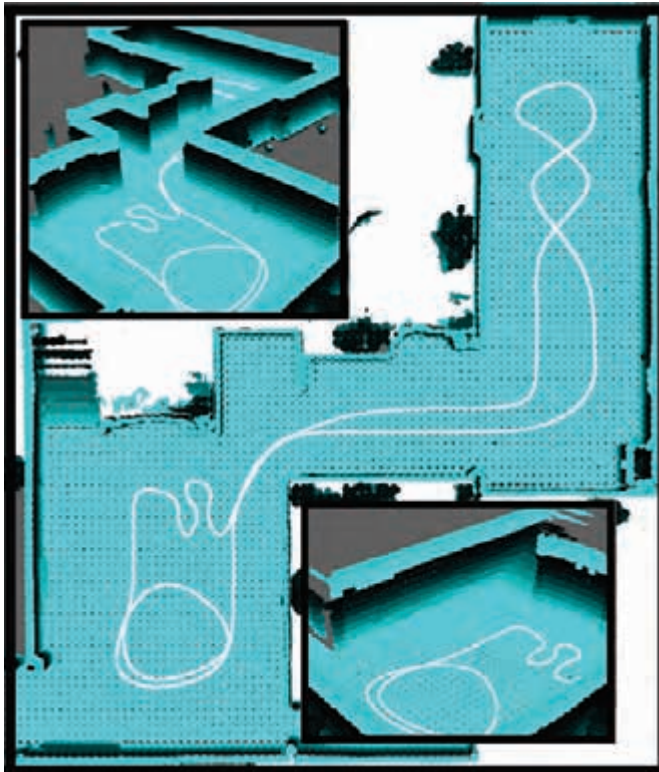
■ Monte Carlo Localization with NDT-OM

- standard Monte Carlo localization
- use NDT map for measurement update instead of grid map
 - » exploit that NDT is a likelihood model



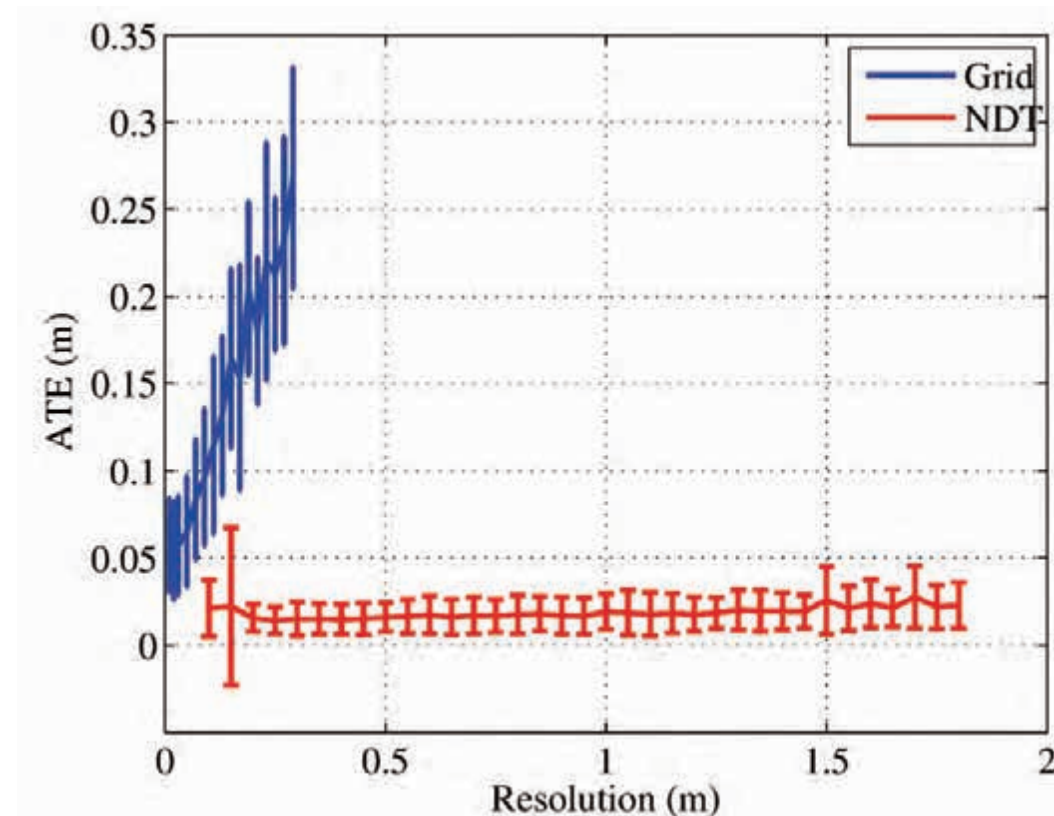
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 - » absolute error
 - static environment
 - trajectory: 120m
 - grid-MCL = amcl in ROS



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 - » absolute error
 - » closed loop tests
 - grid map resolution: 0.03m
 - NDT map resolution: 0.5m





NDT-MCL

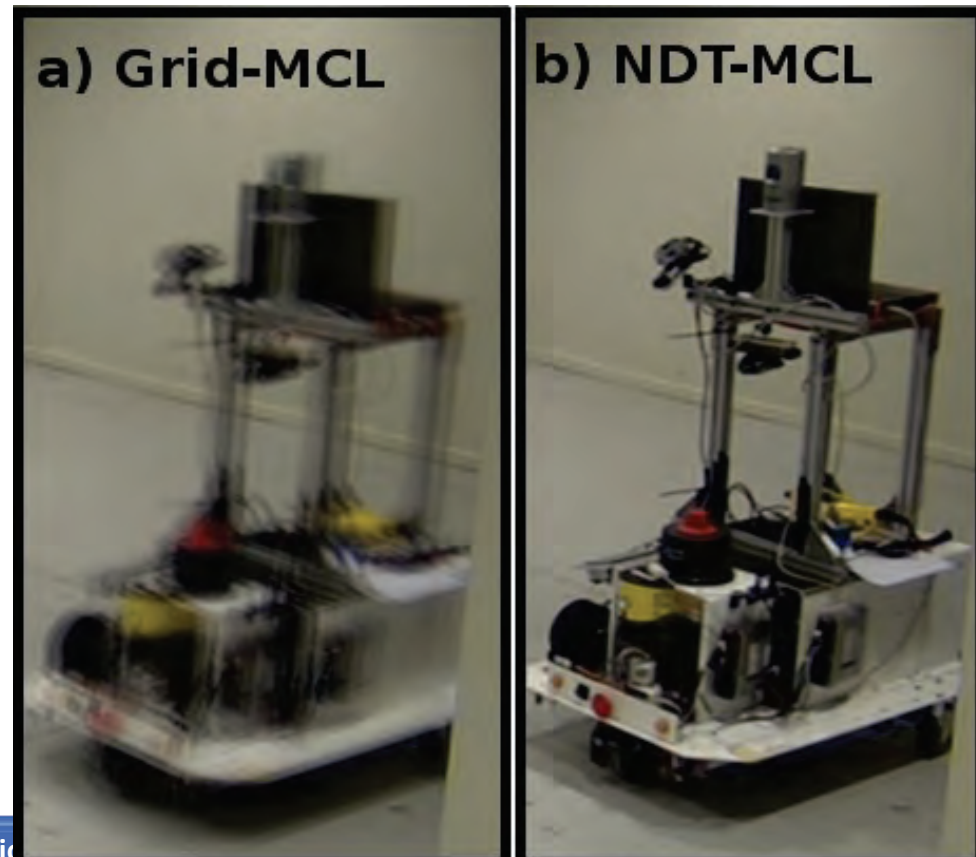
Normal Distributions Transform Monte Carlo Localization

Jari Saarinen
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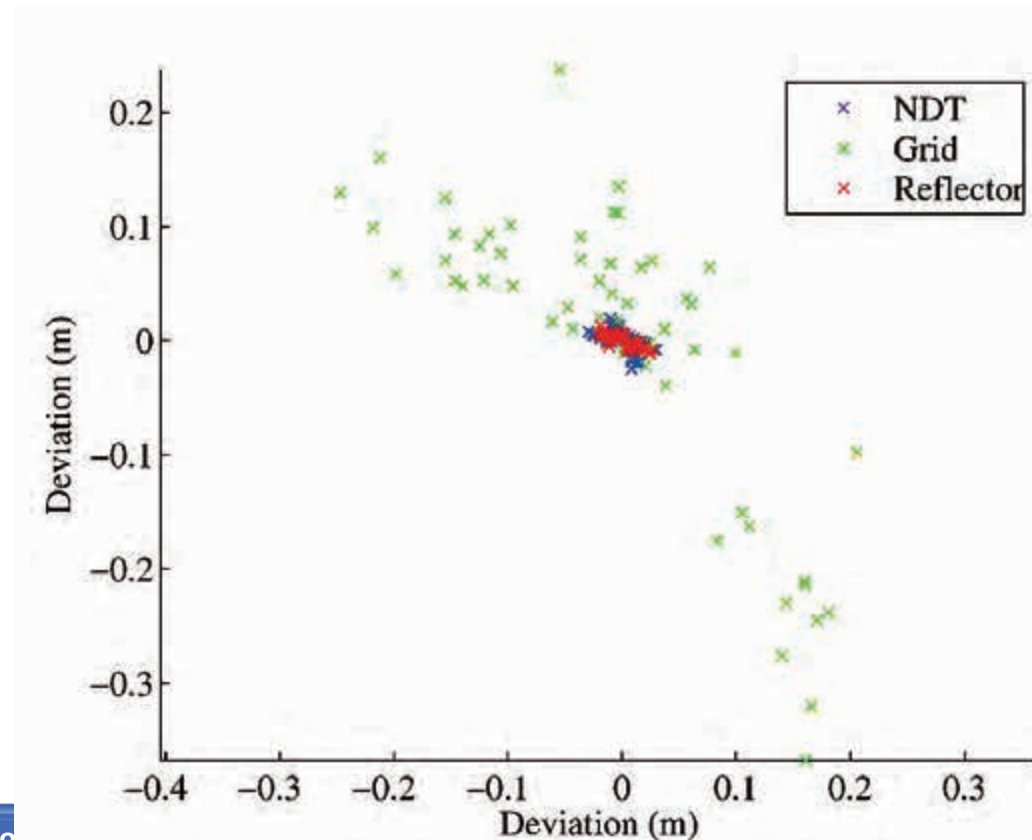
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Summary



■ Profile



MR&O
MOBILE ROBOTICS & OLFACTION



AASS
ÖREBRO UNIVERSITET



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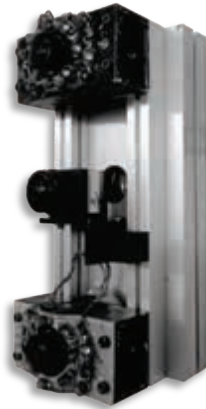
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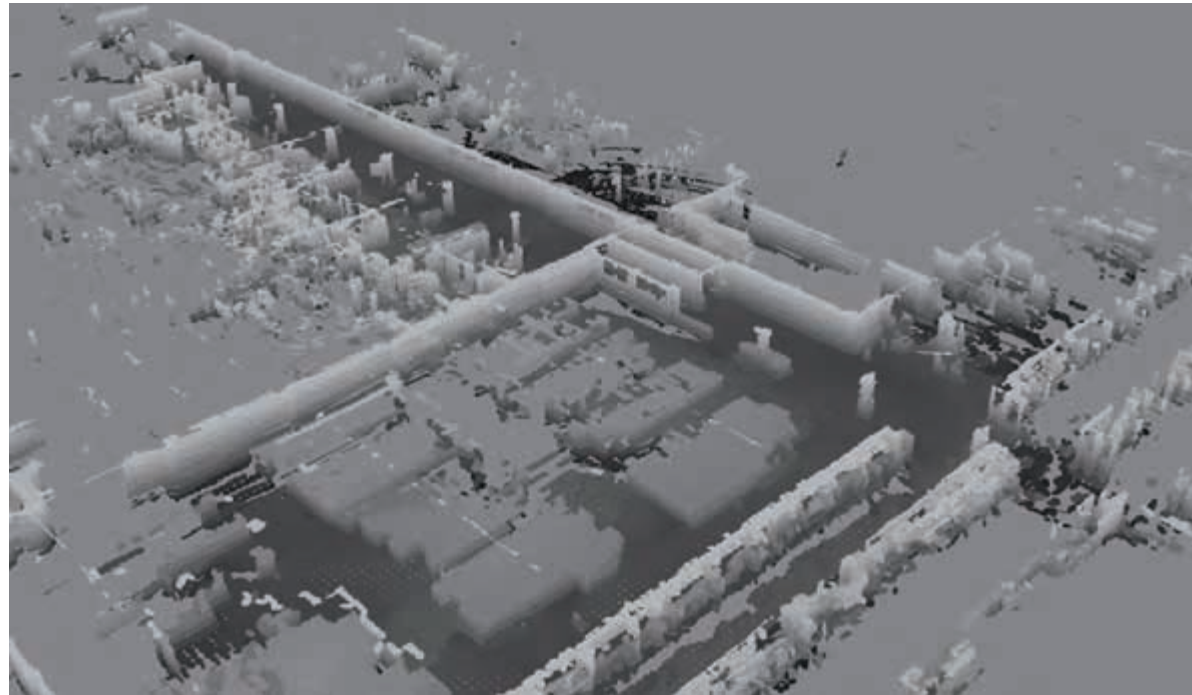

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- MR&O Lab Projects



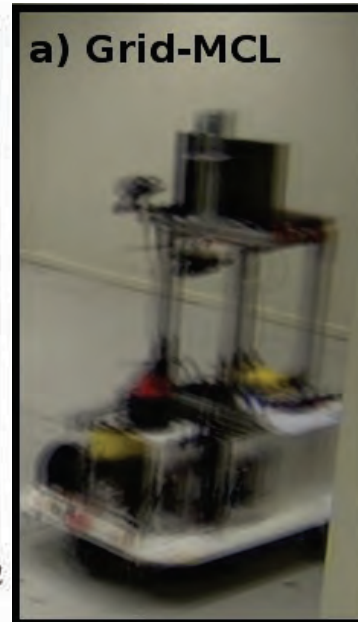
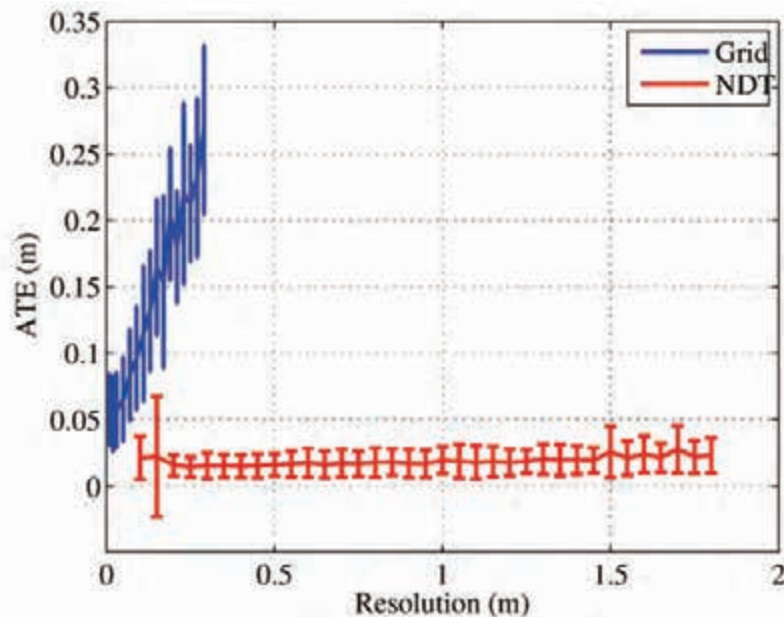
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 - 3D NDT-OM for Mapping

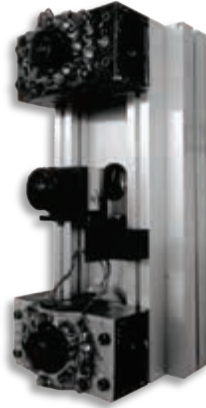


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- **Highly Accurate Navigation in Dynamic Environments**
 - 3D NDT-OM for Mapping
 - Monte Carlo Localization with NDT (NDT-MCL)



■ Technology Transfer

- Industrial prototype of flash camera
- First tests at customer site of SAUNA system





Thanks for your attention!

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