3D Perception
for Industrial Mobile Robots

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1. AASS MR&O Lab – Profile

2. Field Robotics and 3D Perception Projects at AASS

3. Rich 3D for Industrial Applications

4. 3D-NDT Representation

5. Rich 3D Perception – Recent and Ongoing Work
   - NDT-to-NDT Registration
   - Real Time Registration of RGB-D Data using Local Visual Features and 3D-NDT Registration
   - iMAC Occupancy Grid Maps for Representation of Dynamic Environments
   - 3D-NDT in Dynamic Environments (A First Glimpse)
AASS MR&O Lab – Profile
Örebro and its University

- 59°16' north, population ~130k
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- ~17k students, ~1200 employees,
- 7 schools, 15 research centers
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Center for Applied Autonomous Sensor Systems
- established in 1998
- largest Swedish research center in robotics
- two research labs
  » Cognitive Robotic Systems lab (CRS)
  » Mobile Robotics and Olfaction lab (MRO)
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<tr>
<th>Name</th>
<th>Since</th>
<th>Position</th>
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<tr>
<td>Achim J. Lilienthal</td>
<td>Jul 2005</td>
<td>(Ass. Professor)</td>
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<tr>
<td>Marcello Cirillo</td>
<td>Feb 2011</td>
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D1 – Mobile Robotics

- for autonomous and safe long-term operation in the real world
- technology transfer through collaborative projects with industrial partners in the area of logistics robots
- examples: autonomous forklifts and autonomous wheel loaders
1. Forklift Trucks (Danaher Motion, Linde MH, Stora Enso)

Picking up paper reels at unknown positions
Demonstration held at Vänerhamn, Karlstad 2009-04-03
- **Forklift Trucks** (Danaher Motion, Linde MH, Stora Enso)
  - environment with a dynamic "background"
### Forklift Trucks (Danaher Motion, Linde MH, Stora Enso)

- environment with a dynamic "background"
- requires 3D sensing

1 meter “drop” to the railway tracks
- **Forklift Trucks** (Danaher Motion, Linde MH, Stora Enso)
1. **MR&O Lab Profile – Two Major Research Directions**

- **Forklift Trucks** (Danaher Motion, Linde MH, Stora Enso)
- **Wheel Loaders** (VolvoCE, VolvoTech, NCC)
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- **Mining Vehicles** (Atlas Copco, Fotonic)
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- Hospital Transport Vehicles (RoboCab)
- Garbage Bin Collection and Cleaning (RoboTech)
- D2 – Artificial and Mobile Robot Olfaction
  - Artificial Olfaction = gas sensing with artificial sensor systems
  - we study particularly open sampling systems
  - develop "electronic nose" towards a "mobile nose"
  - examples: gas sensor networks (air pollution monitoring), inspection robots (landfill site surveillance, gas leak localization)
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- **Hospital Transport Vehicles** (RobCab)
- **Garbage Bin Collection and Cleaning** (RoboTech)
  - ... and pollution monitoring
1. **Mobile Work Machines**

- **Forklift Trucks** (Danaher Motion, Linde MH, Stora Enso)
- **Wheel Loaders** (VolvoCE, VolvoTech, NCC)
- **Mining Vehicles** (Atlas Copco, Fotonic)
- **Hospital Transport Vehicles**
- **Garbage Bin Collection and Cleaning** (RoboTech)
- **Landfill Site Inspection** (Atleverket)
Field Robotics and
3D Perception Projects at AASS
2. History of "Field Robotics" Projects

  - behavior-based autonomous LHD vehicle navigation in mines
  - main contribution
    - mixed autonomous/teleoperated control
    - (now a commercial product)
History of "Field Robotics" Projects

- NSAL (2005–2012)
  - Multiple autonomous forklifts for loading and transportation applications
  - main contribution
    - navigation without reflectors
    - autonomous paper reel handling
History of "Field Robotics" Projects

- NSAL (2005–2012)
  - Multiple autonomous forklifts for loading and transportation applications
  - Safe autonomous industrial vehicles for industrial environments
  - topics
    - localization w minimum infrastructure (single fish-eye camera, 2D LRF)
    - obstacle detection/avoidance at "high speed"
2. History of "Field Robotics" Projects

- NSAL (2005–2012)
  - Multiple autonomous forklifts for loading and transportation applications
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  - Topics
    - Localization with minimum infrastructure (single fish-eye camera, 2D LRF)
    - Detection and distance prediction of humans with reflective vest
2.

History of "Field Robotics" Projects

- NSAL (2005–2012)
  - AASS, Kollmorgen, Linde MH
  - Multiple autonomous forklifts for loading and transportation applications
  - Safe autonomous industrial vehicles for industrial environments
  - topics
    - localization w minimum infrastructure (single fish-eye camera, 2D LRF)
    - obstacle detection/avoidance at "high speed"
    - trajectory prediction / path planning, with traffic rules (flexibility + predictability)
### History of "Field Robotics" Projects

- **NSAL (2005–2012)**
  - Logistics + safe autonomous vehicle navigation in dynamic environments
### History of "Field Robotics" Projects

- **NSAL (2005–2012)**

  » logistics + safe autonomous vehicle navigation in dynamic environments

  - **Objective 2 – Rich 3D Perception**
    - compact 3D representation, registration on compact 3D representations (localization), mapping in dynamic environments, identification of drivable areas, 3D HMT SLAM
2. History of "Field Robotics" Projects

- NSAL (2005–2012)
  - logistics + safe autonomous vehicle navigation in dynamic environments
    - Objective 2 – Rich 3D Perception
    - Objective 1 – Safe Motion
      - collision avoidance, trajectory modification, tracking of vehicles/humans, real-time response
History of "Field Robotics" Projects

- NSAL (2005–2012)

> logistics + safe autonomous vehicle navigation in dynamic environments

- Objective 2 – Rich 3D Perception
- Objective 1 – Safe Motion
- Objective 3 – Hybrid Planning
  - automate mission planning process (mission + motion planning), take into account multiple types of requirements/constraints, incomplete prior knowledge
2. History of "Field Robotics" Projects
   - NSAL (2005–2012)
     - logistics + safe autonomous vehicle navigation in dynamic environments
     - requirements elicited from industrial partners
     - solutions integrated into a "SAUNA System"
2. History of "Field Robotics" Projects

- NSAL (2005–2012)
  - logistics + safe autonomous vehicle navigation in dynamic environments
  - challenges
    - fleets of mixed autonomous and human-operated vehicles
    - high speeds (up to 30-40 km/h)
    - rich 3-D perception for enhanced safety and performance
    - automated mission planning capabilities at several levels of abstraction
    - collision and deadlock avoidance throughout mission planning, trajectory computation and execution
    - flexible operation, accommodation of run-time changes
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  - logistics + safe autonomous vehicle navigation in dynamic environments
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   - NSAL (2005–2012)
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   - All-4-eHAM (2009–2012) AASS, Volvo CE, NCC Roads
     » Autonomous wheel loaders for efficient handling of heterogeneous materials
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» Autonomous wheel loaders for efficient handling of heterogeneous materials
  - robust autonomous operation in 3D, slowly-changing terrain
  - pile detection and attack pose estimation
  - scanning while moving
  - obstacle and people detection in 3D data
### History of "Field Robotics" Projects

- **NSAL (2005–2012)**
- **SAUNA (2011–2014)**
- **All-4-eHAM (2009–2012) → ALLO (2012–2015)**
  - Autonomous wheel loaders for efficient handling of heterogeneous materials
  - Autonomous Long-Term Load-Haul-Dump Operations
    - quantitative evaluation of pile handling and maintenance
    - long-term strategies for pile handling
    - task planning and scheduling (gravel recipes for asphalt production)
    - maintenance of 3D maps in dynamic environments
    - path planning and scheduling in dynamic environments
    - map quality assurance (certification)
2. History of "Field Robotics" Projects

- NSAL (2005–2012)
- SAUNA (2011–2014)
- RobLog (2011–2015) AASS, Vollers, Qubica, BIBA, Jacobs, Pisa, HSRT
  » Unloading Containers (Cognitive Robot for Automation of Logistic Processes)
2. **History of "Field Robotics" Projects**

- NSAL (2005–2012)
- SAUNA (2011–2014)
- RobLog (2011–2015) AASS, Vollers, Qubica, BIB.

  » Unloading Containers
    - industrial scenario (coffee sacks)
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- **SPENCER (2013–2016)** AASS, TUM, Twente, CNRS, RWTH, BlueBotics, KLM, Freiburg
  - group-friendly navigation
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  - identification of likely spokespersons
  - Schengen fast track scenario
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- **All-4-eHAM (2009–2012) → ALLO (2012–2015)**
- **SPENCER (2013–2016)**
  - **AASS, TUM, Twente, CNRS, RWTH, BlueBotics, KLM, Freiburg**

  » **challenges**
  - localization and mapping in dynamic and social environments
  - identify dynamics of objects
  - → robust and precise localization in highly dynamic environments
  - learning of socially annotated maps
  - related to spatial event distribution models
3D-NDT in Dynamic Environments
(A First Glimpse)
5. **3D-NDT Model Maintenance (Saarinen et al.)**
   - online updates
5. **3D-NDT Model Maintenance (Saarinen et al.)**

- online updates
- create model at different timescales (diff $\rightarrow$ dyn. objects)
3D Perception for Industrial Mobile Robots

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