Rich 3D Perception for Safe Autonomous Navigation

Henrik Andreasson, Abdelbaki Bouguerra, Marcello Cirillo, Dimitar Dimitrov, Dimiter Driankov, Martin Magnusson, Federico Pecora, and Achim J. Lilienthal
1. Transport Robots@AASS

Professional Service Robots for Transport Applications at AASS
1. Transport Robots@AASS

2. The SAUNA Project
   - Safe Autonomous Navigation
1. Transport Robots@AASS

2. The SAUNA Project

3. Sensors
1. Transport Robots@AASS
2. The SAUNA Project
3. Sensors
4. Rich 3D Perception
   - what and why?
1. Transport Robots@AASS

2. The SAUNA Project

3. Sensors

4. Rich 3D Perception

5. Rich 3D in SAUNA
Professional Service Robots for Transport Applications at AASS
<table>
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<th>Application Area</th>
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**Major Projects at the AASS MR&O Lab (www.aass.oru.se/Research/mro)**

- ALL-4-eHAM
- SAUNA
- Gasbot
- HANDLE
- DIADEM
- SaNa
- RobLog
- ELWAYS
- Robosanis
Major Projects at the AASS MR&O Lab (www.aass.oru.se/Research/mro)

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- **Forklift Trucks** (Danaher Motion, Linde MH, Stora Enso)

  *Picking up paper reels at unknown positions*

  *Demonstration held at Vänerhamn, Karlstad 2009-04-03*

  speed x 2
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
1. Professional Service Robots for Transport Applications

- Forklift Trucks (Danaher Motion, Linde MH, Stora Enso)
- Wheel Loaders (VolvoCE, VolvoTech, NCC)
Professional Service Robots for Transport Applications

- **Forklift Trucks** (Danaher Motion, Linde MH, Stora Enso)
- **Wheel Loaders** (VolvoCE, VolvoTech, NCC)
- **Mining Vehicles** (Atlas Copco, Fotonic)

![Image of mining vehicles and a mine scene](image-url)
1. Professional Service Robots for Transport Applications

- Forklift Trucks (Danaher Motion, Linde MH, Stora Enso)
- Wheel Loaders (VolvoCE, VolvoTech, NCC)
- Mining Vehicles (Atlas Copco, Fotonic)
- Hospital Transport Vehicles (RobCab)
1. Professional Service Robots for Transport Applications

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- Hospital Transport Vehicles (RoboCab)
- Garbage Bin Collection and Cleaning (RoboTech)
Professional Service Robots for Transport Applications

1. Forklift Trucks (Danaher Motion, Linde MH, Stora Enso)
   - Wheel Loaders (VolvoCE, VolvoTech, NCC)
   - Mining Vehicles (Atlas Copco, Fotonic)
   - Hospital Transport Vehicles (RobCab)
   - Garbage Bin Collection and Cleaning (RoboTech)

   Requirements
   - perception
   - manipulation (for picking up and unloading material / goods)
   - planning and execution
   - safe navigation
1. Professional Service Robots for Transport Applications

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**Requirements**
- perception
- manipulation (for picking up and unloading material / goods)
- planning and execution
- safe navigation

→ SAUNA!
SAUNA

Leading Edge Research in

Safe Autonomous Navigation
Mobile Service Vehicles for Autonomous Transportation

- transportation of goods by **one or more vehicles**
- **time** and **resource** constraints
- **non-holonomic** vehicles
2. Mobile Service Vehicles for Autonomous Transportation
   - transportation of goods by one or more vehicles
   - time and resource constraints
   - non-holonomic vehicles

2. Challenges
   - fleets of mixed autonomous and human-operated vehicles
   - high speeds (up to 30-40 km/h)
   - rich 3D perception for enhanced safety and performance
   - automated mission planning capabilities at several levels of abstraction
   - flexible operation, accommodate run-time changes
   - collision avoidance throughout mission planning, trajectory computation and execution
2. **Scientific Objectives**

- Rich 3D Perception (depth + additional information)
  - mapping, localization
  - object identification and localization
  - real-time performance
  - long-term operation
2. Scientific Objectives

- Rich 3D Perception (depth + additional modalities)
  - mapping, localization
  - object identification and localization
  - real-time performance
  - long-term operation

- Safe Motion
  - obstacle detection
### Scientific Objectives

- **Rich 3D Perception** (depth + additional modalities)
  - mapping, localization
  - object identification and localization
  - real-time performance
  - long-term operation

- **Safe Motion** (→ very reliable collision avoidance)
  - tracking of vehicles and humans
    - predicted collisions
### Scientific Objectives

- **Rich 3D Perception (depth + additional modalities)**
  - mapping, localization
  - object identification and localization
  - real-time performance
  - long-term operation

- **Safe Motion (→ very reliable collision avoidance)**
  - tracking of vehicles and humans
  - collision avoidance (trajectory modification)
  - real-time response at medium and high speeds (up to 30km/h)
### Scientific Objectives

- **Rich 3D Perception (depth + additional modalities)**
  - mapping, localization
  - object identification and localization
  - real-time performance
  - long-term operation

- **Safe Motion (→ very reliable collision avoidance)**
  - tracking of vehicles and humans
  - collision avoidance (trajectory modification)
  - real-time response at medium and high speeds

- **Flexible Operation (no fixed action plans)**
  - automated mission planning process (both mission and motion planning)
  - multiple types of requirements/constraints
  - incomplete prior knowledge
2. **Realization**
   - in simulation
   - in real-world prototype robots
2. Assumptions on the Environment

- minimal infrastructure
2. Assumptions on the Environment

- minimal infrastructure

High-Speed Navigation without Additional Infrastructure (MALTA)

speed x 1
Assumptions on the Environment

- minimal infrastructure
- environment is 3D
  - 3D workspace map
Assumptions on the Environment

- minimal infrastructure
- environment is 3D, but navigation is in 2D
  - 3D workspace map
  - planning in 2D
    - locally flat environment
2. Assumptions on the Environment

- minimal infrastructure
- environment is 3D, but navigation is in 2D
- fully dynamic objects
  - other vehicles
  - humans
  - navigation areas can be blocked
Assumptions on the Environment

- minimal infrastructure
- environment is 3D, but navigation is in 2D
- fully dynamic objects
- slow dynamic changes
  - e.g., piles of objects/gravel
2. Assumptions on the Environment

- minimal infrastructure
- environment is 3D, but navigation is in 2D
- fully dynamic objects
- slow dynamic changes
- incomplete prior knowledge about the whereabouts of objects to transport
Sensors
### Sensors for Autonomous Vehicles

- laser scanner (2D LRF)
Sensors for Autonomous Vehicles

- laser scanner (2D LRF)
- laser scanner (3D LRF)
Sensors for Autonomous Vehicles

- laser scanner (2D LRF)
- laser scanner (3D LRF)
- laser scanner (3D a-LRF)
3. Sensors for Autonomous Vehicles

- laser scanner (2D LRF)
- laser scanner (3D LRF)
- laser scanner (3D a-LRF)
- TOF camera

Fotonic B70 (≈5k€)
3. **Sensors for Autonomous Vehicles**

- laser scanner (2D LRF)
- laser scanner (3D LRF)
- laser scanner (3D a-LRF)
- TOF camera
- range sensor + perspective camera (→ Rich 3D)

courtesy B. Huhle
### Sensors for Autonomous Vehicles

- laser scanner (2D LRF)
- laser scanner (3D LRF)
- laser scanner (3D a-LRF)
- TOF camera
- range sensor + perspective camera (→ Rich 3D)
  - Kinect sensor (→ Rich 3D)

Kinect Data

Kinect (≈0.2k$)
Sensors for Autonomous Vehicles

- laser scanner (2D LRF)
- laser scanner (3D LRF)
- laser scanner (3D a-LRF)
- TOF camera
- range sensor + perspective camera (⇒ Rich 3D)
  » ⇒ "industrial Kinect"
Rich 3D Perception
Rich 3D Perception

- rich 3D = spatial data augmented with additional information
  - additional dimensions: e.g. colour

![coloured point cloud (example of rich 3D data) [Andreasson, 2005]]
Rich 3D Perception

- Rich 3D = spatial data augmented with additional information
  - Additional dimensions: e.g. colour

Coloured point cloud (example of rich 3D data) [Andreasson, 2005]
**Rich 3D Perception**

- rich 3D = spatial data augmented with additional information
  - additional dimensions: e.g. colour, temperature

"thermal" point cloud (example of rich 3D data) [Andreasson, 2006]
4. Rich 3D Perception

- rich 3D = spatial data augmented with additional information
  - additional dimensions: e.g. colour, temperature, remission, semantic label, confidence estimate, ...

$$x_i = (x_i, y_i, z_i, r^{(1)}_i, \ldots, r^{(n)}_i)$$
Why do we need "rich" 3D?
Why do we need "rich" 3D?
- helps to establish the identity of obstacles
  - contains more information
  - can be important to maintain people tracks
  - can help to identify drivable areas
Why do we need "rich" 3D?
- helps to establish the identity of obstacles
- improved localization in areas without geometrical features
Why do we need "rich" 3D?

- Helps to establish the identity of obstacles
- Improved localization in areas without geometrical features
- Object separation in cluttered scenes
Why do we need "rich" 3D?
- helps to establish the identity of obstacles
- improved localization in areas without geometrical features
- object separation in cluttered scenes

... here rich 3D is necessary
Why do we need "rich" 3D?

- Helps to establish the identity of obstacles
- Improved localization in areas without geometrical features
- Object separation in cluttered scenes
- Additional dimensions can carry the meaning of a map
  - Classification labels, uncertainty
Why do we need "rich" 3D?

- Helps to establish the identity of obstacles.
- Improved localization in areas without geometrical features.
- Object separation in cluttered scenes.
- Additional dimensions can carry the meaning of a map.
- May even allow for more compact representations (because it provides ways to instantaneously identify the most important information in the "rich 3D space").
Rich 3D Perception in SAUNA
Rich 3D Perception in SAUNA – Expected Outcome

(1) develop algorithms to create and maintain a single compact and truthful rich 3D workspace model
Rich 3D Perception in SAUNA – Expected Outcome

1. create/maintain compact and truthful rich 3D map
2. localize within rich 3D workspace model
Rich 3D Perception in SAUNA – Expected Outcome

- (1) create/maintain compact and truthful rich 3D map
- (2) localize within rich 3D workspace model
- (3) detect obstacles wrt rich 3D workspace model
Rich 3D Perception in SAUNA – Expected Outcome

- (1) create/maintain compact and truthful rich 3D map
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Rich 3D Perception in SAUNA – Expected Outcome

1. create/maintain compact and truthful rich 3D map
2. localize within rich 3D workspace model
3. detect obstacles wrt rich 3D workspace model
4. identify drivable areas in rich 3D workspace model

Rich 3D Perception => Produce Really Useful Maps
Rich 3D Perception in SAUNA – Expected Outcome

- (1) create/maintain compact and truthful rich 3D map
- (2) localize within rich 3D workspace model
- (3) detect obstacles wrt rich 3D workspace model
- (4) identify drivable areas in rich 3D workspace model
Rich 3D Perception in SAUNA – Expected Outcome

- Create and maintain a compact and useful rich 3D workspace model ... and use it!
Rich 3D Perception for Safe Autonomous Navigation

Rich 3D@SAUNA

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