Mobile Robot Olfaction at the
Mobile Robotics and Olfaction Lab
@ AASS

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§ General Focus ...
  o perception systems for mobile robots
    (fundamentals for autonomous and safe operation)

§ Objective ...
  o advance theoretical and practical foundations that allow mobile robots to operate in an unconstrained, dynamic environment

§ Approaches are Characterized by ...
  o fusion of different sensor modalities
  o timely integration into industrial demonstrators
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
- **Forklift Trucks** (Danaher Motion, Linde MH, Stora Enso)

  *Picking up paper reels at unknown positions*

  *Demonstration held at Vänerhamn, Karlstad 2009-04-03*
MR&O Lab Profile – Two Major Research Directions

- Forklift Trucks (Danaher Motion, Linde MH, Stora Enso)
- Wheel Loaders (VolvoCE, VolvoTech, NCC)
1. MR&O Lab Profile – Two Major Research Directions

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- Wheel Loaders (VolvoCE, VolvoTech, NCC)
- Mining Vehicles (Atlas Copco, Fotonic)
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- Hospital Transport Vehicles (RobCab)
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- Mining Vehicles (Atlas Copco, Fotonic)
- Hospital Transport Vehicles (RobCab)
- 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), mobile robots for surveillance of landfill sites, gas leak localization
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)
Major Research Areas
Mobile Robot Olfaction

- research question
  - how do we enable intelligent gas-sensitive systems to perform in the real world?
Mobile Robot Olfaction

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  - how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions
  - description of basic tasks and environments for gas-sensitive mobile robots
    - Survey: Airborne Chemical Sensing with Mobile Robots [Lilienthal et al., Sensors 2006]
Mobile Robot Olfaction

- research question
  - how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions
  - description of basic tasks and environments for gas-sensitive mobile robots
    - Survey: Airborne Chemical Sensing with Mobile Robots [Lilienthal et al., Sensors 2006]
    - Gas distribution in unventilated indoor environments [Wandel et al., ICAR 2003]
2. Mobile Robot Olfaction

- research question
  - how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions
  - gas discrimination with open sampling systems?
Mobile Robot Olfaction

- research question
  » how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions
  » how do we combine gas sensor measurements into a spatial model?
    • spatial model of mean concentration with Kernel DM [Lilienthal et al., RAS 2004 / IROS 2003]
Mobile Robot Olfaction

- research question
  » how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions
  » how do we combine gas sensor measurements into a spatial model?
    • spatial model of mean concentration with Kernel DM [Lilienthal et al., RAS 2004 / IROS 2003]
    • spatial of mean and variance concentration ...
      • ... with GP Mixture Model [Stachniss et al., AURO 2009 / RSS 2008]
Mobile Robot Olfaction

- research question
  - how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions
  - how do we combine gas sensor measurements into a spatial model?
    - spatial model of mean concentration with Kernel DM [Lilienthal et al., RAS 2004 / IROS 2003]
    - spatial of mean and variance concentration ... 
      - ... with GP Mixture Model [Stachniss et al., AURO 2009 / RSS 2008]
      - ... with Kernel DM+V [Lilienthal et al., IROS 2009 / ISOEN 2009]
Mobile Robot Olfaction

- research question
  - how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions
  - how to include wind information when creating the gas distribution model?
4. Mobile Robot Olfaction

- research question
  - how do we enable intelligent gas-sensitive systems to perform in the real world?

- key contributions, general
  - experiments under non-artificial conditions (accept turbulent environment)
  - experiments outdoors
  - towards real-world applications

- ongoing work
  - gas sensing on flying robots
Projects
1. Bio-gas can be produced at landfill sites by decomposing biodegradable waste

- Bio-gas = primarily methane (CH\(_4\)) and carbon dioxide (CO\(_2\))

- Landfill produced biogas is of economical importance
1. Bio-gas can be produced at landfill sites by decomposing biodegradable waste

- Bio-gas = primarily methane (CH₄) and carbon dioxide (CO₂)

- **Landfill produced biogas is of economical importance**
  - Used for electricity production, heating and as an alternative fuel for vehicles
  - Germany, France, United Kingdom, Netherlands and Spain combined extract 4 million tons of biogas which can roughly cover the energy consumption of Brussels for one year
In Örebro, Atleverket manages waste disposal and bio-gas production

Bio-gas is extracted from two different facilities:
- A decommissioned landfill located at Venan (closed in 1978)
- An operational landfill located at Atleverket’s headquarters

Both facilities produce approx. 20,000 MWH of bio-gas
How does a landfill look like?

This is an active landfill
(Atleverket, Örebro)
1. How does a landfill look like?

This landfill was closed 30 years ago (Rynningeviken, Örebro)
Landfill emissions account for 2% of the total greenhouse gases (GHG) released by human activity.

The GHG released from landfill sites are mainly methane (CH$_4$) and carbon dioxide (CO$_2$), and to a minor extent mixtures of oxygen (O$_2$), nitrogen (N$_2$), and hydrogen (H$_2$).

Also poisonous gases like hydrogen sulfide (H$_2$S) can be released in landfills.

Leaks are difficult to detect and with current monitoring technologies it can take weeks before a leak is detected and localized.
A landfill operator is required by law to collect one sample a month for a few predetermined locations

- Delay and inaccuracy in the leak detection mainly due to spatio-temporal sparsity of the collected samples

Mobile robots can adaptively collect sensor measurements, cooperate with other systems and provide useful indications to landfill operators

- High density of measurements
- Minimize the exposure of human operators to hazardous compound (e.g. H$_2$S)
- Mobile robots offer the required accurate localization and computational resources to compute for example, on-line gas distribution models
1. A landfill operator is required by law to collect one sample a month for a few predetermined locations
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2. Mobile robots can adaptively collect sensor measurements, cooperate with other systems and provide useful indications to landfill operators
   - High density of measurements
   - Minimize the exposure of human operators to hazardous compound (e.g. H$_2$S)
   - Mobile robots offer the required accurate localization and computational resources to compute for example, on-line gas distribution models
2. **Overview**

- **Proof of concept (mobile robot for monitoring and mapping of Biogas emissions at landfill sites).**

- **Project Runtime**
  - 2011-01-01 to 2013-12-31

- **Funded by Robotdalen and developed in cooperation with Atleverket (as an end-user)**
2. Tasks

- Localization in a semi-structured environment

- Measure absolute gas concentrations (ppm)
  - Raw sensor response → information about identity and concentration.

- Exploration of the environment
  - Not necessarily autonomous (could be a predefined trajectory).
  - Autonomous → sensor planning required.

- Gas distribution modelling
  - Spatial model for sensor planning and source localization

- Detect and localize gas sources
  - Based on gas distribution model and tracking strategy
Olfactory robots have been often tested in simplified environments, under unrealistic assumptions, like e.g. steady and uniform airflow.

The majority of robots that have been proposed for gas source localization take inspiration from insects (e.g. bio inspired approaches) and try to track an odour plume up to its source, where they declare the end of their task.

Experiments in mobile robot olfaction have often been carried out with dummy substances like ethanol. Gas discrimination has been neglected for a long time.

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* Mobile robots for localizing gas emission sources on landfill sites: is bio-inspiration the way to go?

3. Gasbot Platform

- **Gill Windsonic**
  2-D anemometer

- **IMU /GPS Module**
  Localization

- **ATRV-JR**
  All Terrain Robotic Platform

- **Sewerin RMLD**
  Remote gas sensor

- **PID / E-nose**
  *In-situ* gas sensors
3. Gasbot Platform

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  - All Terrain Robotic Platform
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IMU /GPS Module
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PID / E-nose
In-situ gas sensors

Sewerin RMLD
Remote gas sensor
Sewerin’s RMLD (Remote Methane Leak Detector)

- Exclusively developed for detecting methane gas and shows no cross-sensitivity to other hydrocarbons
- Detection principle
- Measurement specifications
- Laser Specifications
3. **Sewerin’s RMLD (Remote Methane Leak Dector)**

- Exclusively developed for detecting methane gas and shows no cross-sensitivity to other hydrocarbons

- Detection principle
  - TDLAS (Tunable Diode Laser Absorption Spectroscopy)

- Measurement specifications

- Laser Specifications
3. Sewerin’s RMLD (Remote Methane Leak Dector)

- Exclusively developed for detecting methane gas and shows no cross-sensitivity to other hydrocarbons
- Detection principle
- Measurement specifications
  - Detection range up to 30 m
  - Integral measurements given in ppm*m
  - 5 ppm*m at a distance of 0 to 15 m / 10 ppm*m at a distance of 15 to 30 m
- Laser Specifications
Sewerin’s RMLD (Remote Methane Leak Dector)

- Exclusively developed for detecting methane gas and shows no cross-sensitivity to other hydrocarbons
- Detection principle
- Measurement specifications
- Laser Specifications
  - Class 1 laser (no eye protection required)
  - Conical beam, width 56 cm at 30 m
3. Gasbot Platform

- **ATRV-JR**: All Terrain Robotic Platform
- **Gill Windsonic**: 2-D anemometer
- **IMU /GPS Module**: Localization
- **Sewerin RMLD**: Remote gas sensor
- **PID / E-nose**: In-situ gas sensors
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