Sicherheit in Technik und Chemie

20.05.2022

RASEM – ROBOT-ASSISTED ENVIRONMENTAL MONITORING FOR AIR QUALITY ASSESSMENT

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Motivation

Major risk for the worker's health

Dust and Gases

Airborne by-products

Robot-assisted Environmental Monitoring for Air Quality Assessment

- **Runtime** April 2019 – March 2022,
  extended until 31.12.2022
- **Funding**
  - » SAF€RA
  - » Finnish Work Environment Fund
- **Partners**

Key Research Questions

Question 1

- How could a modern method to air quality monitoring look like?

Question 2

- What insights can we get from an industrial steel factory?

Question 3

- How can RASEM complement traditional measurement campaigns to capture the air quality situation?

Question 1

How could a modern method to air quality monitoring look like?

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Goals of RASEM

Dense Measurements

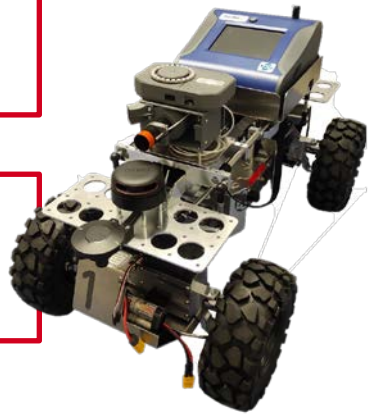
- Spatial and temporal dense measurements of dust, gases, temperature, humidity
- Measurements with mobile and stationary platforms

Enhancement of Traditional Measurements

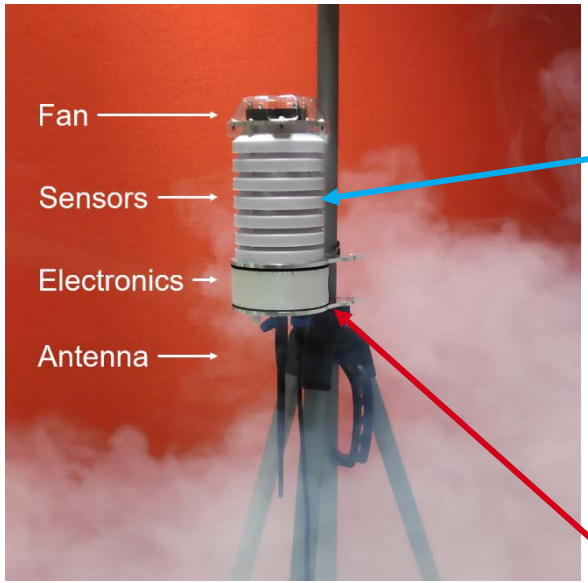
- Continuous, long-term measurements on weekends, holidays…

New Exposure Models

- Combination of occupational health expertise with robotics research



Sensing Node Design

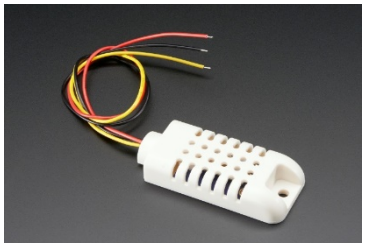


Environmental Sensors

Dust (WaveShare / Sharp GP2Y1010AU0F)

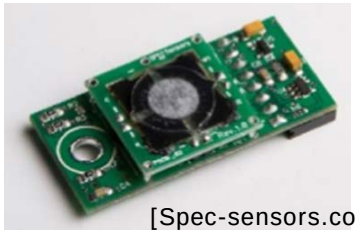
[Waveshare.com]

Temperature & humidity (DHT22)



[Adafruit.com]

Gas: CO, NO2, *indoor air quality (IAQ)* (SPEC DGS)



[Spec-sensors.com]

Electronics

- Microcontroller (Espressif ESP32)
- Real-time clock (DS3231)
- Storage on microSD (Adafruit MicroSD)

[WINKLER ET AL., SMSI 2021]

Unmanned Aerial/Ground Vehicle

- **High quality sensors**
  - **TSI DustTrak II**
    - » 0.1 to 10 µm
    - » High weight, heigh cost
  - **OPC-R1 Particle Monitor**
    - » PM1, PM2.5, PM10
    - » Low weight, mid cost
  - **Temperature sensor**
    - » Pt100
- **Additional sensors:**
  - » RASEM sensing node sensors
  - » Lidar (light detection and ranging)
    - → Precise altitude (of the drone)

Indoor localization using geo-referenced tags

Question 2

What insights can we get from an industrial steel factory?

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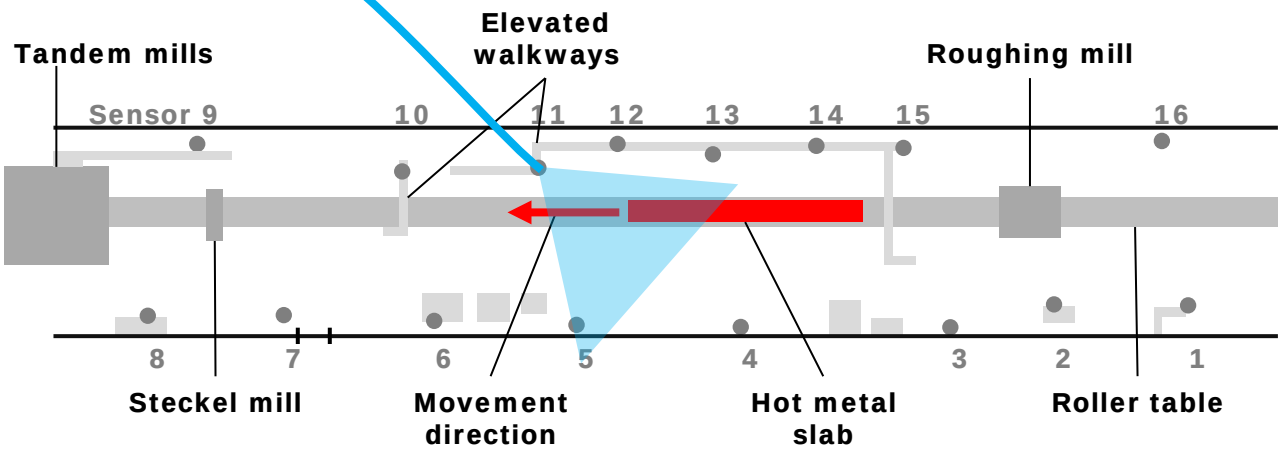
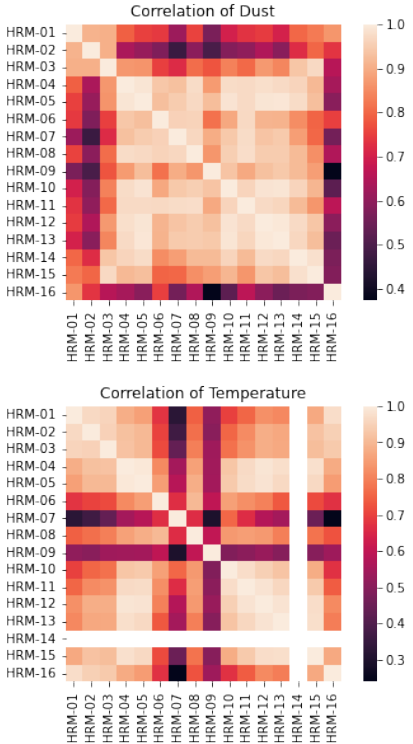
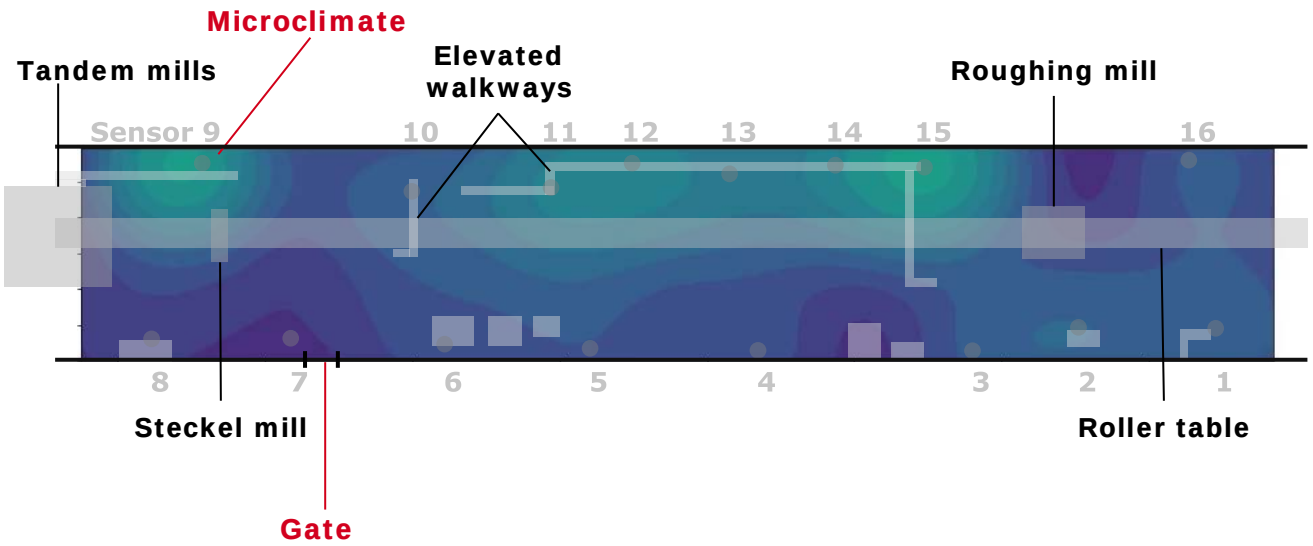
Air Quality in Steel Factory: Factory Layout



Air Quality in Steel Factory: Correlation and Dust Mapping





Question 3

How can RASEM complement traditional measurement campaigns to capture the air quality situation?

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RASEM & Traditional Methods

How to define *air quality situation*?

Here, we distinct between:

1. Hazard mapping of the working area
2. Individual exposure during a working day

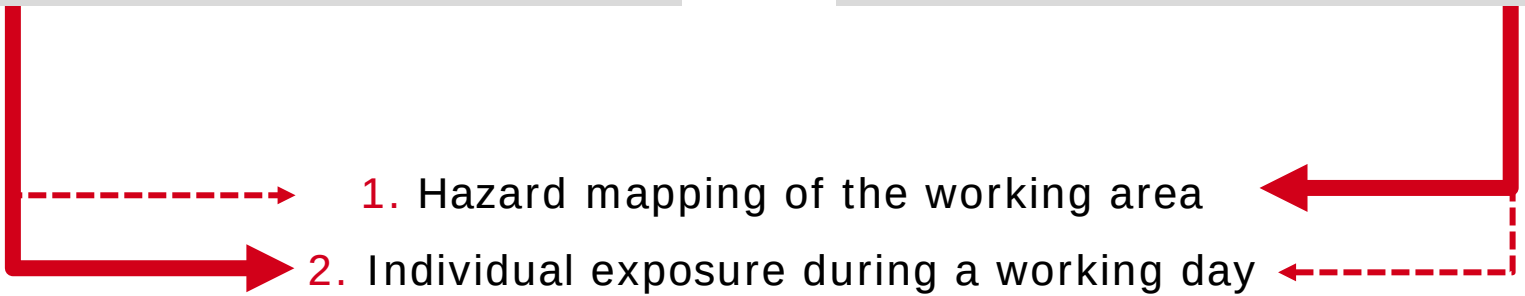
RASEM & Traditional Methods: They are complementary!

Traditional methods

- 7 measurement days (usually less)
- ~40 measurements (short-term)
- Time averaged concentrations
- Specific information of chemical substances from laboratory analysis

RASEM

- 365+ measurement days
- 16 locations (long-term)
- Time specific concentration levels
- Measurements by mobile robots

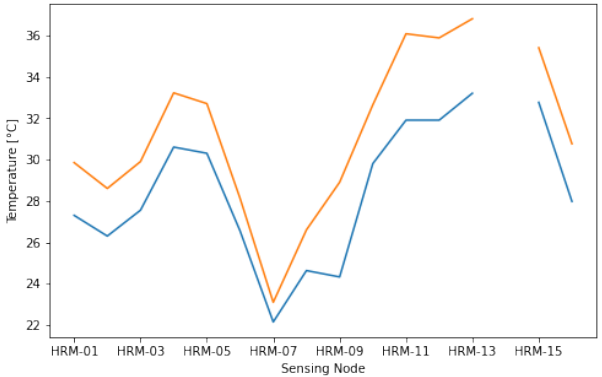


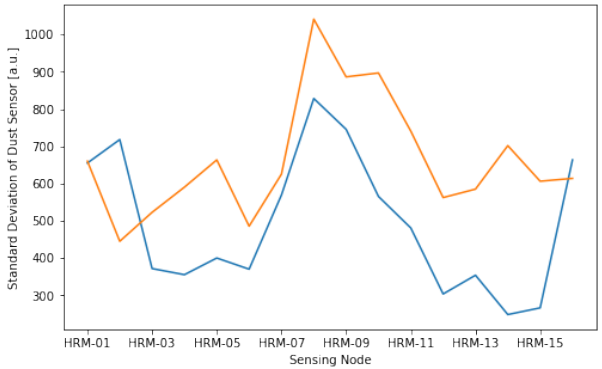
RASEM & Traditional Methods: Direct Comparison

- How is the air quality during the measurement campaign compared to the every day variation?
  - Temperature is lower
  - Variance in dust measurements is smaller
  - Unexpected breaks in the production during measurement campaign

→ **RASEM helps to evaluate representativeness of a traditional measurement campaign**

Measurement campaign
Everyday situation





Take Home Message

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Conclusion

1. RASEM is a new approach for air quality monitoring using
   - » Low-cost and high-quality sensors
   - » Stationary and mobile platforms
2. Sensor networks can enhance traditional exposure assessment methods
3. RASEM helps to evaluate representativeness of a traditional measurement campaign
   - » Potentially special conditions during a single measurement day

Outlook

June ’22: Measurement with **mobile robots**

NO_2 on **Tallink-Silja car deck** (20 nodes)

CO emission on **Outokumpu factory site** (8 nodes)

Thank you for your attention.

Contact:

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8.1 Sensors, Measurement and Testing Methods

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Appendix

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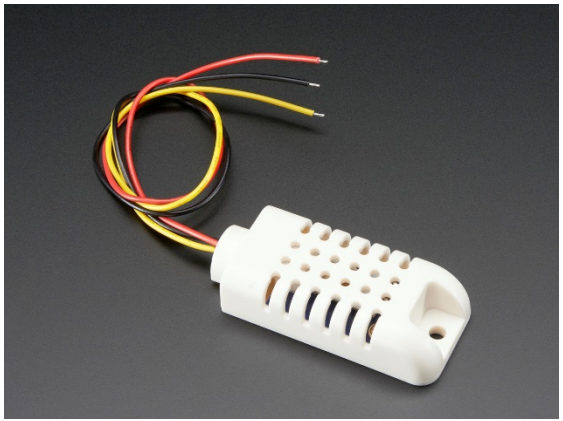
Dust measurement devices

- ELPI+ 10 nm – 10 µm (Dekati Oy)
- Respirable dust <4µm
  - Gravimetric analysis
  - Cyclone sampler
- Inhalable dust <100µm
  - gravimetric analysis
  - IOM sampler
- Grimm optical particle counter
  - 0.3-34 µm
- TSI sidepak <10µm

DHT22

- 3 to 5V power and I/O
- 2.5mA max current use during conversion (while requesting data)
- Good for 0-100% humidity readings with 2-5% accuracy
- Good for -40 to 80°C temperature readings ±0.5°C accuracy
- No more than 0.5 Hz sampling rate (once every 2 seconds)
- Body size 27mm x 59mm x 13.5mm (1.05" x 2.32" x 0.53")
- 3 wires 23cm long (9")
- 27mm wide x 58.75mm tall x 13.30mm deep



[Adafruit.com]

Dust Sensor

- Sensitivity : 0.5V/(100μg/m3)
- Measurement range : 500μg/m3
- Power : 2.5V~5.5V
- Operating current : 20mA(max)
- Operating temperature : -10℃~65℃
- Storage temperature : -20℃~80℃
- Life time : 5 years
- Dimension : 63.2mm×41.3mm×21.1mm

[Waveshare.com]

SPEC Digital Gas Sensor

MEASUREMENT PERFORMANCE CHARACTERISTICS

Based on Standard Conditions 25 °C, 50% RH and 1 atm	
Measurement Range	0 to 1000 ppm
Resolution	0.1 ppm (1)
Zero Accuracy	± 1 ppm (2)
Measurement Accuracy	15% of reading
Measurement Repeatability (2)	< ± 3% of reading or 2 ppm, whichever is greater
T90 Response Time (100 ppm step)	< 30 seconds (15 seconds typical)
Power Consumption	1 mW for 1 minute triggered samples 12 mW for continuous sampling 5, 10 30, 60 second intervals
Expected Operating Life	> 5 years (10 years @ 25± 10C; 60 ± 30% RH)
Operating Temperature Range	-20 to 40 °C (-30 to 55 °C intermittent)
Operating Humidity Range	15 to 95% (0 to 100% non-condensing intermittent)
Mechanical Dimensions	1.75 x 0.82 x 0.35 in. (44.5 x 20.8 x 8.9 mm)
Weight	< 2 Ounces

[Spec-Sensors.com]

Alphasense OPC-R1

- Particle range (µm spherical equivalent size)
  0.35 to 12.4
- Size categorisation (Number of software bins)
  16
- Sampling interval (Histogram period (seconds))
  1 to 30
- Total flow rate (L/min (typical))
  0.24
- Max particle count rate (particles/second)
  10,000
- Max coincidence probability
  (%concentration at 10^6 particles/L)
  0.7

[alphasense.com]

TSI DustTrak II

Sensor Type
90° light scattering

Particle Size Range
0.1 to 10 µm

Aerosol Concentration Range

8530 Desktop	0.001 to 400 mg/m³
8530EP Desktop with External Pump	0.001 to 400 mg/m³
8532 Handheld	0.001 to 150 mg/m³

Resolution
±0.1% of reading or 0.001 mg/m³, whichever is greater

Zero Stability
±0.002 mg/m³ per 24 hours at 10 sec time constant

Flow Rate
3.0 L/min set at factory, 1.40 to 3.0 L/min, user adjustable

Flow Accuracy
±5% of factory set point, internal flow controlled

Temperature Coefficient
+0.001 mg/m³ per °C

Operational Temp
32 to 120°F (0 to 50°C)

Storage Temp
-4 to 140°F (-20 to 60°C)

Operational Humidity
0 to 95% RH, non-condensing

Time Constant
User adjustable, 1 to 60 seconds

Data Logging
5 MB of on-board memory (>60,000 data points)
45 days at 1 minute logging interval

[TSI.com]

Key Idea of RASEM
A Heterogenous Sensor Network

RASEM

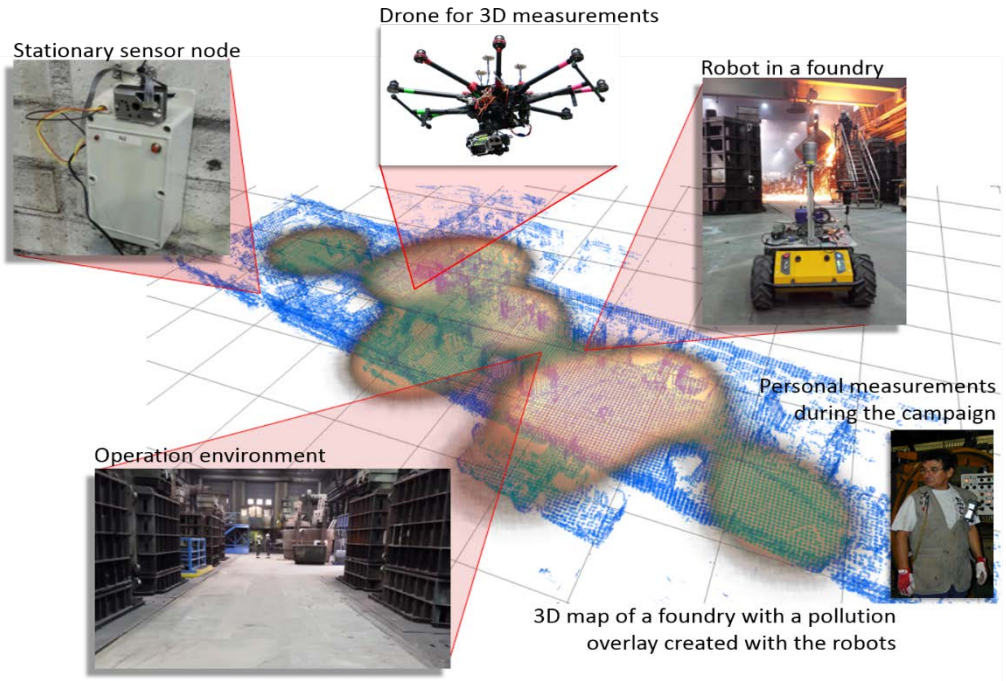
…augments sensor networks with robots, drones, and other mobile units

…combines dust and gas measurements with varying quality and spatial resolution

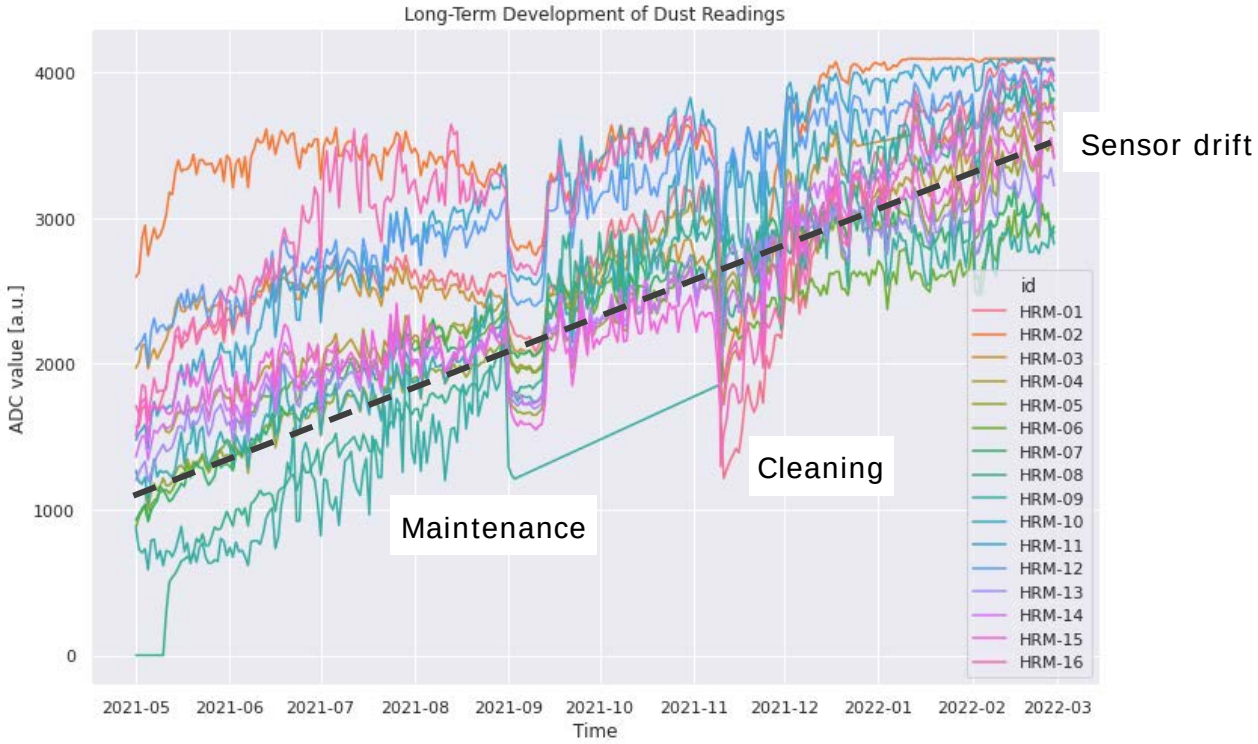
…creates 3D dust and gas exposure maps (time- and event-dependency)

…provides sensor planning methods to find optimal sampling locations

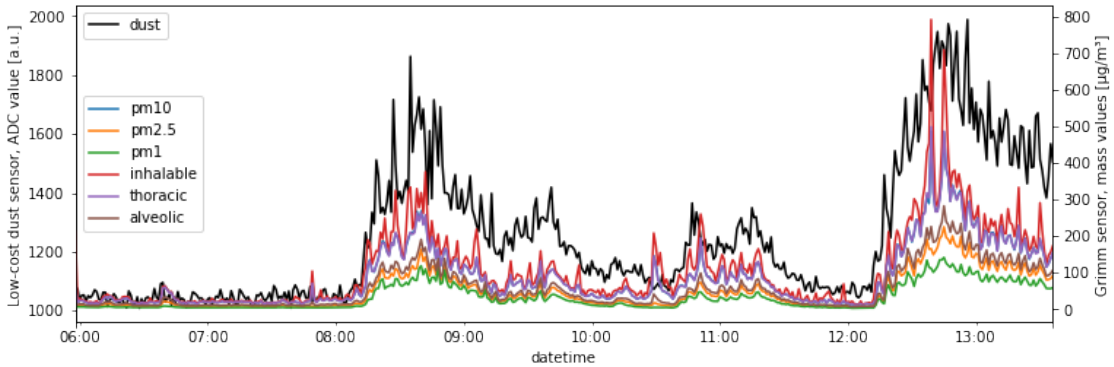
…provides sophisticated models for worker exposure estimation exploiting its dense sampling capabilities

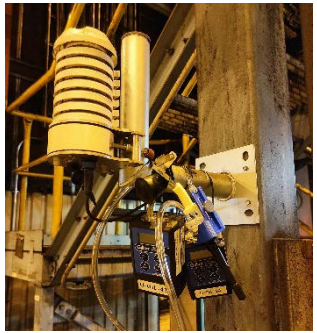


Air Quality in Steel Factory: Long-Term Dust Measurements



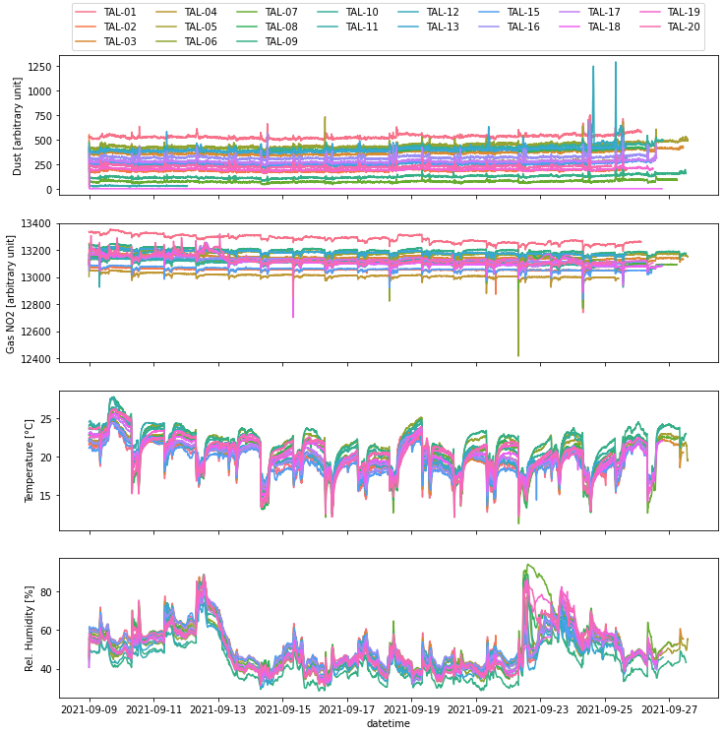
RASEM & Traditional Methods: Direct Comparison



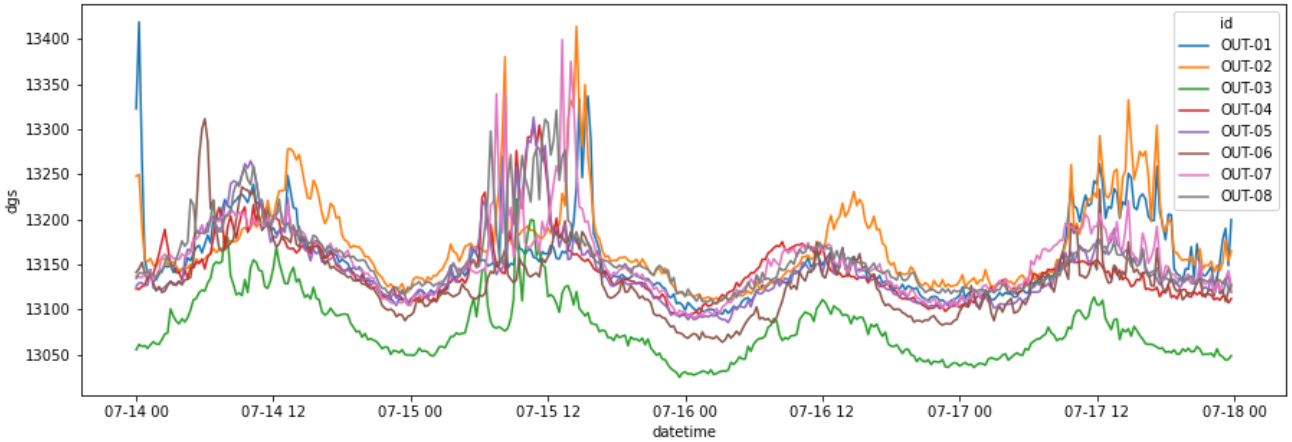


	FIOH Grimm Sensor					
	PM 10	**PM 2.5**	**PM 1**	**Inhalable**	**Thoracic**	**Alveolic**
Sensing Node	0.92	0.94	0.94	0.87	0.92	0.94

Scenario 1:
NO2 Monitoring on a Cruise Ship’s Car Deck

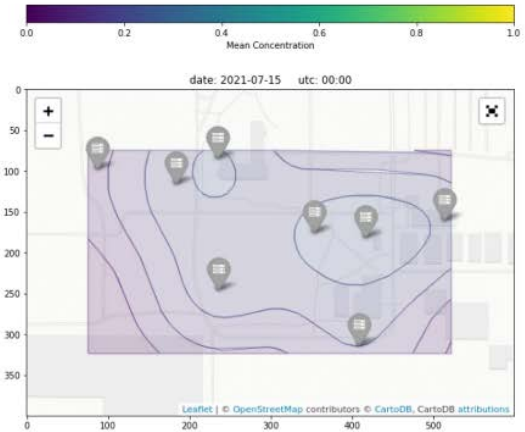


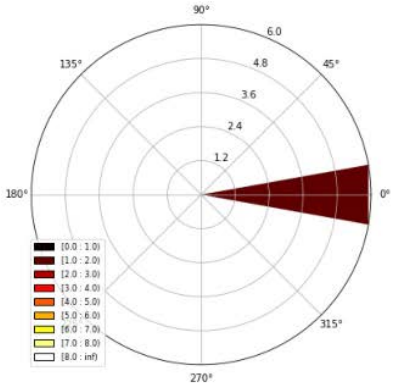
Scenario 2: Outdoor – CO



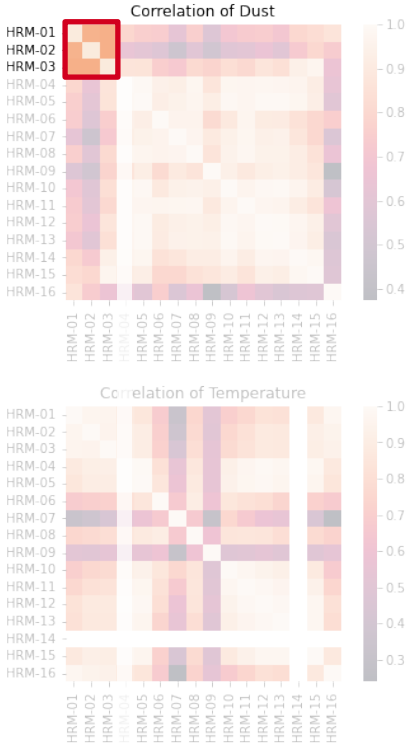
Scenario 2: Outdoor – CO

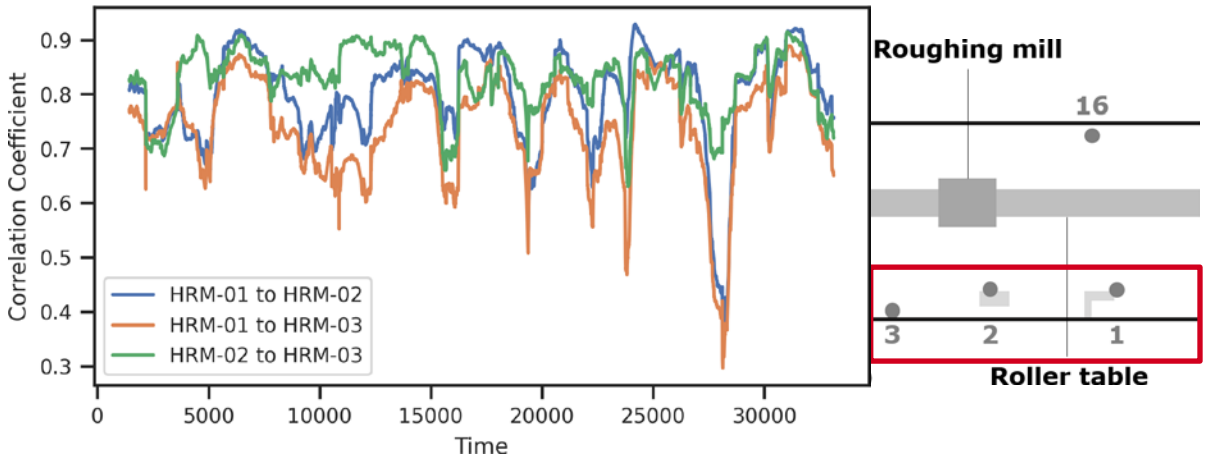
Influence of wind on the distribution of CO on the factory site (Kernel DM+V) [LILIENTHAL ET AL., IROS 2009]





Air quality of Steel Factory: Correlations Fluctuate Over Time!





[WINKLER ET AL., IEEE SENSORS 2021]