Feasibility study on the application of low-cost sensors for epidemiological investigations

Low-cost sensors (LCS) – expanding horizons in AQ monitoring

- Regulatory Air Quality Monitoring
- Suppl. Monitoring
- Epidemiological Studies
- Set the Data Quality Objectives (DQO)
- Prove causality
- Air Quality Directives
- WHO Air Quality Guidelines
- Recommend Limit Values

Lower accuracy

Higher accuracy

Education
Citizen Science
Sensor Networks
Model input/verification
Safety and Security
Smart City Management
Epid. studies/Personal Exposure

Low-cost sensors possible applications
Objectives of the pilot project

- Design of a measurement strategy for the use of low-cost sensors for epidemiological investigations → Focus in QA/QC
  - Evaluation and selection of LCS for NO$_2$ and PM$_{2.5}$
  - Design of sensor boxes for indoor and outdoor monitoring
  - Carry out the pilot project with COPD and Asthma patients
  - Evaluation of the uncertainty

NO$_2$ → Data post-processing → MLR and machine learning models (RF, SVR and ANN)

PM$_{2.5}$ → Air-preconditioning → Thermal low-cost dryer and LR

ANN: artificial neural networks
COPD: chronic obstructive pulmonary disease
LCS: low-cost sensors
LR: linear regression
MLR: multilinear regression
QA: quality assurance
QC: Quality control
RF: random forest
SVR: support vector regression
Evaluation and selection of LCS for NO$_2$ in a climatic chamber

- Relative humidity: 15 - 80 %
- Temperature: 18 - 43 °C
- NO$_2$ concentration: 0 - 230 ppb
Evaluation and selection of LCS for PM2.5 in a particle chamber

**Raw Data**

- **Reference**
- **SPS30**
- **SDS011**
- **PMS 5003**

**Corrected Data with LR**

- **Reference**
- **SPS30**
- **SDS011**
- **PMS 5003**

Alphasense OPC-R1 was selected

**LR:** Linear Regression
Design of sensor boxes for indoor and outdoor monitoring

Basic components:

- Alphasense NO₂ B43F
- Alphasense OPC R1
- IST AG HYT221 (Temp, RH sensor)
- Microcontroller: Arduino UNO + Datalogger
Low-cost dryer for PM sensor

- Switched on when RH>65%
- Regulated with the OPC R1 temperature to avoid excess of heating

Studying the influence of the low-cost dryer on the growth of hygroscopic particles

- Sensor without dryer
- Sensor with dryer
- RH

<table>
<thead>
<tr>
<th>Time in hh:mm</th>
<th>PM2.5 in µg/m³</th>
</tr>
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<tbody>
<tr>
<td>9:47</td>
<td>~40 %RH</td>
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<tr>
<td>9:51</td>
<td>100 µg/m³</td>
</tr>
<tr>
<td>9:56</td>
<td>~80 %RH</td>
</tr>
<tr>
<td>10:00</td>
<td>220 µg/m³</td>
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<tr>
<td>10:04</td>
<td>220 µg/m³</td>
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<td>10:09</td>
<td>220 µg/m³</td>
</tr>
<tr>
<td>10:13</td>
<td>220 µg/m³</td>
</tr>
</tbody>
</table>

Preprint available
Measurement strategy

Phase I
- Calibration-Training/Validation-Testing
  - Indoor boxes → 14 days co-location in the laboratory
  - Outdoor boxes → 14 days co-location in University of Stuttgart monitoring station

Phase II
- Measurements in the houses of 7 patients with COPD or Asthma for 30 days
  - Indoor and outdoor boxes with NO2 and PM sensors
  - Passive samples for NO2
  - Environmental questionnaire (once)
  - Protocol of activities (daily)
  - Symptomatic questionnaire + Spirometry (daily)
  - Feedback (once)

Phase III
- Data post-processing and evaluation

Cal./Val. 14 days
Patient 1
30 days

Cal./Val. 14 days
Patient 2
30 days

COPD: chronic obstructive pulmonary disease
How to evaluate the performance of the LCS during the campaign?

1. Passive samples

[Bar charts showing indoor and outdoor NO₂ concentrations for different periods and locations.]

**Indoor NO₂ Concentration in µg/m³**

- First period: Living room Pat. 134, Living room Pat. 261, Living room Pat. 271, Living room Pat. 652, Living room Pat. 777
- Second period: Living room Pat. 261, Living room Pat. 271, Living room Pat. 652, Living room Pat. 777

**Outdoor NO₂ Concentration in µg/m³**

- First period: Street Pat. 261, Backyard Pat. 271, Street Pat. 652, Backyard Pat. 777
- Second period: Backyard Pat. 777

**Legend:**
- NO₂-Passive sample
- MLR
- SVR
- RF
- ANN

**Abbreviations:**
- ANN: artificial neural networks
- MLR: multilinear regression
- RF: random forest
- SVR: support vector regression
How to evaluate the performance of the LCS during the campaign?
2. Identifying possible sources of air pollution indoors

The protocol of activities helps to identify the sources of PM peaks.
How to evaluate the performance of the LCS during the campaign?

3. Comparison with official monitoring stations

Start of Corona lockdown in Germany

University of Stuttgart monitoring station (1.6 km distance)
Evaluation of the measurements during the validation/testing period

Sensor-to-sensor variability

- DQO Class 1 (25%)
- DQO Class 2 (75%)
- MLR 10 min
- SVR 10 min
- RF 10 min
- ANN 10 min

ANN: artificial neural networks
DQO: data quality objective
MLR: multilinear regression
RF: random forest
SVR: support vector regression

Pat. 261
Pat. 271 Garden
Pat. 271 Street
Pat. 121
Conclusions

- Low concentrations has higher uncertainties with LCS, but peak concentrations are well detected → symptoms and pollutions peaks can be correlated

- LCS are a useful tool to characterize the local air quality in the surroundings of the patients.

- A combination of reference devices and LCS is the key to a successful study.

LCS: low-cost sensor
Thank you!

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