Evaluating low cost chemical sensors for air pollution measurement

Peter M Edwards¹, Alastair C Lewis², James D Lee², Marvin Shaw¹,², Mat J Evans¹,², Sarah J Moller¹,², Katie Smith¹, Matthew Ellis¹, Stefan Gillot³, A White⁴

[3] Environment Department, University of York, Heslington, York, UK.

Based on Lewis et al., Faraday Discuss. 2015, DOI: 10.1039/C5FD00201J
Sensors – a revolution in air pollution measurement?

- Current approach offers high quality measurements but poor spatial coverage.
- Distributed sensors could greatly improve coverage – personal exposure.
- Relies on assumption that the sensor data is fit for purpose.
Some of the hype......

Welcome to your preview of The Times

Air pollution monitors fitted to schools

The New York Times

Experimenting at Home With Air Quality Monitors

APRIL 13, 2015

In Hong Kong, the dense population is exposed to high levels of vehicle exhaust. Photograph: Agence France-Presse — Getty Images.

Two years ago, when Thomas Talhelm was a Fulbright scholar in Beijing, he built his own air purifier after growing concerned about the city’s notorious pollution. To test his handiwork, he spent about $260 for a portable device that counts tiny particles in the air.

Mapping air quality with hire bike sensors

AirPublic proposes to put sensors on London’s rental bikes so as to fill in the gaps in air quality sensor networks.

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The Heathrow: Democratising air data to meet local needs

Breathe Heathrow uses air quality sensors to help residents understand how the airport affects their area, bringing more data into the hands of communities to address local needs
A crowded marketplace

- Air Quality Tester function (Excellent / Good / Moderate / Bad) by collecting indoor air quality levels.
What is in the box?

**sensor**

/aʊnsər/

noun

noun: sensor; plural noun: sensors

- a device which detects or measures a physical property and records, indicates, or otherwise responds to it.

1. **Metal oxide**
   - ~ £5
   - ~ 1960

2. **Electrochemical/voltammetric**
   - ~ £50
   - ~ 1980

3. **Photochemical**
   - ~ £100
   - ~ 1990

4. **Micro-optical**
   - > £100
   - ~ 2000

Sensor ➔ Micro-electro-mechanical (MEMS) device
Hype Cycle and Technology Adoption Lifecycle

"Hype Cycle" model used by Gartner since 1995 and the "Technology Adoption Lifecycle" model popularized by Rogers and Moore

"The Chasm"
Hype Cycle and Technology Adoption Lifecycle

- **Technology Trigger**
- **Peak of Inflated Expectation**
- **Trough of Disillusionment**
- **Slope of Enlightenment**
- **Plateau of Productivity**

**Innovators**

- **Traditional Model**
  - "Technique" papers
  - "First to measure" papers
  - "Us too" papers
  - "Evaluations"
  - "Intercomparisons"
  - "Reference method"
  - "Public data"

**Early Adopters**

- Universities Institutes

**Early Majority**

- National Agencies

**Late Majority**

- National Regulators

**Laggards**

- Local Regulators

"The Chasm"

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Sensor interferences from co-pollutants

<table>
<thead>
<tr>
<th>Sensor</th>
<th>CO</th>
<th>SO$_2$</th>
<th>NO</th>
<th>O$_3$</th>
<th>NO$_2$</th>
<th>CO$_2$</th>
<th>H$_2$</th>
<th>%RH$^a$</th>
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<tbody>
<tr>
<td>CO - B4</td>
<td>0.378</td>
<td>-0.013</td>
<td>0.000</td>
<td>0.0200</td>
<td>0.032</td>
<td>0.000</td>
<td>-0.032</td>
<td>0.201</td>
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<tr>
<td>OX-B421</td>
<td>0.000</td>
<td>-0.016</td>
<td>-0.110</td>
<td>0.439</td>
<td>0.44</td>
<td>9.5 x 10$^{-5}$</td>
<td>0.560</td>
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<tr>
<td>SO$_2$-B4</td>
<td>0.013</td>
<td>0.210</td>
<td>0.023</td>
<td>-0.014</td>
<td>-0.32</td>
<td>9.8 x 10$^{-6}$</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>NO-B4</td>
<td>0</td>
<td>0.007</td>
<td>0.558</td>
<td>-0.011</td>
<td>-0.590</td>
<td>1.8 x 10$^{-5}$</td>
<td>-0.303</td>
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<tr>
<td>NO$_2$-B4</td>
<td>0</td>
<td>0.004</td>
<td>-0.008</td>
<td>0</td>
<td>0.148</td>
<td>2.3 x 10$^{-5}$</td>
<td>0.000</td>
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</tbody>
</table>

Working electrode responses (in mV ppb$^{-1}$ of co-pollutant) induced by the presentation of co-pollutants in zero air across five electrochemical sensors
**NO₂ sensor interference example**

- NO₂ electrochemical sensor has a small cross sensitivity to CO₂
- But CO₂ is generally in huge excess to NO₂.
- At low [NO₂] the sensor is primarily sensing CO₂

![Graph showing the fraction of sensor response due to NO₂](image-url)
Twenty sensor intercomparison

- Reference methods used UV, Chemiluminescence, GC, TEOM-FDMS
- Devices initially calibrated to the reference value (e.g. slope applied on 11 Oct)

Ozone intercomparison – a success story?
Collective accuracy is good, but individual accuracy is poor.

Useable for research?? Probably.

For the public?? They are not overtly misleading, since no collective bias
NO$_2$ – sensor to sensor variability

- **Bias of** $3.2 \pm 1.7$ – sensors over-measure vs. reference
- Poorer agreement on trends – some other parameter e.g. CO$_2$?
- Misleading public data – widespread exceedences indicated
Not all sensors components are equal – e.g. PM

- Large observed variability in sensor performance.

  - PM10 sensor 1

  - PM10 sensor 2

  - Not obvious which sensors / technologies used in commercial units.
Can we separate the signals?

- Interferences from other variables are the key sensor weakness
- These can interact with one another in non-linear ways
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These can interact with one another in non-linear ways.
Conclusions

- Low cost sensors are an **exciting opportunity**.
- Wide range of sub-components of variable quality.
- **Publication bias**, few independent tests reported, limited academic publication.
- **Cross-interferences** from other pollutants.
- Unit – to – unit **reproducibility** can be very poor.
- Can generate misleading information - **over-reporting** is commonplace.
- ‘Miniaturized’ instruments using known methodologies look more promising, e.g. OPCs.
- Long-term stability is untested.
- Statistical methods offer considerable promise, if backed up by lab work.
- **Buyer beware!**