Practical and Demonstrated Uses of Low-Cost Sensors from Regulation to Education: The Rest of the Story

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Atlanta, GA
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Approach

- Background
- Three examples
- Predictions

Take-home points
- Air sensors are already here
- Air sensors can be used for many applications
- Air sensor cost can be misleading
Low Cost Drives Innovation
What’s Happening

Disruptive Technology

AQ Instrument Manufacturers
- Starting with proven technology
- Lowering costs
- Shrinking size

Industry, Universities, NGOs
- Starting with low-cost sensors
- Improving quality
- Designing packaging
- Sensor networks
Why This Is Happening

Drivers

• Microprocessors – cheaper
• Internet – everywhere
• Sensors – cost decreasing
• Online communities – growing
• Personalized health – rapidly increasing
Such Promise!

“What if every mobile device had an air quality sensor?”
CommonSense

“50 billion devices will be connected to the Internet by 2020.”
Cisco

“Air sensors can lead to better protection of public health and the environment….”
EPA Roadmap for Next Generation Air Monitoring

“I think [air sensing] is going to have a big impact in the future.”
Charles Elkan, Computer Science professor at UC San Diego

“The Internet of things will augment your brain.”
Eric Schmidt, Google
A Reality Check

• Low cost – kind of
• Small – yes
• Sufficient quality – that depends
• Lot of devices – many sizes, shapes, costs, etc.
• Useful – depends
• Promise to change the world – I think so
## Many Components Enable Air Sensing

<table>
<thead>
<tr>
<th>Sensor or Instrument Component</th>
<th>Sensor Cost Relative to Traditional Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing device</td>
<td>Cheaper</td>
</tr>
<tr>
<td>Microprocessor</td>
<td>Cheaper</td>
</tr>
<tr>
<td>Power</td>
<td>Same</td>
</tr>
<tr>
<td>Communications</td>
<td>Same</td>
</tr>
<tr>
<td>Shelter</td>
<td>Cheaper</td>
</tr>
<tr>
<td>Quality Assurance</td>
<td>More expensive</td>
</tr>
<tr>
<td>Data Processing Software</td>
<td>More expensive</td>
</tr>
<tr>
<td>Quality Control</td>
<td>More expensive</td>
</tr>
<tr>
<td>Data Interpretation</td>
<td>More challenging</td>
</tr>
</tbody>
</table>
Three Studies Using Air Sensors

1. Ozone Gradient Study

2. Heathrow Airport Sensor Network

3. Kids Making Sense

http://www.epa.gov/research/airscience/docs/roadmap-20130308.pdf
Ozone Gradient Study

Background

• Objective – Examine ozone gradients around new monitoring site
• Sponsored by San Joaquin Valley Unified Air Pollution Control District
• Six weeks, late summer 2013

New site showed ozone concentrations that were about 10% lower than those at the old site. This issue raised concerns in the community, and the U.S. EPA has indicated that the differences may hinder EPA’s ability to determine whether the region has reached attainment.
Air Sensor Usage

Components

• 21 sites (18 sensors; 3 collocated with Federal Equivalent Method [FEM] monitors)

• Sub-hourly ozone data using low-cost, low-power, portable Aeroqual S500 sensors

• Collocation study at beginning and end to calibrate sensors against an FEM monitor

• Quality control and data analysis
Extensive QA Program

Collocated with a Transfer Standard Teledyne API Model T400 UV absorption ozone monitor
• The accuracy of the 1-hr measurements is about 3 ppb
• The precision is ±4% at the 95% confidence level
• Data meet data accuracy requirements for understanding spatial gradients
• New site is representative of old site
• Analysis used by air agency in their Attainment Determination Request to EPA
Lessons Learned

- Sensor systems needed additional integration/testing
- Drift was an issue
- Unknown interferences
- Required substantial QA program
Heathrow Airport Study

Background

• Objectives
  – Evaluate sensor network deployment approaches
  – Calculate emission factors
  – Evaluate dispersion modeling

• One year of monitoring (completed)

• Research in progress

• Funded by the National Environment Research Council and the Engineering and Physical Sciences Research Council
Air Sensor Usage

- 50 sensor nodes
- Measured NO, NO$_2$, CO, CO$_2$, SO$_2$, O$_3$, VOCs, PM
- Transmitted data every 20 sec

Figure source: Popoola et al. (2013) A portable low-cost high-density sensor network for air quality at London Heathrow Airport. Poster presented at the EGU General Assembly, 7-12 April 2013, Vienna, Austria.
Results

Time-Series Plot of Data from One Sensor Node at Heathrow Airport

Figure source: Popoola et al. (2013) A portable low-cost high-density sensor network for air quality at London Heathrow Airport. Poster presented at the EGU General Assembly, 7-12 April 2013, Vienna, Austria.
Results

Pollution rose showing NO concentrations (color scale), wind speed, and wind direction from a sensor node at Heathrow Airport.
Kids Making Sense (KMS) aims to teach youth how to measure particle pollution using air quality sensors and to interpret the data they collect. Pilot workshops in Brooklyn, San Francisco, Washington DC, and Los Angeles.

http://www.sonomatech.com/project.cfm?uprojectid=1203
Kids Making Sense

Background

• Kids Making Sense concept
  – Use sensor measurements to “Make Sense” of air quality
  – Have students “Make Air Sensors”

• Funded by Knight News Foundation and Taiwan EPA (STI and HabitatMap)

• Engage students with their environment
  – Train teachers, engage students to build air quality sensors
  – Deploy sensors, collect data, interpret and share results, identify causes of local air pollution
  – Create civic action to protect public health
Results

AirBeam vs. Reference Instrument  Santa Rosa, CA  January 25-26, 2014

- Red line: AirBeam estimate of PM2.5 (µg/m³)
- Blue line: Reference instrument measurement of PM2.5 (µg/m³)
Results
units = hundreds of particles per cubic foot
Class Field Exercise 4/18/14
Lessons Learned

• All engaged – youth and teachers
• Real-time feedback maintained participants’ attention
• More devices would foster more individual learning
• Components need updating
  – Curriculum and teaching aids
  – Website software
# Future of Air Sensing

<table>
<thead>
<tr>
<th>Metric</th>
<th>Now</th>
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<tbody>
<tr>
<td>Pollutants</td>
<td>Ozone, CO, NO₂, PM</td>
</tr>
<tr>
<td># of devices</td>
<td>1000s</td>
</tr>
<tr>
<td>Users</td>
<td>Researchers, communities</td>
</tr>
<tr>
<td>Companies</td>
<td>Startups, instrument developers</td>
</tr>
<tr>
<td>Quality</td>
<td>Variable</td>
</tr>
<tr>
<td>Price</td>
<td>$300-$2500</td>
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## Future of Air Sensing

<table>
<thead>
<tr>
<th>Metric</th>
<th>Now</th>
<th>2 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollutants</td>
<td>Ozone, CO, NO₂, PM</td>
<td>PM&lt;sub&gt;2.5&lt;/sub&gt;</td>
</tr>
<tr>
<td># of devices</td>
<td>1000s</td>
<td>1 million +</td>
</tr>
<tr>
<td>Users</td>
<td>Researchers, communities</td>
<td>AQ agencies, industry</td>
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<td>Large tech companies</td>
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## Future of Air Sensing

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<th>Metric</th>
<th>Now</th>
<th>2 Years</th>
<th>5 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollutants</td>
<td>Ozone, CO, NO$_2$, PM</td>
<td>PM$_{2.5}$</td>
<td>Benzene, BC, some toxics</td>
</tr>
<tr>
<td># of devices</td>
<td>1000s</td>
<td>1 million +</td>
<td>10 million +</td>
</tr>
<tr>
<td>Users</td>
<td>Researchers, communities</td>
<td>AQ agencies, industry</td>
<td>Cities, individuals</td>
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<tr>
<td>Companies</td>
<td>Startups, instrument developers</td>
<td>Large tech companies</td>
<td>“Phone” manufacturers</td>
</tr>
<tr>
<td>Quality</td>
<td>Variable</td>
<td>Improving</td>
<td>Very good</td>
</tr>
<tr>
<td>Price</td>
<td>$300-$2500</td>
<td>$50-$100</td>
<td>&lt;$50</td>
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