Overview of Emerging Air Sensors

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Overview of the overview

Why is there a demand for new air monitoring methods?

What are these new technologies?

What is the future forecast?
Traditional air monitoring paradigm

Government-provided data, Air Quality Index provided on broad time and spatial scales.

Expensive instruments
Specialized training required
Large physical footprint
Large power draw
However, research shows that air pollution can vary over small spatial increments e.g., Over 45 million people in the United States live within 100 meters of a major transportation system.

Many near-source zones potentially of interest for more finer-grained monitoring
e.g., near-source areas around trucking routes, rail lines, and intermodal facilities

(Brantley et al., in review)
High interest by public for more information

Public demand for more personalized information – what about *my* exposure, *my* neighborhood, *my* child??
Example environments for NGAM application

Near-road assessment:
- Improved data on exposure
- Mitigation assessment
- Urban planning
- Personal health decisions

Industry fence line
- Increase emissions understanding
- Improve worker safety
- Reduced product loss
- Benefit local air quality
- Provide transparency
- Improve public relations
What are some of these new air sensors?

**Particle-phase**

**Ultrafine particles (<0.1 µm)**

*Active detection principle:*
Size (if detected): Classifies particles by size according to motion of charged particle

Count:
Option A: Electrometer-based detection
Option B: Grow particles (condensational growth) and then count by light scattering

Particle distributions in a typical urban aerosol (adopted and modified from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)
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Possible measurement challenges for sensors:
Very small sample volume, dynamic pollutant
Detection limit (lower) with electrometers

Recent EPA grant recipient:
Da-Ren Chen (Virginia Commonwealth University)
“Development of Cost-effective, Compact Electrical Ultrafine Particle (eUFP) Sizers and Wireless eUFP Sensor Network”

Existing methods

Emerging sensor (example): miniaturized particle count sensor

Unipolar min-charger
What are some of these new air sensors?

Particle-phase

Larger particles (>0.1 µm)

Active detection principle:

Size (if detected):
Option A: Create cut point by how particle moves around an obstacle (cyclone, impactor)
Option B: Photodetection – small particles generate small pulses of light, large particles generate larger pulses (optical particle counter)
Option C: Accelerated air flow / inertial separation (Aerodynamic particle sizer)

Mass:
Options:
Mass – beta-attenuation, tapered element oscillating microbalance (TEOM)

Mass estimate – optical particle counter + assumptions, nephelometry + assumptions (main assumption: particles in environment = calibration aerosol)

Particle distributions in a typical urban aerosol (adopted and modified from "Atmospheric Physics and Chemistry", Seinfeld and Pandis, 1998)
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Sensor detection:
- Most emerging particle sensors operate using a light-scattering measurement principle.
- Most do not have a physical size cut (cyclone, impactor)
- Some use a passive means to move air through sensing region; others have a fan

Possible sensor measurement issues:
- Particle detection capability – transport of particles to sensor, sensor sensitivity
- Signal translation to concentration estimate

Example diagram (from: http://www.takingspace.org/make-your-own-aircasting-particle-monitor/)
What are some of these new air sensors?

**Particle-phase**

**Larger particles (>0.1 µm)**

Light scattering detection: what is actually being detected?

*At 550 nm light, strongest scattering signal per unit mass for $D_p \sim 0.2\text{-}2$ µm*

*Increasing scattering signal with diameter, per particle*
What are some of these new air sensors?

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Light scattering detection: what is actually being detected?
What are some of these new air sensors?

Particle-phase

Larger particles (>0.1 μm)

Particle mass detection: e.g., miniature particle mass sensor with virtual impactor and mass-sensing oscillator

What are some of these new air sensors?

**Gas-phase**

e.g., Nitrogen dioxide, ozone, carbon monoxide

"Real-time" detection principle:

**Metal oxide sensors:**

Operates by contact of gas with semiconductor material, free electrons in reaction reduces resistance by increasing the flow of electrons.

Possible sensor measurement issues:

- Interfering gases in mixture
- Measurement artifact due to temperature and humidity
- Eventual failure of sensor

**Figure.** CO reaction with CO metal oxide sensor MiCS-5525 (e2v, 2009)
What are some of these new air sensors?

**Gas-phase**

e.g., Nitrogen dioxide, ozone, carbon monoxide

**“Real-time” detection principle:**

**Electrochemical sensors:**

Operates by oxidation reaction at sensing electrode and then reduction reaction at counter electrode

Possible sensor measurement issues:

- Interfering gases in mixture
- Measurement artifact due to temperature and humidity
- Eventual failure of sensor

**Figure.** Electrochemical sensor (e2v, 2007)
What are some of these new air sensors?

**Gas-phase**

*e.g., VOCs*

“Real-time” detection principle:

**Photoionization sensors:**

Operates by exposing sample gas to ultraviolet light, which ionizes the sample, detector outputs voltage signal corresponding to concentration.

Possible sensor measurement issues:

- Baseline drift
- Eventual failure of sensor based on lamp lifetime.

*Figure. PID sensor (baseline-mocon.com)*
Other developments supporting new sensing technology

Smartphones / Tablets in wide use

Miniaturization of sensors

e.g., fitbit activity tracker

Low cost controls and communications

e.g., Arduino microprocessor

Crowd-funding supporting do-it-yourself (DIY) innovation

e.g., Kickstarter
Other developments supporting new sensing technology
Emerging data-viewing/communication apps

- OzoneMap App!
  - Mobile App
  - OzoneMap - Air Alliance Houston, in collaboration with University of Houston and the American Lung Association have developed a new mobile phone app with real-time ozone data for the Houston area. Check it out here!
  - [airalliancehouston.org](http://airalliancehouston.org)

- AirCasting App
  - [aircasting.org](http://aircasting.org)

- Air Quality Egg
  - [airqualityegg.com](http://airqualityegg.com)

- LondonAir
  - [londonair.org.uk/iphone](http://londonair.org.uk/iphone)
Air sensors in full spectrum of monitoring

Higher cost systems

Traditional air monitoring shelter

Moveable mobile laboratory

Lofted sensor platforms

Vehicle air pollution mapping systems

Wearable sensors

Desirable direction

Lower cost systems

Lower spatial resolution

Desirable direction

Higher spatial resolution

Other factors: sensor reliability, data quality, sampling rate
Next-generation air monitoring R&D has been a rapidly moving area

**FY12**
- ASAP workshop
- Mobile system development and application
- Sensors Evaluation and Collaboration

**FY13**
- Regions workshop
- Short-term sensor field tests (DISCOVER-AQ, AIRS, roadside, wildfire, fenceline)
- Data visualization support: RETIGO
- Designing/building autonomous systems: Village Green Project, S-Pod
- Mobile system development and application

**FY14**
- Air sensors workshop
- Citizen Science Toolkit
- Short-term sensor field tests (DISCOVER-AQ, AIRS, roadside, wildfire, fenceline)
- Sensor network intelligent emissions locator tool (SENTINEL)
- Designing/building autonomous systems: Village Green Project II, S-Pods
- Long-term testing of sensors: Regional Methods Project
- Data visualization support: RETIGO
- Mobile monitoring systems
Next-generation air monitoring R&D has been a rapidly moving area

Recent relevant publications and other resources: http://www.epa.gov/research/airscience/next-generation-air-measuring.htm
## Sensor performance evaluation: lab and field

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Laboratory controlled test</th>
<th>Short-term field test</th>
<th>Long-term field test</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>n/a</td>
<td>Near-road, ambient (2013-2014)</td>
<td>CAIRSENSE (2014-2016)</td>
</tr>
</tbody>
</table>

- Report on laboratory evaluation of ozone and nitrogen dioxide sensors to be released in 2014

*Points of contact: Ron Williams, Russell Long, Gayle Hagler*
Sensor performance evaluation: lab and field

Example: Cairpol sensor for NO$_2$/O$_3$

Point of contact: Ron Williams
Sensor performance evaluation: lab and field

\[ y = 1.0911x + 11.366 \]
\[ R^2 = 0.9913 \]

(counts)

(slides courtesy of Ron Williams)
Air sensor system development to characterize emission plumes

Very small sensors undergoing laboratory testing in advance of field tests of source emissions
Air instruments (PM, ozone), power system and communications components stored securely behind bench

Sensor system development

Points of contact: Gayle Hagler, Ron Williams
Sensor system development

- Solar panel
- 3D Sonic anemometer
- Prototype sensor package (pres. temp. RH. PID VOC)
- Battery backup and data logger, communications
- Drop-in-place Sensor Pod (SPod)
- Inside of battery box

Point of contact: Eben Thoma
Conceptual application

Drop-in-place in SPod ($$) using inverse source algorithms

EPA PID sensor board
(PID from Baseline Mocon Inc.)

Point of contact: Eben Thoma
Sensor system development

Data processing exploration to maximize sensor utility:

Original PID sensor output (in Volts)

Estimation of sensor baseline drift

Recovered signal, allowing local-source influence to be detected
Region 2 / ORD RARE Project – Citizen Science Toolkit and the Ironbound Community Corporation

**Citizen Science Tool Box:**

1. Basic SOP for hand-held sensors
2. One-page, quick-start guide
3. Training materials on sensor use
4. Guidance and deployment based on pollutants and sources
5. Basic ideas for data analysis, interpretation, and communication

http://www.epa.gov/research/airscience/next-generation-air-measuring.htm
Objective: reduce barriers to participating in mobile air monitoring data analysis

Mobile air monitoring data:
- A function of time, location, and pollutant
- Often collected at a high time resolution (large time series)
- Variable format, location, instruments

Mobile air monitoring data analysis and exploration:
- Analysis often limited to those individuals with advanced training and access to specific software tools (e.g., MATLAB, GIS, etc.)

We are building RETIGO to support mobile air monitoring individuals and teams, reducing the technical barriers to visualize the complex data and complement advanced data analysis techniques.
Data visualization support: RETIGO

- Allows exploration of data over time and space
- Supports plotting concentration as a function of distance from a hypothesized line or point source

Point of contact: Gayle Hagler
What else is out there? : Education focus

- Supporting project-based learning and STEM (science, technology, engineering, and mathematics) education

Components
- Low cost particle sensor
- Arduino microprocessor
- Breadboard, LEDs, wires
What else is out there? : Education focus

- Supporting project-based learning and STEM (science, technology, engineering, and mathematics) education

*Hacking a fiber-optic flower centerpiece to change colors with CO₂ levels*

CO₂ NDIR sensor

Fiber optic flower demo
What does this all mean?

**Current Approach**

- **How data are collected?**
  - Limited Mostly to Governments, Industry, and Researchers

- **Who collects the data?**
  - Compliance Monitoring, Enforcement, Trends, Research

- **Why data are collected?**
  - Government Websites, Permit Records, Research Databases

- **How data are accessed?**
  - Sensor Technology

**New Paradigm**

- **Expanded Use by Communities and Individuals**

- **New and Enhanced Applications**

- **Increased Data Availability and Access**
Challenges and opportunities

Opportunities:
• Unprecedented access to data on neighborhood-scale air quality
• Lower cost strategies to achieve air monitoring goals
• Engagement with communities, schools, industry

Challenges:
• Data interpretation and public messaging
• “Big data” analysis
• Support for do-it-yourself/citizen science
Ongoing work at EPA

- Field and laboratory research to characterize performance of new sensors
- Development of tools for managing and visualizing sensor data
- Ongoing dialogue on policy implications and public health messaging
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