EnviroInfo 2013: Environmental Informatics and Renewable Energies
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Harnessing Sensor and Information/Communication Technologies to Revolutionize How Environmental Data are Collected and Integrated to Protect Public Health

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Monitoring the levels of pollutants in ambient air has long been the responsibility of environmental agencies, and traditional programs have relied on a relatively small number of fixed stations that are expensive to install and operate. The spatial coverage of pollutant data ranges from limited in many urban areas to very sparse in smaller suburban and rural areas. Increasingly, the latter are being affected by new pollutant sources such as backyard drilling systems for energy development, and concentrated animal feeding operations and biodiesel production facilities on former agricultural lands. Regional measurement stations are not able to inform local communities about the types and concentrations of pollutants in their ambient and indoor air. Meanwhile, epidemiology studies and clinical data continue to indicate a link between air pollutants and adverse health effects, including respiratory and cardiovascular disease. With asthma on the rise and heart disease among the leading killers, the public has become increasingly concerned about knowing what their personal exposure levels are so they can determine appropriate measures to protect their health.

To address this long-standing need, the U.S. Environmental Protection Agency (EPA) has embarked upon an innovative program to improve the understanding of air pollution at the community and neighborhood scales. This program harnesses striking advances in sensor technology, mobile applications, and environmental informatics, with citizens playing a key role. The goal is to facilitate the development and widespread use of inexpensive mobile sensors, for widespread collection and integration of air quality data by citizens across the nation (and world), to help guide environmental health protection programs.

Although some air quality applications (apps) exist, their usefulness is limited because of the underlying limitation in spatial coverage. Furthermore, the number of pollutants addressed is relatively small. These apps tap data from the standard monitoring stations, which focus on six criteria pollutants for which national ambient (outdoor) air quality standards have been established: carbon monoxide, lead, ozone, particulate matter, nitrogen oxides, and sulfur oxides. However, the public is also interested in many other pollutants, such as ammonia and methane from agricultural operations to acrolein from burn pits and biomass conversion facilities.

In planning this initiative, the EPA Office of Research and Development (ORD) solicited inputs from a number of groups interested in air quality to determine priorities. These include Agency program offices (including children's health) and regions (including those assisting "fenceline communities" near oil and gas facilities), as well as environmental researchers and community groups. To identify promising technologies and priority gaps, the first step of the evaluation process involved pursuing recent research literature for sensors and architectures and pollutants of concern to the public.

More than 1,000 information sources were considered, of which nearly half were tapped to highlight data related to sensor technologies and sensing techniques, architecture and infrastructure approaches, and mobile applications. More than 100 measurands were identified from this evaluation, from which a set of 14 pollutants were selected for initial study. This set includes the six criteria pollutants identified above, five defined as hazardous air pollutants (acetaldehyde, acrolein, benzene, 1,3butadiene, and formaldehyde), and three indicator pollutants (ammonia, hydrogen sulfide, and methane).

The second step involved identifying illustrative concentrations for these 14 study pollutants, to help guide detection targets for mobile sensors. The concentrations compiled spanned a variety of settings and conditions, from urban to

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rural air, and freeway tunnel exits to forest fires to indoor air. They also ranged from discrete measurements to annual ambient averages.

The third step involved identifying health-based benchmark concentrations for the study pollutants. That is, beyond understanding what concentrations of specific pollutants are in air, it is essential to provide the environmental health context – i.e., to indicate what concentrations are considered safe over what exposure durations, and at what concentrations could breathing those pollutants be harmful to varying degrees. In order to provide that context, three types of health-based benchmark were sought: (1) emergency response levels, e.g., those that indicate at what concentrations in air a community should be evacuated to assure their safety; (2) occupational levels, established for adults in the workplace; and (3) ambient concentrations considered safe for continuous exposures over a lifetime, including for sensitive subgroups (such as children and the elderly). These benchmarks served as crucial comparison context for reported sensor detection levels, to determine the type of application for which a given technology or technique may be most suited.

The final step in the evaluation involved comparing reported detection levels for the mobile research sensors with both the health-based benchmarks for each study pollutant and illustrative concentrations in ambient and indoor air. This information was used to identify current gaps and opportunities for developing mobile sensors, for the initial study set.

Findings indicate that spectroscopy, chemistry, and ionization are the three main categories of technologies/techniques for research sensors, and nanotechnology (within the chemistry technique) is a major research theme. In terms of pollutants, of the six criteria pollutants, no inexpensive mobile sensors were found for lead in air, although this chemical is a key public concern for environmental health. A similar gap exists for other particles in terms of affordable mobile sensors. Although research sensors and novel systems that use commercial sensors are available for a number of chemicals, inexpensive mobile sensors are needed for acrolein and 1,3butadiene; benzene also represents an opportunity area for these sensors. In terms of detection limits compared to health-based benchmarks, results of the initial study indicated certain gaps exist, notably to detect lower levels considered safe for lifetime exposures (such as for acrolein).

Architecture/infrastructure insights indicate that portable, hand-held, and vehicle-mounted architectures are relatively common, while wearable sensors are less common. Sensor systems that leverage existing infrastructure components such as fixed and mobile elements of transportation systems offer an opportunity for urban systems. Sensor components are commonly and increasingly integrated with mobile phones (with Bluetooth/wireless networks), and the trend toward increased use of tablets and other devices represents a further opportunity. Additional findings relate to; size and mobility (increasing miniaturization); sensitivity (via nanomaterial coatings, which may themselves ultimately have environmental exposure implications); selectivity (chemical-specific measurements remain an issue, including due to interferences from field conditions such as high relative humidity as well as other pollutants); response time (important for real-time data collection and sharing); power consumption (with novel energy sources, including human).

Environmental informatics is at the heart of this transformative research field. Approaches and algorithms to standardize data processing, quality assurance and control, data scrubbing, transformation, integration, and visualization are among the active opportunity areas for changing the way environmental data are collected, assessed, and used. Cloud computing and visualization tools are making it possible to effectively upload, store, integrate, display, and cross-compare data over time, via tools such as Calibree, Halo, and Quintet. Privacy is a key concern for citizen sensing, and anonymizing techniques continue to be an active research area. User interface design and access to real-time data remain areas for improvement for mobile apps, and do-it-yourselfers illustrate the active landscape for citizen participation in environmental programs. Project plans include leveraging across organizational resources and increasing developer and public awareness of opportunities for citizen sensing, toward the aim of widespread understanding of pollutant exposures that can be used to guide personalized approaches for protecting and promoting environmental health across neighborhoods and communities, nationally to globally.