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Crowd-sourced air quality studies: A review of the literature & portable sensors

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ABSTRACT

Development of low-cost, portable, and low-power devices for monitoring airborne pollutants is a crucial step towards developing improved air quality models and better quantitating the health effects of human and animal exposure. This review article summarizes recent developments in the field within the context of the establishment/expansion of high spatial and temporal resolution air quality monitoring networks. Current 'crowd-sourced' monitoring efforts are summarized, and recent advances in chemical sensors required for these networks are described. No 'perfect' sensing platform, that meets the requirements of low-cost, portability, selectivity, and sensitivity has yet been achieved. This highlights the need for investment in the fundamental analytical chemistry of the sensing platforms required to achieve such 'smart-cities.' Such investment should include the development of new sensor technologies, and provide for calibration and performance validation for systems enacted. In addition to summarizing the current state-of-the-art, reflections on future needs are also offered.

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1. Introduction

Recent advances in electronics and telecommunications is nothing short of remarkable! Modern smartphones possess more computing capability than the supercomputers of the previous generation, all within the palm of our hands. These devices offer previously unparalleled capability to wirelessly transmit and receive data at rates exceeding 10 Mb/s. When sensors are integrated into smartphones (or used with them as a peripheral), mobile measurements may be made that can begin to truly transform human behaviors, or our understanding of Earth's environment.

One very successful (and familiar) application of smartphone sensors is Google Traffic [1]. This application works by routinely analyzing GPS location data sent from smart phone users to estimate delays on surface roads. Smartphone sensors have also been used to track end-users driving patterns by insurers, monitor noise pollution within the environment, or monitor sunlight intensity [2–6]. In short, combining reliable sensors with the computation and communication capabilities of smartphones creates an opportunity to monitor the end-users environment with previously unparalleled spatial and temporal resolution. Such real-time data is invaluable for making informed policy decisions.

For the case of air pollution (broadly defined), data of high spatial and temporal resolution is required to improve models of air quality and estimates of individual exposure to potentially harmful atmospheric gases and particulate matter (PM). Atmospheric gases and particulate matter is constantly chemically reacting and evolving in the atmosphere [7–10]. If hundreds or thousands of sensors were dispersed through an urban environment and provided data simultaneously, the information could be used to build improved models of pollutant release, formation, transport, and deposition within the urban environment. Such inventories of pollutants could be constructed with spatial resolution of city blocks, rather than grids of tens of kilometers that are currently considered in air quality models.

In addition, the combination of smart devices with sensors will allow improved estimates of personal exposure to pollutants. In turn, this will revolutionize epidemiological studies that relate pollutant exposure to human health. Currently, regional monitoring sites are often used to estimate an individuals' exposure to pollutants such as ozone, NO_x, or particulate matter. In many cases, use of data from regional monitoring sites may not accurately reflect an individual's true exposure. Smart sensing platforms can revolutionize our understanding of how exposure to atmospheric pollutants affects human health.

A final important advantage to a network of dispersed smart sensors is comparison with satellite remote sensing data. Often, the algorithms used for extraction of measurements such as aerosol optical depth, ozone, or NO_x concentration must empirically be tested against high quality datasets. The data set provided by a network of surface sensors will improve society's ability to remotely sense pollutants, and consequently allow better understanding of the atmospheric transport and the climate effects of such pollutants [11–14].

This manuscript begins by briefly summarizing current crowd-sourced sensing efforts related to air quality. This serves to establish the baseline of current approaches. Next, the current state of the analytical chemistry is considered and recent advances in sensor technology germane to atmospheric chemistry are discussed. A discussion of recent advances in liquid–phase sensors has been excluded [15–17] because it was felt that the consumable supplies they require are not compatible with crowd-sourced sensing efforts. Finally, the current state-of-the art is reflected upon, and suggestions are offered for future work.

2. Requirements for crowd-sourced sensing efforts related to air quality and a review of current projects

Massively parallel (crowd-sourced) monitoring efforts related to air quality have gained considerable popularity globally and have been the subject of numerous reports in popular media [18–20]. This analysis uncovered no fewer than 13 current efforts occurring in parallel. Some of these efforts are also discussed within Yi et al. [21]. Despite the significant number of programs, the general architecture of the monitoring efforts is largely conserved between efforts. Fig. 1 outlines the general approach. Sensor data is acquired and sent via Bluetooth or wired connection to a smartphone or portable tablet. The sensor data is then combined with a time-stamp and GPS coordinates, and this data is sent via a wireless connection to a centralized server where all data is compiled and stored. An end-user may acquire the data through download and data processing at a later time, or alternatively, the data stream can be returned to the user via wireless connection to provide near real-time updates of the current environment by overlaying the data on maps or by providing graphs/charts of the user's experience. The power of the approach lies in the very rapid processing and communication steps that provide the end-user with data and allow he/she to make informed decisions.

For any crowd-sourced effort to succeed, the key design criterion is that the end-user is provided with value-added information at little to no cost to the participant. It is the opinion of this author that evaluating current air quality is likely of passing interest to most smart-device users. Therefore, to make crowd-sourced sensing viable, data must be collected automatically, with no user interventions, and no perceived cost to the end user. Clearly, no current approach can achieve these requirements on a large scale. Consequently, the long-term prospects for crowd-sourced environmental sensing ultimately lies in the hands of regulating bodies and/or the benevolence of smart-phone manufacturers.

In the following section, current crowd-sourced efforts that have been identified are summarized. It is entirely possible that other efforts exist and have been overlooked unintentionally. The identified efforts are categorized based upon whether the project is rooted in being an academic pursuit or a commercial enterprise.

Academic Efforts

1. **HAZEWATCH** (http://www.hazewatch.unsw.edu.au). The Haze Watch project originates from a team of electrical engineering students, research scientists, and faculty at the University of New South Wales in Australia [22,23]. The project team builds mobile air pollution sensors that are attached to motor vehicles and used to collect air quality data in and near Sydney. Measurements include carbon monoxide, ozone, sulfur dioxide, and nitrogen dioxide. Sensor measurements are sent via a Bluetooth connection to an iPhone within the vehicle, and both a time stamp and GPS coordinates are collected. All data is then sent to a server via a WiFi or 4 G connection. Reported data is then used to create pollution maps within Google Maps for fast and easy interpretation of pollution readings.
2. **CamMobSens and MESSAGE** (http://www.escience.cam.ac.uk/mobiledata/ and http://www.commsp.ee.ic.ac.uk/~wiser/message/). The Mobile Environmental Sensing System Across Grid Environments project was a £3.5 million, 3 year project lead by Imperial College, London. The project included collaborative researchers at Universities of Cambridge, Leeds, Newcastle, and Southampton and began in 2006 to harness the potential of diverse, low cost and ubiquitous environmental sensors to provide data to address key scientific challenges related to environmental pollution. The project originally aimed to use 'smart-dust' sensors coupled with smartphones and WiFi connections to collect air quality data. Subsequently,