VAISALA

Compact air quality sensors and their use in local air quality management

Part 2: Applications

Technical Paper

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Compact air quality sensors in air quality management

Despite the fact that for example European legislation recognizes the role of "indicative measurements" as part of air quality assessment in certain areas, the role of compact air quality sensors in regulatory air quality assessment and reporting remains somewhat vague. However, their easy deployment and, for many applications, adequate measurement performance make them extremely useful and versatile tools for proactive local air quality management.

The field performance of state-of-the-art compact air quality sensors can be summarized in the following characteristics that also indicate practical use cases for supporting local air quality management.

1. The sensors are sensitive enough to detect the presence of pollutants even in clean ambient air. This gives confidence in their ability to determine transitions from clean air to moderately to heavily polluted conditions.
2. The sensors are stable over a period of several months to a year, which means that they can be used to determine diurnal, weekly or monthly pollution patterns in the location where they are installed. Note that to reach this, the methods and algorithms used to compensate the effects of environmental parameters like temperature and humidity need to be state-of-the-art so the seasonal or daily variations of the environment are not reflected on the variations in pollutant concentrations.
3. The sensors are mutually reproducible to a level where a comparison between readings from sensors at different locations can be made in a meaningful way and the locations can be compared with each other based on their pollution characteristics.

The World Meteorological Organization has issued publications (1,11) with a useful generic framework for describing the state of air sensor technology and their applications. A notion from this report is that the properties of compact air quality sensors are not yet on a level where they could be used for monitoring long-term absolute trends in pollutant levels. The report also points out that there is only limited evidence that compact air quality sensors could be used for determining compliance with air quality standards and regulations such as annual concentration averages.

Supplementary air quality networks

Compact air quality sensors are ideal components for establishing wide-area air quality monitoring networks such as urban regions. The basic purpose of these networks is not to replace sparse reference analyzer networks, but to complement them by providing spatially denser data and extending air quality monitoring to areas where reference monitoring hasn't previously been feasible due to physical (size, infrastructure) or

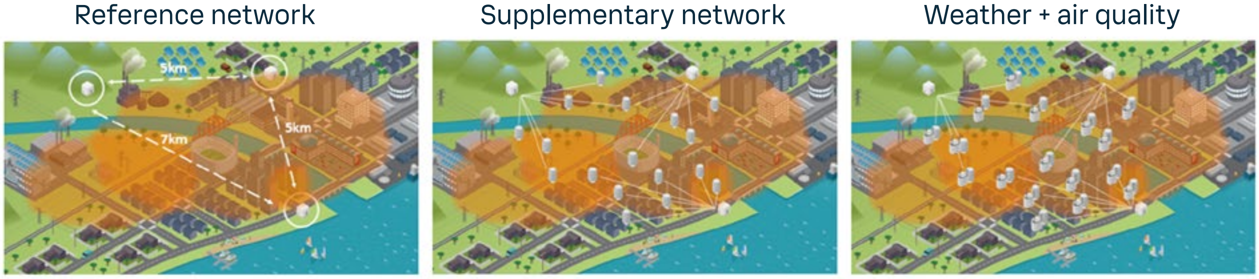


Figure 1: Supplementary monitoring network concept

financial reasons. Complementing the network with compact weather stations giving information on meteorological conditions like wind speed and direction and precipitation will provide a full picture of the quality and movements of urban air.

Figure 1 (previous page) illustrates the supplementary air quality network concept.

Since compact sensors can easily be deployed in different types of locations of interest, their use cases in urban environments can vary widely. By carefully considering the different potential use cases in the target area when designing the sensor locations, a supplementary air quality network can become a multipurpose asset. Following are several brief use cases.

Traffic management

Traffic is the dominant source of urban-area pollutants, the main emissions being nitrogen dioxide and fine particles in vehicle exhausts. In busy intersections and other congested areas, dense populations may be exposed to bad air quality. With in-situ air quality data from key locations, city management can not only evaluate the severity of the situation in real time but also use the data as input for dynamic traffic management and to reduce congestion in heavily affected areas.

Low-Emission and Ultra-Low Emission Zones are urban areas where high-emission vehicles are forbidden or subject to a fee. Compact air quality sensors can be used to verify the effectiveness of establishing the zones by comparing readings before and after the zones have been established, and from inside and outside the zones. Sensor network data can also suggest areas where the zones should be established next.

Combining air quality sensors with cameras used for traffic monitoring and enforcement is economic and efficient, and optimizes placement in locations relevant for traffic emissions.

Street dust management

In wintry areas, street dust from studded winter tires and road sand is a major seasonal air quality issue especially in the springtime. The mineral dust from these two sources is typically seen in the coarse fraction of PM_{10} readings and can efficiently be detected with optical particle sensors.

By placing sensors in carefully chosen locations, city authorities obtain real-time information for initiating and targeting dust control actions such as cleaning or wetting the streets.

Hot spot detection

A conventional air quality analyzer network is typically very sparse and gives almost no spatial information of the air quality situation. Rather, it informs the air quality in single specific locations and in other locations resembling those of the analyzer sites. A complementary dense network of air quality sensors makes it possible to uncover additional city pollution sources. Feeding the network data into an air quality dispersion modelling tool, taking meteorological conditions into account, will further improve analysis accuracy.

Traffic monitoring camera integrates air quality sensor

A London borough has had a significant number of commercial vehicles using residential streets. The traffic causes excessive noise, vibration and air pollution and degrades the quality of life for residents.

A solution provided by Traffic Environment Systems Ltd integrates camera, video analytics and environmental sensing to not only catch the offenders using Automatic Number Plate Recognition (ANPR) technology, but also provide environmental data to monitor the effectiveness of control measures.

ANPR camera and an air quality sensor combined

Near source monitoring

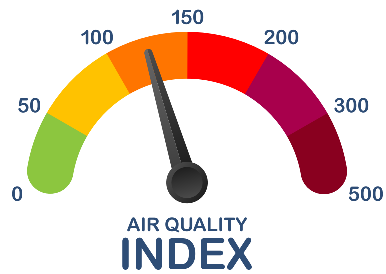
In the vicinity of known pollution sources within the city (e.g., urban industrial estates, bus depots, ports) compact air quality sensors can be used to monitor and understand daily, weekly or monthly pollution patterns and plan emissions mitigation efficiently. Thanks to their easy deployment, the sensors can also be used to conduct measurement campaigns and monitor temporary activities like construction sites. Even more, the data can be used for citizen communication and public outreach and to evaluate the effectiveness of different pollution control strategies.

In many cases, compact sensors measure multiple pollution components in one package such as several different gases and particulates. This adds to their versatility as tools for monitoring a variety of sources.

Community monitoring

With increased awareness of the adverse health effects of air pollution, demand for more localized and relevant air quality data is also growing. By installing compact air quality sensors to locations of concern like schools, daycare centers or playgrounds, authorities can provide citizens with information supporting peace of mind and take rapid action if needed.

However, when communicating air quality data to the public, great care must be taken to analyze, process and present the data in a form that is accurate while minimizing the risk for unnecessary public alarm. For this purpose, the concept of an Air Quality Index AQI (2) illustrating the overall air quality as an aggregate of different gas and particulate concentrations is an excellent tool.



The formulas for calculating the air quality indices vary by country, and local environmental authorities should be consulted in how the AQI should be calculated and communicated to the public.

Health

For patients with lung diseases like asthma or chronic obstructive pulmonary disease (COPD), detailed air quality data with high spatial granularity can help in improving their quality of life. Several scientific studies have shown the significant correlation between $PM_{2.5}$ particle concentrations and asthma or COPD emergency room visits (3, 4). By obtaining targeted information and guidance on air quality, the patients can avoid exposure to polluted air and fine-tune their medication according to current conditions.

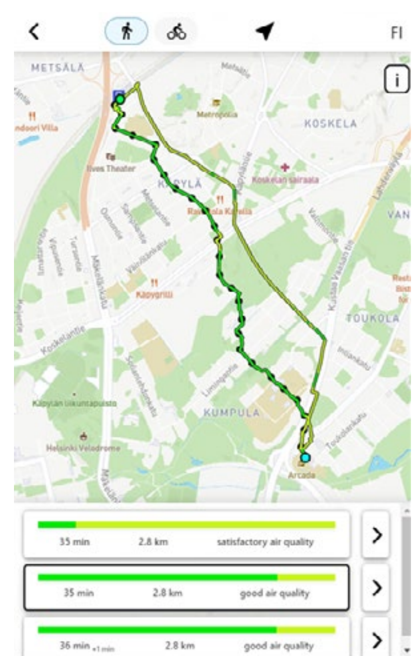
This is not only a benefit for patients, but also diminishes the economic burden for the healthcare system. Based on air quality data from a dense network of sensors, particularly from a high-resolution air quality model which will be discussed later, a service providing this type of information to sensitive groups can be established.

The use of highly localized air quality data for improving public health is not limited to patients with lung problems; any health-conscious citizen can use it for everyday decision making. Examples include choosing the time and place for physical activity to minimize exposure to harmful pollutants (5, 6).

When fused with demographic data or big data from people movement, real-time data from a dense network of air quality sensors can provide new insights into exposure, epidemiological studies and public health assessment (7).

Modelling support

High-resolution air quality modelling is an emerging tool for environmental authorities for understanding, managing and communicating local air quality. With state-of-the-art models, air quality can be modelled at a city block level. The data from such models is available continuously



An example of a clean air route finder utilizing data from a high resolution air quality model. Image Credit: HOPE project/ University of Helsinki.

for example throughout urban areas, and can be used as a basis to provide a wide variety of public services and applications such as clean air route finders or health apps for individuals. By making high-resolution air quality model data available on an open interface, municipalities can open possibilities for local entrepreneurs and businesses for creating innovative new services.

The performance and reliability of high-resolution models depends critically on the quality and granularity of the data that is used as input. Highly accurate reference analyzer stations will provide an accurate baseline for modelling, but a dense grid of in-situ medium accuracy data points will improve the quality of the modelled data (8).

Other uses

The special characteristics of compact sensors suggest even further uses for the sensor data in understanding and managing local air quality. Studying the network data as an ensemble will provide information on potential long-range transport events. For studying pollution phenomena in small scale microenvironments like street canyons, the small size of the sensors makes it possible to collect in-situ data from a dense grid of points in the area of interest in a manner that could not be accomplished with conventional analyzers. Using compact sensors as a time-resolved alternative for passive samplers may also be possible.

In all the cases described above it should be emphasized that proper data analysis, taking into account the properties of the sensors used, is of primary importance.

Smart cities

Environment and sustainability are key themes when the benefits of integrated smart city data platforms are discussed. In these systems, environmental data is collected from a variety of sensors and sources to a central IT platform where the data can be stored, combined with other types of data, displayed on a smart city dashboard and also made available to other IT systems. Figure 3 shows a schematic of such an environmental data platform.

A supplementary air quality sensor network is a typical example of an environmental monitoring component in a smart city platform. Use cases for the sensor data are essentially the same as described in the previous chapter, but the smart city data platform will provide centralized data access for different users, applications and city functions. The platform will also provide a means to deliver for example visualizations or alerts to city residents.

An important part of smart city projects is often smart

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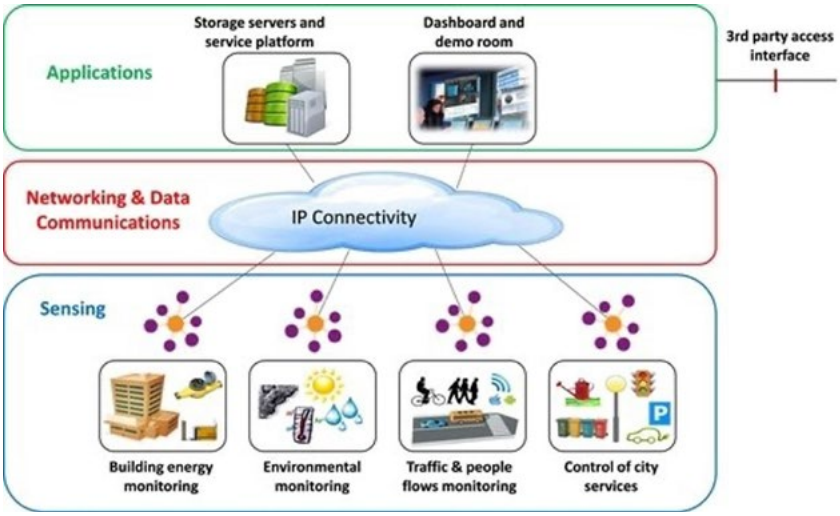


Figure 3: Schematic of a smart city environmental data platform
Source: Sensors 2017, 17(12), 2856; https://doi.org/10.3390/s17122856

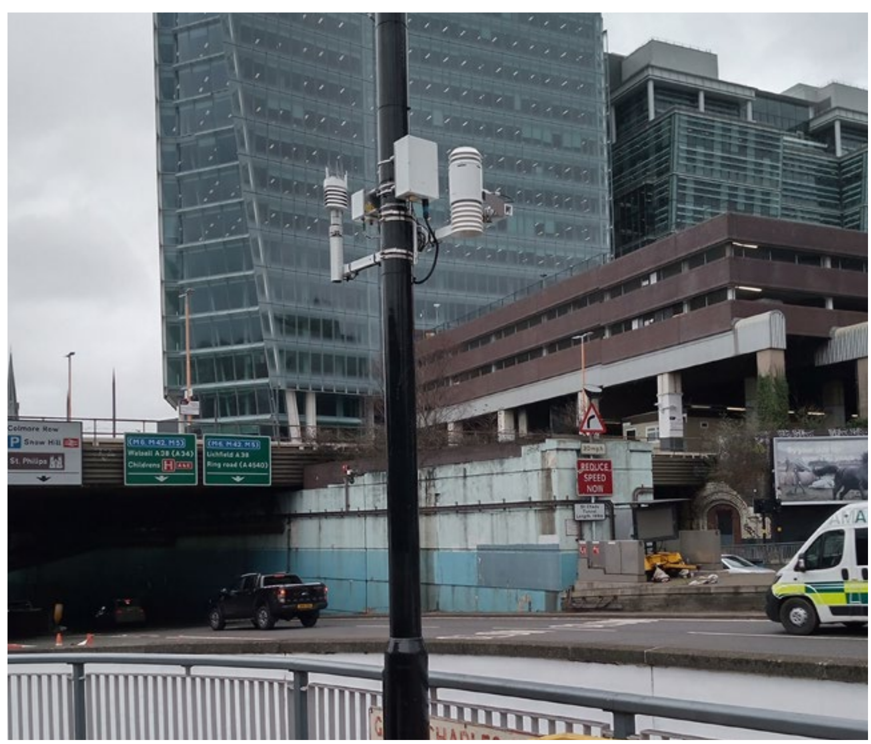
infrastructure, where traditionally passive parts of the infrastructure are turned into connected elements with multiple functions. An example of this is smart lighting, where light poles are turned into smart poles with wireless and potentially 5G connectivity, built-in intelligence and a range of sensors for providing in-situ data from their surroundings. For deploying compact air quality sensors, smart poles are an ideal platform as they can provide the power and communications for the sensors as well as a physical location well suited for ambient air quality measurements. Other elements of urban infrastructure appropriate for air quality sensors are bus stops and electric vehicle charging stations.

Developing countries

The adverse effects of poor air quality are the most extreme in developing countries. Especially in heavily polluted megacities, millions of people are exposed every day to dangerous levels of noxious pollutants. Yet the severity of the problem is often unknown as the areas in question may have no basic infrastructure for air quality monitoring.

Conventional reference air quality analyzer stations provide very accurate readings but are prohibitively expensive and high-maintenance. These may not be the optimal first step to start monitoring air quality, even though a reference analyzer will eventually be needed to establish the baseline for benchmarking compact sensors. In addition to providing a first glance at the overall pollutant levels in a region, a network of compact sensors will provide important indication on the preferred location for commencing reference monitoring.

The use of compact air quality sensors in developing countries has been studied in a number of research projects (9, 10).



A new paradigm for managing and communicating air quality

The technologies and solutions described in this document suggest a whole new paradigm for managing and communicating urban air quality. In this paradigm, the conventional analyzer-based network is on one hand complemented by a densely gridded compact sensor network, and on the other hand by very few supersites with a comprehensive suite of advanced atmospheric analyzers. All observation data flows into a high-resolution air quality model that provides a real-time, hyperlocal air quality indicator and forecast.

As described in previous chapters, this type of infrastructure can provide data and insights that serve a number of key activities in a modern city and address several of the megatrends shaping the world today.

Different components in the proposed new air quality management infrastructure are briefly described here.

Compact sensor network

- Compact sensors measuring criteria pollutants and/or weather
- ~20-100 sensors per city
- Sensors placed in hot spots and places of interest, and to provide area coverage

Reference analyzer network

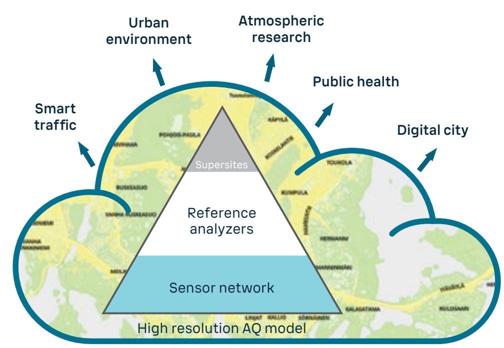
- Criteria pollutant analyzers (EPA/EU certified)
- ~2-20 per city
- Data used as baseline reference for compact sensors
- Data represents site type, not area coverage

Supersites

- Criteria pollutant analyzers + advanced analyzers for atmospheric composition
- 1-3 per city
- Data supports source apportionment and understanding atmospheric chemistry and processes

High-resolution air quality model

- Ingests data from atmospheric (weather) models and known pollution sources to create the current and forecasted view of air quality
- Utilizes measurement data from in-situ sensors and analyzers
- Also fuses GIS and other relevant data for land use, traffic etc.



A hierarchical air quality monitoring infrastructure complemented by a high resolution air quality model

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