OxAria
Policy Briefing Note No.1

Air quality sensing technology: opportunities and challenges for local applications

Overview

- The air quality sensor landscape is rapidly evolving in the UK.
- Air quality sensors provide an affordable and flexible option for informing local air quality management and undertaking citizen engagement.
- The practical and logistical barriers to sensor deployment have reduced due to technological advances.
- Challenges remain for production of accurate and reliable air quality sensor data; notably beyond research settings.
- Local authorities can work in partnership with universities to overcome these challenges.

Until recently most UK real-time air quality measurements were made by established reference methods, involving expensive monitoring equipment which meets international standards for data quality. In the last decade there has been rapid expansion in 'low-cost' air quality sensor technologies which have the potential to be easily and readily deployed to measure gas or particle concentrations.

These devices are available at lower cost than reference instruments (typically >£15,000). Entry level equipment is available for £10-£100s making them accessible for citizen science. Higher end devices at up to ~£5,000 are an increasingly popular option for local authorities, researchers, and practitioners.

Opportunities

Air quality sensors offer clear potential for enhancing air quality assessment and supplementing regulatory monitoring. Key opportunities include:

- Increased **agility and flexibility**, with utility for capturing air quality impacts of interventions, activities, and events.
- **High temporal resolution** data capture to characterise short-term air quality changes (e.g., over minutes or hours).
- Utility to deploy across **monitoring networks**, providing high density coverage, and generating data suitable for modelling purposes.
- **Lower capital costs** in comparison to regulatory monitoring equipment. Operating costs can be variable.
- **Novel research opportunities** including mobile air quality monitoring and citizen engagement activities.

Challenges

Despite their great potential, air quality sensors continue to present challenges which limit operational capability and widespread uptake:

Key barriers include:

- Logistical considerations for sensor operation and deployment.
- Sensor calibration difficulties, both pre- and post-field deployment.
- Variability and instability in response to real-world influences on operating conditions.
- Complex technical challenges for data processing, analysis and interpretation.
- Data signals which are subject to interference, artefacts, and uncertainty.
- Multiple supplier options with no type approval for quality or suitability.
- Limited access to standard technical guidance on field performance.

This briefing includes recommendations for overcoming these challenges, thereby harnessing the potential of air quality sensors.

Practical Recommendations

Air quality sensor deployment requires good advance planning, including a suitable monitoring protocol. This should include considerations for long-term sampling strategy, sensor calibration, maintenance, data processing and storage. These components are important for generating reliable, accurate and informative data for local air quality applications.

Administrative considerations: Sensors can be readily deployed in diverse locations – such as on buildings, highway infrastructure or vehicles. Negotiating installation permissions is a vital process and may involve multiple public authorities or private landowners. Committing administrative resources to securing relevant permissions is essential to optimise site selection, to facilitate maintenance, validate insurance/indemnity and avoid future access or operational difficulties.

Physical environment: Air quality sensors are highly susceptible to changes in air temperature and humidity.[1] Minimising environmental changes to which a sensor is exposed will improve data quality. Standardising physical conditions across a sensor network (e.g., all sensors in full shade) will also improve performance and data quality.

Power and communications: Sensors may be solar, or battery powered or require a mains (240 V) power supply. Devices which use mains power include a standard 3-pin plug which is best connected to a suitably approved, weatherproof outdoor socket.

Sensor data will typically be stored on a SD memory card and ideally should be transferred by 4G or Wi-Fi technology to a hosted environment on the internet. In the latter situation it is important to check for a good 4G signal before installation. If Wi-Fi is used it is important to be aware of password resets, scheduled restarts and outages which could lead to data gaps.

If sensor data are collected directly to Smartphone devices via Bluetooth™ technology, it is recommended that download procedures are tested in advance of field deployment. In locations with high Bluetooth™ usage or radio interference (e.g., close to busy roads, construction sites, shopping centres) the download success rate can be improved by placing both sensor and Smartphone in a secure metal box for the download duration.

Sample handling procedures: All sample handling procedures should be documented in the study sampling protocol, which should be reviewed on a regular basis. At a minimum this will include agreed guidance on how all sensors are deployed and used (e.g., height, orientation, and management plans for wind exposure and vibration during motion).

Data Quality Recommendations

Sensor calibration: Keep a record of the manufacturer's sensor calibration at purchase. Verify this calibration before a sensor is deployed in the field, and periodically thereafter, by co-location alongside reference equipment (or other sensors) to identify its performance relative to the reference or sensor mean. Scatter plots (e.g., sensor data vs reference data) can be used for assessing sensor calibration. There are also statistical approaches which may be used for standardising network wide sensor baseline offsets [2] and which may be tailored to a specific application or context.

Data outlier handling: Sensor data typically include multiple outliers (data points which differ significantly from others usually because of measurement/experimental error or artefact) due to measurement or interference errors. Simple boxplots are a suitable approach for identifying these data points and suitable filtering thresholds to improve data quality.

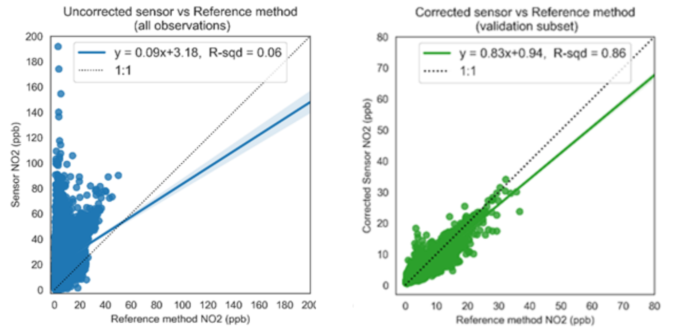
Data storage: Sensors typically generate at least ~3 times the data volume of traditional measurement techniques due to the short logging intervals (e.g., 10-second or 1-minute intervals). Data arising from smaller studies (e.g., ≤6-months) may be stored using CSV files or an Excel spreadsheet. Data arising from larger sensor networks or studies of longer duration will require appropriate storage capacity.

Data processing and visualisation: For small-scale studies it is possible to undertake data processing and visualisation tasks using spreadsheet tools. For larger studies a code-based framework such as 'R' or Python or proprietary equivalents may be used, supported by a wide range of open access code examples and libraries. It is good practice to deposit code for future public use.

Data correction methods: Sensors are commonly sensitive to fluctuations in temperature, relative humidity, and gaseous pollutants. The strength and direction of these interferences is dependent upon multiple influences.

Correction for these influences may be achieved using a range of statistical techniques, such as multivariate linear regression, Principal Components Analysis or Artificial Neural Network approaches.[3] A combination of methods may be required to achieve an acceptable data quality standard.

The combination of multivariate linear regression and machine learning methods has recently been demonstrated to be an effective correction method [2] as shown below. These scatter plots show the relationship between reference and sensor observations for Nitrogen Dioxide (NO_2): (1) before (blue dots) and (2) after correction (green dots). Application of this method has resolved 90% of the uncertainty in the sensor data.



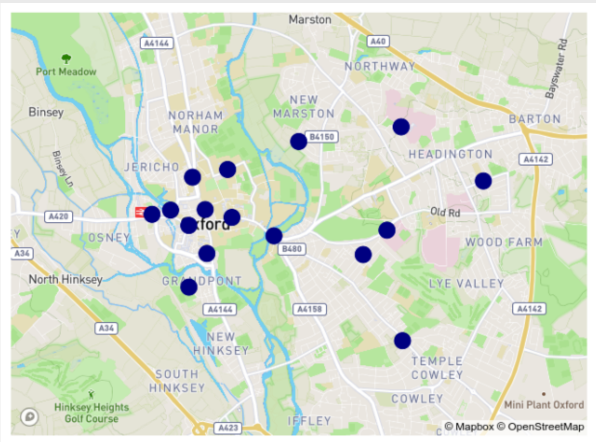
Sensor accreditation: The MCERTS scheme provides Defra accreditation for (particulate) sensor use in the UK.[4] Sensors which have

MCERTS accreditation are likely to offer better quality outputs, however, good data quality assurance and control is still required.

Case Study: The OxAria sensor network in Oxford City

OxAria is a Natural Environmental Research Council funded collaboration between the University of Birmingham and University of Oxford in partnership with Oxfordshire County Council, applying advanced technological and environmental health expertise to understanding air and noise quality impacts of the COVID-19 pandemic.

The study has established a cross-city network of sensors [South Coast Science, Praxis units) in Oxford City, which continuously transmit air quality measurements at 10-second intervals across a cloud-based data network. The 16-sensor network, introduced and rolled out from January 2020, is being used to identify hyperlocal changes in air quality associated with COVID-19 lockdown measures and local transport interventions.



OxAria sensor network in Oxford City
(map shows 16 blue dots denoting sensor locations)

Sensors were calibrated using a novel regression method and interferences across the network were corrected with a machine learning regression method.[2]

Sensor and reference method air quality data were initially integrated with traffic data to explore lockdown impacts.

Traffic reduced by 70% in Oxford city centre during the first national lockdown. This was associated with a reduction in NO_2 concentrations of 38% at roadside, but no change in average $PM_{2.5}$, PM_{10} or O_3 concentrations.[5] Travel patterns also changed, with morning and evening traffic levels and pollutant concentrations peaks of lower magnitude and longer duration compared to pre-pandemic levels.[6]

Sensor data has indicated that daily peaks in PM_{10} & $PM_{2.5}$ concentrations during lockdown periods were on average 9-10 µg/m^3 below levels observed in recent years. Changes in daily mean PM_{10}- and $PM_{2.5}$ concentrations were less pronounced; ~1 µg/m^3 below typical levels. [7] These findings suggest that major traffic reductions had only a marginal influence upon PM concentrations, and that exposure will vary by time of day and site location.

The OxAria study highlights a major role for sensor technology in providing high spatio-temporal resolution data at a hyperlocal level to inform local air quality policy.

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