THE CHALLENGES AND BENEFITS OF USING SMALL SENSOR TECHNOLOGY FOR LOCAL AIR QUALITY MONITORING

In 2017 we wrote an article about the challenges and benefits of local air quality monitoring and it continues to be our most regularly read item on our website. However the 'small sensor' air quality monitoring world has moved on during the last three years and we have identified several new challenges and benefits relating to the continual development of air quality monitoring technology.

It's not all about compliance

The interest in small sensor air quality systems initially related to how they can complement established government reference networks. Whilst it may be tempting to see cheaper small sensor systems as a solution when budgets are tight for maintaining - let alone increasing - reference networks, small sensor technology is not appropriate for compliance use and the real opportunity is recognised as targeted air quality measurement and action.

Small air quality sensors – and the added value systems in which they are supplied - offer varying levels of precision and accuracy, generally defined by correlation and a measure of error when compared against an immediately adjacent, well-maintained reference station. Various air quality authorities are currently developing testing protocols aiming to discriminate between 'near reference' performance and those readings which can only be used as a broad indicator (or not at all) but most small sensors can offer some useful information about differences in air quality over time and/or space, if used carefully. Much air quality management now focuses on targeting and quantifying the effect of action: air pollution mitigation measures. Small sensor systems are ideal for this application when deployed correctly and data is fully understood.

Networks of AQMesh small sensor air quality monitoring pods have been deployed in numerous smart city initiatives across the globe

Traceability, QA/QC and terminology

Air quality professionals and many of the stakeholders involved in the use of small sensors for measuring air quality quite rightly focus on data quality and traceability. Small sensor systems cannot currently follow existing testing protocols, which have been developed for compliance monitoring and focus on particular measurement techniques. Therefore there is a great deal of ongoing discussion about testing methodologies and standards. It is generally accepted that small sensor systems need some form of correction, at least for environmental conditions and cross-gas effects, and that sensor system manufacturers may choose not to share their proprietary correction algorithms. Data quality, traceability and the limitations of small sensors are increasingly being balanced against the value of increasing the number of monitoring points. With traceability back to a reference method, such as through co-location, air quality data from small sensor air quality systems is of enormous value across a wide range of applications.

In our first article the debate was between 'raw' and 'processed' data. Now the focus has generally moved to different forms of processed data. A leading group has recently called for unification of terminology, distinguishing particularly between air quality readings which are estimates derived directly from the measurement principles used and readings which include additional inputs: a step away from "true measurements". They also highlight the need to address traceability: some sensor systems offer repeatable measurements where a given sensor output, through a sequence of fixed processing calculations, will always give the same reading. This may not be the case with readings derived by artificial intelligence or machine learning datasets.

Even when it is understood how a sensor system produces readings and repeatability / traceability needs are satisfied, it is important that appropriate quality management processes are applied by the user. Sensor systems may offer a form of quality control through management of a monitoring project. One example is the AQMesh rebasing process, whereby the output of stabilised sensors is standardised to improve accuracy without any input from local reference or other measurements. Air quality professionals now generally accept that it is beneficial to co-locate small sensor units next to a maintained reference station in order to allow for local correction using scaling and, more importantly, validation of data. This periodic local "calibration" works on the basis that scaling will hold true whilst units are moved around locally during a monitoring project and this can be proven by co-location at the end of the project or after a defined period for continuous or longer monitoring. This sort of periodic comparison can also be used to confirm that the sensors are not showing any change in response over time.

The use of external data, such as from a reference station, either co-located (small sensor and reference inlet within about 1m of each other) or 'nearby' (could be several miles/Km) is a developing area, where modelling and measurement meet. Whilst interesting new approaches are emerging, such as within the hyperlocal Breathe London network, there is a danger that basic AI approaches can lose traceability and gain little in the way of accurate local air quality measurements.

Implementation of a local air quality network

It therefore follows that anyone intending to set up a local air quality monitoring network will need to consider traceability and local scaling of sensors and/or the whole network. The 'gold pod' approach originally described by the AQMesh team, whereby one unit is co-located with and scaled against a maintained reference station and then moved around a network of nodes to calibrate each of the other units, has now been widely adopted and offers an effective way to improve accuracy and achieve traceability. It does require a local team to move pods around but approaches which attempt to shortcut this are still in development and, as yet, unproven.

The best small sensor systems are small, light and easy to install and move around, even allowing for the challenges of working on the pavements of busy city centres and using a ladder to mount units at a height on a post which is relevant to human breathing and minimises the risk of damage to the unit (usually about 2.5m above street level). An autonomous power supply is also a bonus – usually by battery or solar power – as connecting to an AC supply can be problematic. Converted power supplies from lamp posts, generators and cheap DC transformers can provide a very noisy supply, which can mask or distort the sensor signal.

The sensors – particularly electrochemical gas sensors – can only offer single figure ppb sensitivity by working at the limits of the sensors, with electronic noise reduced to a minimum. Simply plugging such a sensitive piece of equipment into a crude AC/DC transformer can cause reading artefacts, such as over-estimation of pollutant concentration. Whilst many small sensor systems appear simple enough to be 'plug and play', the best small sensor systems are sophisticated scientific instruments and users who are prepared to handle them carefully will be rewarded with better data quality.

The Breathe London project uses 100 AQMesh pods as part of its ground-breaking hyperlocal air quality monitoring network

How to provide air quality information across a whole city

We are often asked 'how many units do I need to measure across this city?' Of course this is a very difficult question to answer and depends largely on the project objectives. As the ability to measure air quality with a high level of spatial resolution is relatively new, the degree to which pollutant levels vary across short distances is often not fully appreciated. Pollutants which relate to a direct source, and may be short-lived in the atmosphere, are particularly poorly mixed, such as NO. More 'background' pollutants, such as O3, may be more homogeneous and levels more consistent across a city, but will still vary day by day. Studies show that pollutant levels can vary significantly – by factors of two or more – just across a street, particularly under the influence of street canyon effects.

In practise the number of units necessary to create a network is generally budget-dependent and monitoring sites selected by need or profile, such as being near vulnerable communities, high footfall areas or near expected pollution sources. Good network management and integration of modelling can be effective in 'filling the gaps' or deriving the highest possible local value from a given number of measurement points. Innovative data analysis and presentation can also help to generate more value from small sensor systems. For example, measurement of CO2 as an indicator of local combustion allows indices to be calculated, or regional source. This obviously has a huge implication for local air quality management policy. The academic work illustrating the potential to understand and manage city-wide air quality meets the technology-driven Internet of Things (IoT) in smart city initiatives.

AQMesh air quality monitoring systems have been designed to monitor exactly where monitoring is required

Smart city integration

Aspiring smart cities vary in their ambition and coverage but they generally aim to integrate data from a range of local sensors, to provide information to stakeholders, including the general public. Securing some data channels may be relatively straightforward (such as local temperature) but air quality is more complex. While the focus within such projects may be on data integration and dissemination, the factors which ensure that air quality data is of adequate accuracy for the purpose may be overlooked. As far as smart city projects are concerned, at the current time, air quality sensors cannot reliably be integrated as 'just another sensor' without good understanding and network validation. However effective post-processing of small sensor output and quality control measures developed to ensure real-time data accuracy can be applied to smart city platforms and collaborative teams – including IT and air quality expertise – are making great progress in this area, around the world.

Another area where air quality and IoT meet is in cloud data storage and processing. Initially sceptical, the air quality community is getting used to air quality data being handled in a similar way to so many other data streams, such as financial information. Security of data on a cloud server, using encryption and access tokens, can be extremely high and most small sensor system manufacturers understand the sensitivity of air quality information, being explicit about data ownership and secure access. Cloud data management offers a number of opportunities, including data QA/QC, pollutant exceedance or sensor / equipment failure alerts. There is also the opportunity to integrate readily with other databases and systems for analysing, publishing near real-time air quality data, or for being used for automation control. AQMesh examples include triggering of ventilation systems in road tunnels in France, traffic light sequences in Germany and HVAC systems in the UK.

Communicating air quality information

The prospect of informing the public and other stakeholders about air quality on a local level is very exciting and indeed it is possible to get 'readings' quite easily with a high level of spatial and temporal resolution: street level and near real-time. However, simply pushing these numbers out to the public does carry a risk. Current best practise is to apply quality assurance techniques, such as by delaying publication by anything from a few minutes to a few days, with an example being the Minnesota Pollution Control Agency in the USA publishing data from AQMesh. Things can and do go wrong, from sensor failure to theft of a monitoring point, and it is important that erroneous data is not published, causing false alarms. City authorities, quite reasonably, are also not keen on incorrect air quality information being published, which may reflect badly on their city.

Another phrase we hear is 'I'm not worried about accuracy, I don't need readings to be accurate to the last ppb. A colour-coded index will be fine.' Whilst air quality may be only communicated as an index - as simple as a red-green traffic light approach - a poor and/or poorly managed small sensor network is quite capable of showing 'red' for air quality when it should say 'green'.

There is no short-cut to publishing credible local air quality readings that does not involve starting with the best possible quality of small sensor readings and applying meaningful QA/QC. Some interesting new techniques are being introduced to manage quality control remotely, removing the need for field comparisons and offering faster and more regular network "calibration". Not all approaches are the same: some offer a robust integration of modelling and measurement and are fully traceable; others use AI to give a similar impression, but without the robustness or traceability. But this is a highly dynamic field and we can count on continued development in small sensor air quality monitoring and more networks, with new challenges and benefits. In the meantime, those who are embracing small sensor air quality monitoring are building up direct experience and helping to set the direction of development.

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