Sensors 2019

Sensors and Networks for Environmental Monitoring

Conference with Posters and Exhibition

Conference Programme

A joint conference of the Automation and Analytical Management Group and the Environmental Chemistry Group of the Royal Society of Chemistry

A one day meeting on Wednesday 26th June 2019

At The Royal Society of Chemistry,
Burlington House,
Piccadilly, London W1J 0BA

Email: conference@aamg-rsc.org.uk

ROYAL SOCIETY OF CHEMISTRY

Sensors 2019
Sensors and Networks for Environmental Monitoring

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Wednesday 26th June 2019
at The Royal Society of Chemistry, Burlington House,
Piccadilly, London W1J 0BQ

10:00 Registration and coffee

10:30 Welcome and Introductions

Session 1 Sensor materials and technologies

10:45 Technology for graphene and FET-based sensors
Professor Krishna Persaud
University of Manchester, UK

11:15 Optical sensors for environmental applications
Dr Tanya Hutter
University of Cambridge, UK

11:45 Integrated catchment monitoring of the River Lee
Matt Loewenthal and Harry Lloyd
Environment Agency

12:15 Aquatic measurements
Professor Dominik Weiss
Imperial College London

12:45 - 13:45 Lunch & Exhibition

Session 2 Policy, standardisation and regulation

13:45 Environmental regulation and sensor systems
Dr Rob Kinnersley
Environment Agency

14:15 Setting standards for low-cost sensors
Dr Nick Martin
National Physical Laboratory

14:45 - 15:15 Coffee & Exhibition

Session 3 Sensor networks and modelling

15:15 Marine emissions and health
Dr Matthew Loxham
University of Southampton

15:45 Turning sensor data into knowledge
Professor Rod Jones
University of Cambridge

16:15 Using sensor data and inversion techniques to reduce atmospheric dispersion modelling error
Amy Stidworthy
Cambridge Environmental Research Consultants

16:45 - 17:00 Closing remarks and end of meeting

ABSTRACTS

Organic field effect transistors on flexible substrates for chemical sensing

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ABSTRACT

The ability to continuously monitor our environment for chemical contaminants is increasingly important for health and safety. Organic field effect transistors are emerging as powerful devices for chemical sensing applications. Their electronic conductance is dominated by semiconducting materials whose conductivities vary over many orders of magnitude. The conductance can be perturbed via multiple mechanisms involving surfaces, chemistry in the bulk, and local electric fields. These conductivity variations can be readily induced by analytes adsorbed on the semiconductor. The local electric fields near the semiconductors are induced by adjacent dielectric materials whose polarities and polarizabilities can also be modulated by analytes. We have developed arrays of solution processable, printable organic field effect transistors that operate at low voltages which detect and measure trace concentrations of a range of volatile chemicals. The source-drain current of these devices vary in proportion to the concentration of chemical species detected. The selectivity can be tuned using a library of organic semiconductors or by incorporation of appropriate additives. By creating arrays of sensors based on libraries of organic semiconductors, a large range of compounds can be discriminated. An electronic platform was developed was developed that allows interrogation of the sensor arrays, logging of data as well as semiconductor characterisation. This integrated system has now been deployed for measurements of traces gases such as nitrogen dioxide and carbon dioxide in urban environments.

Acknowledgements: This work was supported by the EPSRC Centre for Innovative Manufacturing in Large-Area Electronics and GRAPHCLEAN, Innovate UK.

Detection of volatile organic compounds using light and nanomaterials

Dr Tanya Hutter

Department of Chemistry, University of Cambridge and SensorHut Ltd

ABSTRACT

The increasing awareness of the harsh environmental and health risks associated with air pollution has placed volatile organic compounds (VOCs) sensor technologies in elevated demand. While the currently available VOC-monitoring technologies are either bulky and expensive, or mostly capable of measuring total VOC concentrations, the selective detection of VOCs in the gas-phase remains a challenge.

I this talk, I will present several sensor technologies with improved performance for VOC detection. The sensors use optical and spectroscopy-based techniques combined with nanomaterials. Such arrangement significantly improves sensitivity and enables sensor miniaturisation onto a small chip, it also opens up new possibilities of designing new configurations and sensors based on optical spectroscopy.

Integrated catchment monitoring of the River Lee

Matthew Loewenthal, ***Harry Lloyd***
The Environment Agency

ABSTRACT

The Environment Agency and its predecessors have used online water quality monitoring systems in water bodies in England since the late 1960s. Current systems allow for real-time, high-resolution monitoring of a number of determinands for a range of regulatory and investigatory purposes. This talk will cover examples of projects where the real-time and high-resolution nature of the monitoring have been key to success. Among these are the River Lee in London, integrating water quality and hydrometric data from along the river and its tributaries, research investigating the impacts of Storm Ophelia on Lake Windermere and regulatory action against Glastonbury Festival in 2014. The talk will conclude by looking at some of the current challenges facing the Environment Agency's water quality monitoring.

Environmental regulation and sensor systems

Rob Kinnersley,
Environment Agency

ABSTRACT

The Environment Agency is responsible for regulation of atmospheric emissions from large scale industrial activities in England, such as electricity generation and oil refining as well as some intensive agricultural activities. We also have wider remits to work with partner Agencies to protect the health of the environment and the people in it, and for assessing air quality during major incidents.

In carrying out these duties we depend heavily on data from monitoring, both to assess the environmental performance and impacts of regulated sites and to develop regulatory positions and advice which are proportionate, targeted and testable. Current challenges include monitoring ammonia at low concentrations, at low cost and at something approaching hourly time resolution or better in order to quantify releases from diffuse sources. This is assuming a new importance with the prospect of beef and dairy production coming into regulation under the Government's Clean Air Strategy. Another challenge is routine monitoring of bioaerosols in a reliable and, again, affordable way.

Increasingly, key sources of air pollution are diffuse, or released in complex built environments. To estimate population exposure and identify ways of reducing such sources there is a need for data that build up a picture of spatial and temporal variability, together with modelling to interpret those data and optimise monitor placement. Satellite data are beginning to give us near real-time measurements of pollutant concentrations, albeit at coarse spatial resolution. At the other extreme networks of low-cost sensors can be used to complement sparser but more precise point measurements made using reference methods, but we need a greater understanding of how/whether such networks can be used to provide an overall reduction in uncertainty (much of which currently stems from spatial variability) despite the lower precision and accuracy of the individual sensors.

We have taken on responsibility for managing and developing the UK air quality monitoring networks. A major project is under way to develop a unified network which will provide the data needed to determine air pollution levels at resolutions, uncertainties and locations of interest to users. The data must be readily accessible, and translatable into the information required by users, with an appropriate, quantified, level of statistical confidence.

The project is reviewing needs across the broad community of air quality information users for data, metadata and data products. Users range from modellers and other researchers, through policy makers and regulators, to local communities and individuals wishing to assess their own exposure to air pollution. Two more work packages are reviewing the current state of the art in monitoring methods and in data management and informatics, while a fourth works with modellers and statisticians to design a framework within which to assess network design options against user needs.

Future trends in air quality monitoring and the role of standardisation

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ABSTRACT

Local and national authorities are responsible for managing and reducing ambient air pollution to reduce its impact on human health, and meet the legislative requirements of EU Directives. Ambient air quality (AQ) assessments currently depend on low resolution data generated from a small number of discretely positioned expensive continuous reference monitors. These high quality measurements are often supplemented by indicative spot monitoring of average concentrations, or estimates from predictive atmospheric models. Advances in the development of modern low cost sensors means that devices measuring atmospheric pollution can be incorporated into a single compact unit. Such systems are revolutionising the AQ monitoring market with the prospect of delivering spatially dense data, in real time, through the implementation of large networks. The Mayor of London, in partnership with C40 Cities and the Greater London Authority, is implementing a pilot study to create a sophisticated air monitoring system for the capital, branded as “Breathe London”, using consortium expertise from the Environmental Defense Fund Europe, Air Monitors Ltd., Google Earth Outreach, Cambridge Environmental Research Consultants, University of Cambridge, National Physical Laboratory, and King’s College London. An important barrier to wider acceptance of this novel technology is the lack of a standard to determine sensor system suitability. This is beginning to be addressed through the development of a technical protocol by the Comité European de Normalization (CEN) TC264 WG42 together with a laboratory and field testing measurement infrastructure.

Port-Related Air Pollution – Why Particulates Matter

Matthew Loxham*[a,b,c]*, Natasha HC Easton[c,d], Matthew J Cooper[d], P Sargent Bray[d], Florentin MJ Bulot[c,e], Simon J Cox[e], Jessica H Whiteside[c,d], Damon AH Teagle[c,d], Steven J Johnston[c,e], Donna E Davies[a,b,c], Gavin L Foster[c,d]

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ABSTRACT

Airborne particulate matter is a leading contributor to premature mortality and diseases of the respiratory and cardiovascular systems. In coastal cities, shipping emissions are major sources of air pollution, while port cities have the added burden of port-related pollution sources including freight haulage and raw material processing. Little is known about these different sources of particulate matter, including their different compositions and toxicity. In this talk, I will present our work investigating the chemistry and toxicology of particulate matter within the Port of Southampton, and discuss ongoing work aimed at further understanding how ship emissions may contribute to port city air pollution.

Turning sensor data into knowledge: first steps with the BreatheLondon hyperlocal air quality network

Roderick L Jones, Lekan Popoola

Department of Chemistry
University of Cambridge

and……..the BreatheLondon Team

ABSTRACT

Air quality is traditionally measured using fixed reference or reference standard instruments each requiring an individual physical validating process involving periodic on-site maintenance and calibration visits and a complex and often lengthy ratification process before ratified data is made available. The implementation of this process is extremely costly, and is a major factor in limiting the numbers of air quality monitoring which can be deployed.

The BreatheLondon project (https://www.breathelondon.org) has multiple components, one being the deployment of a network of over 100 low cost sensor nodes across London each measuring a range of species including NO_2, NO, CO_2 and PM. Within the objectives of the BreatheLondon project, one aim is to explore how air quality sensors, treated as networks rather than individual instruments, can be used to add value to traditional approaches and, for example, to overcome some of the complexities and costs of existing methods.

In this paper we take the first steps towards showing how, by exploiting fast (1 min) measurements and suitable analysis methodologies, a cloud based cross-network calibration can be developed, bypassing the need for individual site visits. The primary focus of the paper will be demonstrating and validating the methods for NO_2,and time permitting, PM.

Using sensor data and inversion techniques to reduce atmospheric dispersion modelling error

Amy Stidworthy, David Carruthers, Ella Forsyth and James O'Neill,
CERC

ABSTRACT

Compiling an accurate air pollution emissions inventory for an urban area is a challenging and time consuming task. Even where comprehensive and detailed emissions inventories exist, emissions errors account for a significant proportion of dispersion model error; in particular, there is high uncertainty in published NO_X emission factors for light-duty diesel vehicles. Traditionally, air pollution dispersion models are validated by comparing measured and modelled concentrations at well-established monitoring sites; at best, modellers manually refine the dispersion modelling to minimise error at these locations; at worst, modellers calculate 'adjustment factors' and apply these to modelled concentrations. Meanwhile, the increasing availability of relatively low cost air pollution sensors that are easy to install and to maintain is allowing networks of such sensors to be installed across urban areas. Although these sensors typically have reduced reliability and accuracy compared with traditional monitors they allow much greater spatial coverage. A systematic method that integrates data from these low cost sensors with models could deliver real benefits in terms of understanding emissions and improving model estimates.

Using a probabilistic approach we have defined a cost function with two terms: one that represents model error taking into account observation uncertainty; and one that represents emissions error taking into account emissions uncertainty. Given an initial set of emissions data, we minimise this cost function using a non-negative least squares solver to find a revised set of emissions data that reduces model error. The system has been tested in Cambridge using data output from the urban air quality model ADMS-Urban together with observed data from AQMesh sensor pods. In London, as part of the Breathe London project, the system has been further developed and tested with ADMS-Urban modelled data and measured data from the existing reference-standard London Air Quality Network; future work will also incorporate observed data from the new Breathe London network of AQMesh sensors.

The results of these tests and the impact of the AQMesh sensor data will be discussed in the paper. A key challenge with this inversion technique is to quantify the emissions error and its covariance between sources of the same type, between sources of different types and between pollutants; similarly, to quantify the observation error and its covariance between monitoring sites and between pollutants. The effect of the error covariance matrix on the solution achieved will be discussed in the paper.

POSTER ABSTRACTS

Hiding in the crowd: the clue to propagation of electrochemical sensor biofouling is hiding in the noise

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POSTER ABSTRACT

Urbanisation and pressures of climate change will increase demand for clean water. Sensor networks offer new strategy to develop robust management of drinking water distribution system that are essential to human health. They offer real-time, online and long-term monitoring strategy. However, sensor networks in water settings can fail in a couple of days or weeks because of biofouling.

When electrochemical sensors are fouled, biofilm covers electrode surface. Owing to our incomplete understanding of the chemistry, physics and biology of bacterial cell and surface interaction, solutions become ineffective. Embracing and understanding the events of fouling in terms of intrinsic response of the sensor could help develop a better anti-fouling strategy. This is important because biofouling will always happen in water settings.

Signal and noise form the response of electrochemical sensor. Biofouling interferes with the signal, but some clues to initial biofilm formation may be present inside the 'noise'. Biofilm formation is essentially a surface modification of the electrode. The presence of a complex adsorbed film will decrease double layer capacitance which is a component of non-Faradaic current; a form of noise, affect electrochemical kinetics due to adsorption on to electrocatalytic sites, and decrease local mass transport. These physico-chemical effects can be quantified using standard electrochemical methods, many of which can be implemented *in situ* to monitor sensor performance and assess the effects of remediation. Example data for electrochemical oxygen sensors will be presented showing the effects of bacterial biofilm adsorption on different electrode materials and the likely impact on sensor performance.

Array metasurfaces based on asymmetric split-H resonator for environment monitoring system

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POSTER ABSTRACT

Due to their high-sensitivity and flexibility, array metasurfaces have been widely employed as label-free optical sensors for organic compounds and eventually used for rapid environmental analysis. We have developed a sensing platform for the specific detection of 17β-Estradiol (E2) using an array of asymmetric split-H (ASH) resonators. We present here the surface functionalization of an array metasurface with specific thiol-terminated aptamers for the targeted analyte is described. Two geometries of ASH resonators, labelled as ASH1 and ASH2, fabricated on a zinc selenide (ZnSe) substrate, were optimized to produce plasmonic resonances that match the mid-infrared molecular vibrations of E2. ASH nanostructures exhibit both transmittance and reflection resonance due to resonance hybridization. The resonances were measured at normal incidence using a microscope-coupled Fourier Transform Infrared (FTIR) spectrometer and observed at mid-infrared wavelengths in the range between 2 and 8 μm, both experimentally and in simulation. This method has been used to demonstrate the detection of E2 in the concentration range from 1 nM to 100 μM with the lowest detection level of 100 nM being equivalent to 27 ng/ml.

The challenge of monitoring air, water and soil in active conflict zones

Dr. Eoghan Darbyshire, Linsey Cottrell and Doug Weir

The Conflict and Environment Observatory (CEOBS), Mytholmroyd, UK

POSTER ABSTRACT

Environmental contamination in conflict zones, either via direct fighting or the collapse of governance, represent serious threats to human wellbeing, ecosystem services and agriculture. Receiving limited academic attention, the scale and magnitude of contemporary and historical impacts remains uncharacterised. Incidents may be locally, regionally or globally significant, and present acute and chronic threats to human health and the wider environment. Authoritative data is imperative to aid humanitarian response, remediation, accountability and environmental peacebuilding.

Traditionally data is collected once a conflict ends, thus missing short lived, high intensity events. Sadly, many contemporary conflicts show no such sign of a finish and even when so, data collection has been limited in scope owing to financial, political and practical constraints. Alone, this model of data collection is not suitable. Whilst advances in satellite remote sensing and processing power provides valuable insights, compositional data is limited and requires validation. Hence data must be collected on the ground. As logistical and financial barriers prevent the use of standard monitoring instrumentation, small low-cost sensors operated by citizens and civil society offer a potential solution.

Our charity intends to deploy such sensors into conflict zones. The question we pose is how best the unique measurement challenges posed by conflict environments can be met by current sensor technology developed for regulatory frameworks unrepresentative of the esoteric release, composition and exposure pathways of conflict zones.

Our poster presents three case studies requiring ground data. We invite attendees to critique, develop, or suggest alternatives to our posited sampling strategies.

Metrology for the validation of low-cost air quality sensor networks

Joe Hayward, Nick Martin, Stefan Bell, Prashant Kumar

National Physical Laboratory

POSTER ABSTRACT

Conventional air quality monitoring techniques require expensive reference quality equipment, on site calibration and maintenance at dedicated deployment sites. These limitations have caused a surge of interest in low-cost air quality sensors. However, the accuracy of these sensors varies depending on the manufacturer. NPL are currently working on methods to calculate the uncertainty not just of individual sensors. but of whole networks.

Low-cost sensors as decision-maker tools in air quality

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POSTER ABSTRACT

Low-cost sensors are attracting a lot of attention lately. Their high resolution time, small size, low cost and the possibility of deploying dense monitoring networks are among their most outstanding features. Whereas part of the scientific community is enthusiastic about them, the other part is reluctant to use them because of the lack of information about the quality of their measurements. It is undeniable, however, that low-cost sensors are tools that can be very valuable in many situations, i.e. when there is no need of an accurate measurement but the detection of anomalous situations or deviations from background values. In this work, we show as an example how a low-cost sensor for $PM_{2.5}$ and PM_{10} can help detect rising concentrations of particles in air when leaf blowers are used to clean the streets, thanks to its high time resolution. These concentrations increase up to 2.2 and 3.2 times when compared to baseline values for $PM_{2.5}$ and PM_{10}, respectively. The particulate matter last resuspended in the air for several minutes. This information acquired from optical sensors can provide useful insight of this cleaning process, which should be taken into account by local environmental decision-makers.

Characterisation of Organic Field Effect Transistors for Ammonia Sensing

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POSTER ABSTRACT

Detection of low concentrations of primary air pollutants such as ammonia and volatile organic compounds (VOCs) is essential for a wide range of applications. It is desirable to have high selectivity to ammonia and to reduce the effects of potential interferents. Here, we report the electrical and morphological characterisation of an OFET. We investigated the potential interference of ethanol, acetone and ethyl acetate on ammonia detection. We report sensing, electrical and surface characteristics of thin film transistors as well as multi-parameter experimental determination of charge transport mechanisms in the semiconducting layer from temperature-charge carrier mobility measurements, transfer and output characteristic curves, and by studying the surface morphology of the deposited thin films with the atomic force microscope (AFM). The charge carrier mobility estimated from the saturated region of transfer curves ranges between 0.01-0.5 cm^2/Vs and the activation energy (E_a) of the poly(3,6-di(2-thien-5-yl)-2,5-di(2-octyldodecyl)-pyrrolo[3,4-c]pyrrole-1,4-dione)thieno[3,2-b]thiophene) (DPPTTT) can be tuned from 80 to 180 meV by altering the thin film fabrication conditions and the molecular weight of the semiconducting polymer. We tested the sensor against 400 ppb-820 ppm of ammonia and its interference with 1.5 ppm of selected VOCs. We have established that with increasing humidity (20-80% relative humidity values) the sensitivity of the sensor increases dramatically due to the complex of ammonia with water. Furthermore, the results indicated that the lower limit of detection (LOD) is strongly dependent on the presence of vaporised water molecules. In the presence of humidity (RH = 80%) the LOD for ammonia is about 200 ppb but at the same time in the absence of humidity (RH = 0%), the LOD ≈ 300 ppb. In investigation of the effect of interferents, the sensing properties of the semiconducting polymer can be very different from the pure ammonia gas depending on the nature of the inter molecular forces, the dipole moment and the solubility of each analyte.

ACKNOWLEDGEMENT

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Chemical sensors using polymer composites for monitoring oil spillage

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POSTER ABSTRACT

The detection and control of petroleum contaminants as a result of oil spillage pollution to the environment remains a major challenge to both developed and developing countries. Crude oil spill discharge to the environment is generally regulated and one of the key parameters used for compliance monitoring is the measure of oil concentration. Environmental laws require oil companies to keep oil spill total hydrocarbons concentration at 50 mg/kg soil (50 ppm). Most soil analyses for spillage use the standard gas chromatographic methods, but these are expensive, require high expertise and not suitable for *in-situ analysis*. This study was conducted to evaluate the possibility of developing cost-effective and simple chemiresistor based sensors for *in-situ* detection of hydrocarbons in soils. Contaminated soils obtained at different depths from different oil spillage sites were extracted using Soxhlet technique and analysed by gas chromatography-flame ionization detector to determine types of hydrocarbons and their concentrations, as they are required to be detected by chemiresistors. The results recorded carbon numbers ranging from C_8 – C_{38} with varying concentrations up to 15125 mg/kg at different sampling sites. Composites of conductive particle (carbon black) and non-conducting polymers were prepared to make chemiresistors. The impact of carbon concentration and geometry on the measured resistance of the polymer composite to hydrocarbons was determined. The optimum response was found to be with 10% w/w carbon black (CB) with 90% w/w polymer (Poly(methyl methacrylate) (PMMA) and Polyvinyl chloride (PVC)). Three chemiresistors CB-PMMA, CB-PVC and CB-PMMA+PVA were constructed by depositing thin films of a carbon black/polymer onto interdigitated electrodes and investigated. The CB-PMMA sensors showed much higher responses when exposed to range of hydrocarbons with varying sensitivities compared to the other two, however the three sensors detected diesel range hydrocarbon concentrations up to Eicosane (C_{20}) more than the existing devices [3]. The sensors responses to the EPA maximum concentration (50mg/kg soil) limits are large (resistance changes), fast (90% in less than 1s), reversible and selective. The underlying mechanism of this high sensitivity of sensors might be due to the strength of the hydrophobic interactions between the polymer and the hydrocarbons.

References

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***Index Terms* — oil spill, petroleum hydrocarbons, chemiresistor, soil contamination**

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Monitoring the lead- and- copper rule with a water- gated field effect transistor

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POSTER ABSTRACT

We use the natural zeolite clinoptilolite as the sensitive element in a plasticised PVC membrane. When we separate a sample- and a reference pool in a water- gated SnO_2 thin film transistor (SnO_2 WGTFT) with such a membrane, we find a membrane potential that leads to transistor threshold shift in response to the common drinking water pollutants Pb^{2+} or Cu^{2+} in the sample pool. Threshold shift with ion concentration, c, follows a Langmuir- Freundlich (LF) characteristic. As the LF characteristic shows steepest slope in the limit $c \rightarrow 0$, this opens a window to limits-of- detection (LoDs) far below the 'action levels' of the 'lead- and- copper rule' for drinking water: Pb^{2+}: LoD 0.9 nM *vs* 72 nM action level, Cu^{2+}: LoD 14 nM *vs* 20.5 µM action level. LoDs are far lower than for membranes using organic macrocycles as their sensitive elements. Threshold shifts at the lead and copper action levels are larger than shifts in response to variations in the concentration of non- toxic co-cations. This qualifies clinoptilolite- sensitised WGTFTs as a low footprint sensor technology for monitoring the lead- and- copper rule, and to confirm the effectiveness of attempts to extract lead and copper from water.