Title: Sensor networks for environmental metrology

Abstract

The current metrology paradigm of standards, calibration and traceability chains is designed for the measurement of single, discrete quantities, e.g., the length of an artefact. However, much of environmental measurement necessarily involves networks of sensors measuring a number of different quantities at several locations with a range of accuracies. The sensor information must then be combined to make inferences at an arbitrary location or aggregated over a region. It is essential to extend the metrology paradigm to sensor networks for environmental monitoring to validate the new paradigm on existing or planned networks.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Energy and Environment on pages 8/9 and 23/24/25.

Keywords

Sensor networks, uncertainty, traceability, calibration, design of experiment, resilience, information gain, data fusion, data assimilation

Background to the Metrological Challenges

EU directives on environment and climate change such as the Ambient Air Quality and Cleaner Air for Europe [1] and the Marine Strategic Framework Directive [2] relate to managing aggregated measurements of environmental variables to bring about improvements over time. No single instrument can deliver data to determine if environmental regulatory limits are being met. Instead, environmental monitoring necessarily involves a network of instruments sampling at discrete locations at discrete times: sensor networks. Independent of the characteristic being measured (for example air pollutant levels, acoustic noise, or sea water salinity), measurements at particular spatial and time locations are used to make inferences at other individual spatial and time locations or are aggregated to make inferences over a region or time period. The quality of the inferences made will depend on how well the network is designed and how the sensor data is used. At the moment, the quality of the inferences is severely limited by the lack of a methodology for uncertainty evaluation applicable to sensor networks.

Current practice treats the sensors as independent individual instruments, so that calibration strategies, for example, are determined without any reference to other sensors in the network. Many existing environmental JRPs focus on the need to make sure that individual sensor measurement results are traceable to standard units. However, decisions are not made on the basis of a result of a single sensor reading but on the basis of a complex aggregation of the sensor data to estimate key environmental variables. This aggregation is sometimes referred to as the transformation of "data to knowledge". The value of a sensor network is judged on the value of the knowledge generated from the sensor data. It is important to ensure that traceability and uncertainty can be applied to the knowledge derived from sensor network data.

The recent advances in mathematical and statistical modelling associated with variables subject to spatial and/or temporal correlation, are possible approaches to convert sensor networks into distributed metrology systems in which concepts such as traceability, uncertainty and calibration can be interpreted correctly. Gaussian process models can be used to describe environmental variables that exhibit a spatio-temporal correlation: the values of a variable at nearby locations and times will be similar. This correlation structure is valuable prior information that can reduce uncertainties in the estimates of the variables since the estimate can take into account neighbouring measurements. Sensor data can be assimilated with meteorological models, models of atmospheric chemistry, etc., to provide enhanced estimates that benefit from the model predictions as well as the measured data. Ensemble Kalman filter techniques can be used to implement data assimilation in a computationally efficient scheme. These algorithms developed primarily for weather forecasting could be very effective in applying data assimilation methods to environmental monitoring.

Wired and wireless communications allow data arising from a sensor network to be sent to a data centre to be analysed. Statistical/machine learning algorithms and other data fusion algorithms, implemented on a cloud computing platform, can then be applied to provide enhanced model of the system, in particular, separating out the effect of environmental influence factors on sensor performance from the values of the environmental variables under study.

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP-Protocol.

The JRP shall focus on the traceable measurement and characterisation of sensor networks in environmental monitoring.

The specific objectives are:

1. To develop generic tools to support sensor networks in three broad areas
   i) mathematical and statistical modelling
   ii) (wireless) communications
   iii) ICT and informatics
2. To ensure that sensor networks give traceable measurements by extending current metrological practice, in particular, defining the appropriate concepts for;
   i) definition of a measurand associated with a network
   ii) uncertainty associated with a network
   iii) calibration of a network, including in situ calibration
3. To optimise network design and operation to maximise the information gain from sensor networks used in environmental monitoring.

Any proposal against this SRT should contain explicit application of the generic tools and concepts to develop more than one environmental monitoring or energy distribution network, and deliverables demonstrating the benefit gained by that network.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the R&D work, the involvement of the user community such as industry, and standardisation and regulatory bodies, as appropriate, is strongly recommended.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP project NEW04 ‘Novel mathematical and statistical approaches to uncertainty evaluation’ and how their proposal will build on those.

EURAMET expects the average size of JRPs in this call to be between 3.0 to 3.5 M€, and has defined an upper limit of 5 M€ for any project. Any proposal received for this SRT is expected to be significantly below 3.0 M€. The available budget for integral Research Excellence Grants is 30 months of effort.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP-Partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the environmental sector.
- provide a common platform to allow correlations to be established across many environmental domains

- will develop, capture and promote best practice in measurement and data analysis in environmental metrology

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology and includes the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe

[2] DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)