European Partnership on Metrology
Call 2022 – Digital Transformation, Health, Integrated European Metrology, Normative and Research Potential

Selected Research Topic number: **SRT-d03**
Version: 1.0

Title: Fundamental principles of sensor network metrology

Abstract

Sensor networks are the basis for a wide variety of developments in digital transformation, with applications ranging from the “Internet of Things” to regulated utility networks. Sensor network technologies offer novel possibilities in metrology, such as co- and self-calibration of measuring instruments, or data-driven event detection and monitoring. However, the required metrological assessment of sensor networks needs a fundamental revision of calibration, uncertainty propagation and performance assessment. Further to this, new approaches for information and data handling regarding individual sensors and their interactions within a network are needed, in order to support the adoption of a systems metrology approach.

Keywords

sensors networks, distributed systems, machine learning, Internet of Things, factory of the future, smart city, smart grid, big data, digital transformation

Background to the Metrological Challenges

Advances in network architecture, communication protocols, network security as well as the increasing use of machine learning (ML) methods have facilitated a rapid uptake of sensor network technologies. A consequence of these developments is the increased use of complex sensor networks in infrastructure and systems of high societal importance such as energy grids, environmental health monitoring, and autonomous driving systems. Traditionally the focus in metrology has been on methods for individual sensors. However, these methods do not capture the complexity, dependencies and correlations present within entire sensor networks. Further to this, novel approaches, such as self- or co-calibration, and the use of sensor redundancy for fault detection require new types of metrological assessment. New challenges for metrology also arise from the size, mixed quality, and volatility of data in practical sensor networks, and from their underlying complex and dynamic models. In addition, ML methods (used for the aggregation of data), further complicate metrological assessments, as the prevalent approaches for the metrological treatment of ML are computationally expensive and time consuming, making them impractical for use in real-world sensor networks.

In many sensor networks it is not feasible to calibrate individual sensors with traditional in-situ or laboratory methods, as the cost per sensor is simply too high. In principle, automated test equipment (ATE) could be redesigned to enable batch calibration. However, an ATE can also be considered a sensor network, meaning that it too needs metrological assessment. Another challenge (e.g. in the utility sector) is that sensors often cannot be removed from the network easily, making calibration by traditional methods infeasible. As a result, sensor measurements need to be assessed and validated remotely. However, sensors in networks are also often used in changing environmental conditions and varying topology. Therefore, multiple sources of information and measurement data need to be fused together, leading to challenges in data integration and measurement uncertainty evaluation.

Sensor networks in specific application areas have been studied for decades, but a consistent and comprehensive sensor network metrology is missing. For example, in some areas, modelling assumptions for sensor networks are based on physical arguments (e.g., parameterised differential equations or state-space models). Propagating uncertainties through these models requires an estimation of the model parameters, including an assessment of model bias. In principle, current guidelines, such as the Guide to Uncertainty in Measurement (GUM), can be applied for such tasks. However, practical methods and guidance for their application is not yet available. At the same time, ML methods are being increasingly used in place of physics-based models. But ML methods still need to be extended to address key issues in sensor networks, such as: incremental learning to cope with the increasing amounts of sensor data; active learning based on detection of uncertain data and feedback from the user and hierarchical modelling for collaborative learning to account for sensor network topologies.

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 protocol.

The JRP shall focus on metrology research necessary to support digital transformation in sensor networks.

The specific objectives are

1. To develop reliable and accurate methods for the assessment of data quality and measurement uncertainty in real-world sensor networks. The methods should be suitable for a wide variety of sensor networks, and should include (i) the propagation of uncertainties, (ii) proper treatment of correlations, and (iii) uncertainty-aware sensor fusion. In addition, to produce metrological guidance for data quality metrics in sensor networks that include not only measurement uncertainty but other common factors that can influence data quality.
2. To extend the results obtained in objective 1 to the case of distributed sensor networks, and to develop reliable and accurate methods for their metrological assessment. The methods should cover a wide variety of sensor networks and geographical distributions (e.g. Smart Grid sensors, IoT networks in Smart Cities). Methods should also consider edge and cloud architectures where sensor data is aggregated locally before communication to other parts of the network.
3. To develop reliable methods for the automated application of the methods in objectives 1 and 2, in large transient networks. This requires novel approaches for the handling of information on the individual sensors, their interaction and metrological characterisation, and includes machine-interpretable and metrology-aware descriptions for complex sensor networks using semantic technologies (e.g. ontologies). These novel approaches should integrate metrological information on data quality with traceability, as provided by digital certificates and sensor network data protocols.
4. To demonstrate the practical validity of the methods developed in objectives 1, 2 and 3, in at least 3 real-world case studies (e.g. industrial processing, environmental monitoring, utility sector). Using the results of the case studies to develop end user guidance and software for sensor network metrology. The end user guidance shall provide improved measurement reliability including (i) standardised methods for in situ metrology, (ii) the use of the software (iii) the use of metrological redundancy, and (iv) error detection.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by end users (industry, advanced manufacturing, environmental monitoring and energy), standards developing organisations (e. g. JCGM/WG 1 and committees associated with the Integrated Pollution Prevention and Control (IPCC) Directive 2008/1/EC (2010/75EU) or the Energy Efficiency Directive 2012/27/EU), and accreditation bodies.

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 research, the involvement of the appropriate user community such as industry, standardisation and regulatory bodies, and other European Partnerships is strongly recommended, both prior to and during methodology development.

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 projects ENG63 GridSens and ENV57 MetroERM and the EMPIR projects 14IND04 EMPRESS, 16ENV04 Preparedness, 17IND02 SmartCom and 17IND12 Met4FoF and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.7 M€ and has defined an upper limit of 2.4 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the 'end user' community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to industry, advanced manufacturing, environmental monitoring and energy sectors.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of the Partnership to develop a coherent approach at the European level in the field of metrology and include 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 EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.