

## **Title: Automated, adaptive and uncertainty-aware smart measurements using machine learning**

### **Abstract**

Multidimensional measurements are ubiquitous in various metrological applications, such as in scanning hyperspectral imaging and photocurrent mapping of semiconductors. However, long data acquisition times commonly challenge their widespread applicability. By combining machine learning and compressed sensing techniques, uncertainty-aware completion of measurements and reconstruction of linear inverse problems will be made possible. As a result, automated and adaptive measurement plans will be developed and improve the efficiency of data acquisition. This will generate good practice guides, example applications and establish a reference data and software platform.

### **Keywords**

Digitised measurement, compressed sensing, machine learning, uncertainty evaluation, experimental design, validation, quality assurance.

### **Background to the Metrological Challenges**

The proposal addresses a critical need in metrology by advancing the state of the art in multidimensional measurements, particularly in applications such as scanning hyperspectral imaging (sHSI), photocurrent mapping of semiconductors, and related areas, where measurements are performed in a sequential manner or under various multidimensional scenarios. In these applications, there is a current and urgent need for compressed measurement techniques since even the state-of-the-art scanning instruments often perform measurements over multiple hours to a day. These long acquisition times do not satisfy the measurement requirements, for instance, in large scale user facilities or in the quality control of production lines, where there is a stringent limit on available measurement times. Fast, reliable, and specifically targeted measurement strategies are therefore needed to reduce measurement times. The urgency for advancing compressed measurement methodologies is also evident in clinical routine applications, such as magnetic resonance imaging (MRI), where long measurement times impose significant costs and patient loads. Moreover, current challenges in medical imaging (e.g., fastMRI) underscore the need for more efficient and accurate measurement techniques in multidimensional measurement scenarios and emphasize the importance of innovative approaches across a wide range of metrological applications. A promising mathematical and statistical approach to reduce full-scale measurements is compressed sensing (CS). CS has demonstrated its versatility across various applications, including medical imaging (e.g., MRI), scanning-based measurements (e.g., IR measurements), and photocurrent mapping of semiconductors.

### **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 proposal shall focus on metrology research necessary to support digital transformation in smart multidimensional measurements with significantly reduced experimental effort and validated uncertainty quantification.

The specific objectives are:

1. To develop automated machine learning approaches for the solution of general linear inverse problems based on digitised measurements, arising in scanning hyperspectral imaging or photocurrent mapping of semiconductors. To go beyond the state of the art by basing and extending these approaches with techniques from compressed sensing, low-rank reconstruction, and deep learning. To also train machine learning models to represent prior knowledge and statistically regularise the inverse problem, using both real and synthetic data.
2. To develop uncertainty quantification methods for the approaches in objective 1 and create generalised tools to metrologically validate the uncertainty quantification. These tools would include statistical uncertainty assessments and calibration analysis, as well as have the capacity to validate the robustness and reliability of the machine learning model.
3. To develop automated and adaptive measurement strategies for the methods developed in objectives 1 and 2. To achieve a targeted measurement uncertainty while satisfying the constraints of specific metrology applications, such as scanning hyperspectral imaging or photocurrent mapping of semiconductors. To also define a digitised measurement framework to include data management strategies and appropriate automated feedback procedures.
4. To implement the approaches developed in objectives 1 to 3, for metrological applications, such as scanning hyperspectral imaging and photocurrent mapping of semiconductors. To design automated and adaptive measurement strategies by taking into consideration any physical constraints imposed by measurement instruments or methodologies of the applications and develop experimental prototypes.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by standards developing organisations and end users (semiconductor industry, medical imaging etc.) and to disseminate good practice guidelines and a public database for reference data to all relevant stakeholders.

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.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.4 M€ for this proposal.

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 proposal's 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,
- Facilitate improved industrial capability, or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the semiconductor sector.

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 Metrology 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.

### **Timescale**

The project should be of up to 3 years duration.