European Partnership on Metrology
Call 2023 –Fundamental Metrology, Industry, Normative and Research Potential

Selected Research Topic number: **SRT-i17**
Version: 1.0

Title: Thermometry with embedded SI traceability for industrial applications

Abstract

Almost every technological process relies on temperature measurement, which directly influences product quality and energy efficiency. All current temperature sensors exhibit calibration drift leading to inefficiencies and sub-optimal processing. Implementing embedded traceable thermometry *in-situ* through driftless practical primary thermometry and self-validation, gas/combustion thermometry, and new techniques to enable traceable 2D surface temperature measurement, would help to overcome specific process control challenges.

Keywords

Temperature, Johnson noise thermometry, practical primary thermometry, phosphor thermometry, thermal imaging, surface thermometry, gas thermometry, artificial intelligence, process efficiency

Background to the Metrological Challenges

There is a wide range of unsolved temperature measurement challenges which impede improvements to the efficiency of industrial manufacturing and processing. Poor surface temperature measurement causes process control problems in advanced manufacturing. Poor gas temperature measurement causes sub-optimal noxious emissions and reduced efficiency. The need to address process control challenges has been highlighted by different sectors, e.g. both the EMN (European Metrology Network) for Advanced Manufacturing and EMN for Climate and Ocean Observation have identified *in-situ* calibration and measurement as one of their key needs.

The thermal imaging remains a key process monitoring technique in many applications, but the difficulty of characterising the surface emissivity when performing quantitative thermal imaging results in measurement uncertainties which are often so large that the process quality/efficiency is significantly adversely affected. Existing phosphor thermometry techniques are well established from ambient temperatures up to 500 °C, with prototype instruments able to reach 750 °C. However, there is a growing need to measure down to -100 °C where traditional thermal imaging is particularly challenging due to the low signal levels and relatively high background thermal radiation. Besides, current primary thermometry techniques are generally very large, complicated apparatus which do not meet industry requirements. Progress has been made with more practical Johnson noise thermometry, but there is still a need to improve the probe and sensing element to make it useable in harsh environments (e.g. electromagnetic interference, high temperature), and to define the measurement traceability scheme. In addition, phosphor thermometry needs to be advanced through the development of robust coatings, new phosphor formulations and higher temperature operation for both imaging and single spot technologies, and needs to operate up to 1 250 °C bringing many relevant applications in its purview e.g. steel processing and marine manufacturing.

Self-validating thermometers which make use of an *in-situ* invariant temperature reference to overcome calibration drift have been developed to the point where they are viable in industrial applications, however, while the acquisition of temperature as a function of time can be automated, the particular feature which enables *in-situ* re-calibration, must be identified manually by a human operator. Attempts to develop conventional algorithms for automating this process have failed; artificial intelligence techniques such as machine learning are needed to perform autonomous identification of key features in the indicated temperature versus time signal, as well as robust techniques for assessing the associated uncertainty.

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 development of thermometry with embedded SI traceability for industrial applications.

The specific objectives are

1. To develop techniques for traceable quantitative thermal imaging, for the low-to-medium temperature ranges -100 °C to 500 °C, by using objects with known temperature (e.g. phosphors) in the field of view of the thermal imager, including the emissivity characterisation (e.g. of the surface or of the phosphor itself) and *in-situ* correction for camera non-uniformity.
2. To improve practical primary thermometry with uncertainty less than 3 °C, by developing a robust probe for use to 1 200 °C that is compatible with practical Johnson noise thermometry instrumentation and demonstrating the sensor performance in harsh environments.
3. To develop thermographic phosphor thermometry with uncertainty of less than 3 °C to a target temperature of 1 250 °C to provide low uncertainty traceable surface temperature measurement.
4. To develop artificial intelligence approaches to enable *in-situ* temperature traceability which shall be exemplified by case studies including practical demonstrations, e.g., the application of artificial intelligence to self-validating thermometers to enable autonomous, continuously traceable operation and to spectroscopic infrared thermometry for *in-situ* gas temperature profile measurements using new generation infrared detectors. The target for in-process traceable measurement uncertainty is less than 2 %.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (sensor manufacturers), standards developing organisations (e.g. IEC), end users (manufacturing sector, space sector, petrochemical industry, nuclear power industry), and via the EMN for Advanced Manufacturing.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

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 ENG08 METROFISSION, EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2 and how their proposal will build on those.

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 2.3 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,
- 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 manufacturing 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 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.