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

Selected Research Topic number: **SRT-D02**
Version: 1.0

Title: Trustworthy virtual experiments and digital twins

Abstract

Virtual experiments and digital twins were recently developed, implemented, and applied in various industrial applications in manufacturing, medicine, and city planning. In metrology, they can be used to explore the accuracy of measurement devices, to specify required machine tolerances, part characteristics, and to identify significant sources of uncertainty. The proposed research aims to provide mathematical and statistical frameworks for virtual experiments and digital twins including both model-based and data-driven approaches. Substantiated validation tools combined with appropriate uncertainty evaluation methods will guarantee the traceability of modern measurement systems and boost and strengthen the European lead worldwide.

Keywords

Virtual experiment, digital twin, uncertainty evaluation, validation

Background to the Metrological Challenges

Virtual experiments and digital twins, simulation models that accurately replicate physical systems and characteristics in a virtual environment, have recently been implemented in various industrial applications, such as advanced manufacturing processes, personalised medicine, and risk identification and mitigation in city planning.

Virtual experiments, in combination with Monte Carlo methods, are used for evaluating measurement uncertainties. However, the results of these approaches generally differ from a GUM-compliant uncertainty evaluation, which marks the *de facto* standard for uncertainty evaluation in metrology. To facilitate the use of results from virtual experiments into traceable measurement chains a GUM-compliant uncertainty evaluation based on virtual measurements is needed.

The essential elements of a digital twin are a virtual representation (model), a physical realisation (asset), and a transfer of data / information (connected) between the two. The virtual representation can consist of purely data-based models, physics-based models, or a combination of both (termed a ‘hybrid twin’).

The key value of digital twins in metrology is the ‘closed loop’ with manufacturing and design, earlier warning of the development of problems, continuous prediction, and the optimisation of measurement activities via communication among different devices.

However, for digital twins, uncertainty evaluation is usually only available for ‘static’ cases, where it is assumed that the digital model does not change over time. To account for time-dependent influences, such as mechanical deformations, thermal drifts, or vibrations, the dynamical case needs to be considered. Hence, digital twins need to be updated with data from actual measurements collected in real time.

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 the reliability and trustworthiness of virtual experiments and digital twins in metrology necessary to support digital transformation within Industry 4.0 and the European Green Deal.

The specific objectives are

1. To develop methods for evaluating the uncertainty associated with real measurements for at least 3 different applications by using the results from corresponding virtual experiments in line with the

current state-of-the art for uncertainty evaluation, such as Bayesian or Monte Carlo approaches or documented in the GUM.

2. To develop methods for uncertainty quantification for digital twins representing complex measurement processes and mechanisms for at least 2 different applications, in each case including the effect of dynamical influences on the digital model such as thermal drift or vibrations. The model should be updated based upon data obtained during the project's lifetime.

3. To develop approaches for the validation of virtual experiments and digital twins for all applications of objectives 1 and 2, using statistical procedures for the assessment of differences between calibrated standards and corresponding data from their virtual counterpart. Methods should include accounting for errors, specifically for computationally expensive systems, where surrogate models often need to be used.

4. To demonstrate the practical applicability of the developed methods, using at least 5 different case studies covering different metrological applications (e.g. coordinate measurement, optical form measurement, flow measurement, electrical measurement, 3D robotic measurement). Guidance should be documented on how to employ the methods in other cases and good practice guidelines should be drafted in collaboration with industrial project partners and stakeholders and disseminated within e.g. EU industry, CCL, TC-L and ISO communities.

5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMI's/DI's, accredited laboratories, material testing laboratories, calibration laboratories), standards developing organisations (ISO, IEC) and end users (advanced manufacturing, personalised health care and urban planning).

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.

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 the digital 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.