

## **Title: Traceable industrial 3D roughness and dimensional measurement using optical 3D microscopy and optical distance sensors**

### **Abstract**

Optical measuring systems have widespread applications in surface and coordinate metrology. These systems are fast, have high resolution, and can operate in contactless and non-destructive mode; aspects which are essential for the factory of the future. However, optical measurements are often not traceable due to the complexity of the interaction between the measurand and measuring system. Proposals addressing this SRT should improve the measurement infrastructure to enable the traceable measurement of optical roughness, form and dimension, and develop guidance to end-users, therefore supporting the successful implementation of dimensional metrology in industry.

### **Keywords**

Dimensional measurement, roughness measurement, coordinate metrology, optical microscopy, optical distance sensing

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

Optical microscopes and optical sensors have become indispensable in manufacturing and controlling processes. The possibility to integrate these into production lines enables fast and non-destructive measurements, and fast data evaluation accelerates the evolution of Industry 4.0. The European dimensional metrology market generated revenues of \$1.11 billion in 2017 and is estimated to continue growing by 6 % (CAGR, Compound Annual Growth Rate) until 2022.

EURAMET project #1242, which focused on the measurement of areal roughness by optical microscopes, has revealed discrepancies of roughness values, e.g.  $S_a$  (arithmetical mean height) and  $S_q$  (Root mean square height), which depend on the measurement principles. For example, the deviation of  $S_q$  can reach 85 % for  $S_q \sim 50 - 60$  nm and 60 % for  $S_q \sim 100$  nm. Moreover, the measured parameters also depend on the optical instrument's setup, the chosen analysis strategy, and the feature geometries of the surfaces, i.e. amplitudes, spatial frequencies, slopes, and curvatures. Each of these is critical to understand if a given instrument can reliably measure a certain roughness. Yet, end users have little guidance on the selection of a suitable instrument (and align the settings) to accurately measure roughness.

In recent years, a major effort has been made to investigate the performance of optical instruments. The international standard ISO 25178-600 introduced a calibration framework where the instrument is calibrated with suitable material measures and procedures to determine the metrological characteristics of the optical instruments, including amplification coefficient, topographic spatial resolution and topography fidelity. In this ISO standard the new term "topography fidelity" is defined as the closeness of agreement between a measured surface profile or measured topography and the one whose uncertainties are insignificant by comparison. However, a quantity which can be determined, is still missing.

Within EMRP project IND59 Microparts, prototype samples with focused ion beam (FIB)-produced roughness fields on curved surfaces were produced, which can be used for simultaneous form and roughness measurements. In the German BMBF project OPTASSYST, a framework of a software package was developed that can be used as first-step decision aid for measurements. It includes advice on the selection of purpose-oriented transfer standards, subject to the particular features of a surface and specifications of an instrument. However, this numerical package is so far limited to two instruments and only a few samples. Uncertainties for roughness measurements cannot be deduced from it yet.

Dimensional measurements with optical distance sensors (areal sensors similar to optical microscopes and point sensors like chromatic confocal sensors) are also strongly influenced by the surface characteristics of the measured object (in particular roughness and slope). This results in a significant deviation in the determination of geometrical measurands, as demonstrated in literature for the measurement of sphere diameter and curvature of concave forms, and it limits traceable optical measurements of dimensions. In standardised acceptance and reverification tests, the influence of the object's surface is also not considered and reference standards with ideal surfaces (cooperative surfaces) or reference standards provided by the manufacturer are commonly used for testing. However, even with an optically cooperative coating the results differ highly between instruments; an issue that was recognised by the standardisation committee ISO TC 213 WG10 (Coordinate measuring machines).

Fine and complex geometries and textures machined by advanced precision manufacturing technologies introduce new measurement challenges. To maintain the outstanding position of European metrology industry it is necessary to improve the accuracy and usability of optical sensors and microscopes.

## 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 traceable 3D roughness and dimensional measurements using optical 3D microscopy and optical distance sensors, with special emphasis on giving guidance for selection of most suitable instrumentation for a particular purpose.

The specific objectives are

1. To determine suitable surface texture parameters of different types of samples: (i) new silicon lapped roughness samples with  $S_a$  ranging from 20 nm to 1100 nm; (ii) typical technical surfaces made by turning, milling, grinding, polishing, lapping or spark-erosion; (iii) roughness samples produced by new manufacturing technologies (e.g. FIB, lithography, and additive manufacturing); and (iv) spheres with different surface characteristics.
2. To characterise the measurement capabilities of 3D optical microscopy and optical distance sensors, including (i) power spectral density (PSD), (ii) topography fidelity, (iii) maximum local slope, (iv) bandwidth and (v) dimensional measurement deviations of selected features. Additionally, to investigate the influence of (i) measurement principle, (ii) hardware setup, (iii) feature geometries (e.g. amplitude, spatial frequency, slope distribution, curvature) and (iv) software on 3D roughness and dimensional measurements.
3. To develop a numerical model for the measurement results based on analytical models or computation using FE (finite element), FDTD (finite-difference time-domain) or BE (boundary element) methods. This should include the development of approaches for the correlation between roughness and dimensional parameters and the PSD, topography fidelity and slope distribution. Additionally, to evaluate the performance of a systematic error analysis and error correction.
4. To develop and validate procedures for the selection of appropriate instrumentation for a given measurand. The target uncertainties are 5 nm (10 % deviation for  $50 \text{ nm} < S_q < 100 \text{ nm}$ ) for optical roughness measurements and 100 nm for optical dimensional measurements. This should include the development of methods for data evaluation and simplified uncertainty estimation.
5. To facilitate the take up of the technology, measurement infrastructure and good practice guides developed in the project by the measurement supply chain, standards developing organisations (e.g. ISO TC 213 WG10 and WG16) and end users (in the fields of optical, semiconductor, automotive and mechanical engineering).

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 IND59 Microparts and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution across all selected projects in this TP.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded 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 advanced 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 EMPIR 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.