Title: Multi-sensor data fusion in dimensional metrology

Abstract

New demanding applications for complex miniature components and optical microstructures, as used in the automotive industry, in medical applications and in microtechnology, require the development of improved sensors and measurement systems. These developments should be supported by related numerical modelling to improve reliability. This topic aims to develop new multi-sensor techniques to measure the complete 3D geometry of such components in a robust and traceable manner. There is also a need to ensure traceability for these new techniques as well as understanding the uncertainties associated with the measurements they produce. The large amount of measurement data from the different sensors must be intelligently processed to produce useful, reliable outputs.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008, section on "*Metrology R&D for applied and fundamental metrology"* related to *Industry* on pages 13, 38 and 39.

Keywords

Dimensional metrology, multi-sensor metrology, coordinate metrology, miniature components, micro technology, data fusion, computed tomography, optical sensors, tactile probes, virtual instruments, modelling, bi-directional measurements.

Background to the Metrological Challenges

Small components with complex 3D geometries can be found in many industrial fields. Typical examples are micro-sensors and injection system components in the automotive industry (e.g. small diameter and high aspect ratio), small gears in insulin pumps for medical applications and fibre optic components (e.g. connectors) used in telecommunication industries. In many cases the complete inner and outer geometry of these parts must be verified to ensure their quality and functionality. Some geometrical features of these parts are inaccessible using the current optical sensors and tactile probes. Moreover the data from available sensors is often not traceable to the SI unit (the metre) due to complex influencing variables (in particular for optical sensors and computed tomography systems) or the measurement uncertainty is not adequate. Some measurements are performed indirectly by combining separate measurements of form and size. Finally, the analysis of the large number of data points is often not reproducible due to the complexity and manual handling of the data.

To illustrate the demand by industry: The German "VDI/VDE Society for Measurement and Automatic Control (GMA)" has identified in its roadmap "Precision Engineering" urgent needs in the field of micro and nanometrology to meet the future challenges. The main trends addressed in the roadmap are new sensor principles, extensive data processing, determination of measurement uncertainty by simulation of multi-sensors- and computed tomography measurements [1]. The roadmap 'Precision technology of the innovation-driven research program (IOP) on precision technology, SenterNovem' [2] named 3D measurements of geometrical structures of miniature parts, large area and fast data processing and optical sensors as key enablers. In the process of finalising the draft standard ISO 10360-7 [3] the role and importance of bi-directional artefacts for optical CMM is currently discussed internationally within ISO TC 213 1. Under 6.2.2 in Note 2 it is explicitly stated that the uncertainty of bi-directional measurements may be significantly larger than those of unidirectional measurements due to the limited availability of suitable calibrated artefacts.

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For dimensional measurements of small precision components the current methods used are tactile probes, optical sensors and computed tomography (CT) systems. Considering the complexity of the geometries, often a single sensor cannot fulfil all the requirements. Therefore, synergetic data acquisition is required from different sensors capable of capturing multiple information from the same workpiece and fused to produce a multi-sensor data set.

In the case of tactile probes, although traceability and very small measurement deviations can be achieved, challenges exist related to the realisation of smaller probe diameters with known (reduced) form error (and propagation of this error into measurement uncertainty), better understanding of probe-surface interaction and special probe designs for micrometre sized features. With optical micro-sensors the challenge lies in achieving traceability, increasing the resolution and quantifying uncertainty for accurate surface measurements. Furthermore a substantial improvement in industrial bi-directional optical measurements needs to be achieved by optical image simulation approaches, improved measurement procedures and suitable calibration standards.

Computed tomography, capable of measuring inner and outer geometries, requires further development of traceability and significant reduction of measurement errors for reliable measurement of small structures.

A small number of commercial software packages are available to handle and analyse the large datasets generated by CT-systems or optical sensors, which are being continuously improved. At present the data handling and analysis is often very time consuming and requires manual manipulations, e.g. to change the data format and to register data sets. Furthermore, due to the need for manual manipulation the results are often not reproducible. There is also a requirement to develop procedures for exchangeability of various datasets (e.g. from tactile, optical, CT measurements).

Scientific and Technological 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 JRP protocol.

The overall objective is the improvement of accuracy and traceability of dimensional measurements of complex miniature components and optical microstructures applying new multi-sensor coordinate measurement techniques covering tactile sensors, optical sensors, optical imaging, and computed tomography.

The specific objectives are:

1. Development of improved sensors and measurement systems
    a. Development of complex mechanical probing styli and their full 3D characterisation for measurements on micrometre sized features and optical sensors to measure areas of complex 3D-structures that are currently difficult to access.
    b. Realisation of probes with very small probing elements (diameter $\ll$ 100 µm) for tactile measurements on complex geometries.
    c. Implementing bi-directional measurements with optical imaging.
2. Development of related numerical modelling
3. Establishment of traceability, determination of measurement uncertainty
    a. Development of suitable methods and artefacts to achieve traceability for optical sensors, optical imaging and CT
    b. Determination of measurement uncertainties (e.g. by numerical simulation). This includes research on virtual instruments.
    c. Establishment of test procedures for CMMs to assess and specify the instruments' performance.
    d. Research on workpiece-probe interaction and its influence on the measurement results.
4. Providing intelligent data processing
    a. Handling the large number of data generated by different sensor types and CT-systems.
    b. Development of automated procedures for registration and fusion of measurement data from different sensors.
    c. Development of correction procedures where necessary for data fusion

Proposers shall give priority to work that meets documented industrial needs and that which supports transfer into industry e.g. by cooperation and/or by standardisation.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links with the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project. In your JRP submission please detail the impact that your proposed JRP will have on any Directives.

You should also detail other Impacts of your proposed JRP as detailed in the document “Guidance for writing a JRP”.

You should detail how your JRP results are going to:

- feed into the development of urgent standards through appropriate standards bodies
- transfer knowledge to the mechanical engineering, electrical engineering, communication technologies, process engineering & production technologies, automotive, aerospace and medical sectors.
- be taken up by the manufacturers of measurement systems

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. 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 Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] VDI-GMA Roadmap “Fertigungsmesstechnik 2020“, (Teil 3), H. Bosse, R. Schmitt, Von Mikro zu Nano, QZ, 54 (2009) 7, p. 28.

[2] “Roadmap Precisietechnologie”, Innovation-driven research program (IOP) on precision technology, SenterNovem, “http://www.senternovem.nl”, Utrecht, The Netherlands, 22 January 2004

[3] ISO/DIS 10360-7: 2008; Geometrical Product Specifications (GPS) - Acceptance test and reverification test for coordinate measuring machines (CMMs) - Part 7: CMMs equipped with imaging probing system