Title: Large volume metrology in industry

Abstract

Large volume metrology is key for many high value industries where the EU is globally competitive. However, instrument development for large volume metrology is currently encountering fundamental technical & environmental issues which are limiting its achievable accuracy and uptake. These issues include: refractive & thermal effects on optical tools; poor traceability; a lack of reference data analysis software algorithms; non-optimum procedures for instrument performance; a lack of sound metrological knowledge and poor understanding of the dynamic behaviour of large volume metrology tools.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Industry & Fundamental Metrology on pages 13 and 38.

Keywords

large volume; performance verification; traceability; reference data, software and algorithms; laser trackers; photogrammetry; multi-component assemblies; refractive index effects

Background to the Metrological Challenges

The end-users of large volume metrology include such industries as: aerospace, the automotive industry; power generation; civil engineering; advanced science (e.g. particle collider alignment, beam-lines for science) and healthcare. Many of these industries are highly progressive and high-tech and there is constant demand from end-users for better large volume metrology (including accuracy in non-NMI environments), faster verification of commercial equipment, trusted software and cheaper tools.

The current state of the art for large volume metrology in terms of online 3D accuracy are laser trackers, typically achieving around 2 µm accuracy at a few metres range, increasing by around 2 µm per metre of range, with a 5 µm to 10 µm increase in the tangential error, per metre of range. These figures are for interferometer fringe counting distance measurement and typical absolute distance measurement (ADM) performance is approximately a factor of two worse. Fundamentally, the basic laser tracker design is the same now as when it was invented in the 1980s, apart from using ADM technology. Photogrammetry has achieved incremental improvements using digital cameras and video cameras, but is limited to around 10^{-5} relative uncertainty. 'Indoor GPS' (iGPS), based on fanned infrared beams from base-stations, can transform large production facilities into metrology-enabled work-spaces, but the typical accuracy is around 200 µm. iGPS is perhaps the closest approximation of a high-accuracy, high speed, relatively cheap, scalable, multi-user, frameless coordinate measurement system capability for advanced high-value manufacturing. However, the accuracy is insufficient to compete with even short-range photogrammetry. In terms of dynamics, laser trackers typically achieve a few hundred samples per second when performing spatial scans of a single target, but the accuracy is compromised during scanning.

Almost all large volume metrology instruments use optical techniques with electromagnetic beams propagating through ambient air. The length scale of such systems is therefore dependent on the refractive index of the air along the beam path. 'Weather stations' provided with instruments provide a single point local refractive index measurement (to ~10^{-7}) at slow repetition rate. Erroneous refractive index compensation leads to scale errors and poor uncertainties, limiting the available accuracy over ranges of more than a metre. Thermal gradients within a large work-space also induce beam bending that leads directly to coordinate errors (~0.5 mm), which currently cannot be compensated for. Furthermore there are currently no systems that can provide 2D, 3D or 4D (3D with time varying trend analysis) for refractive index.

When measuring critical features on large, complex assemblies, the dominant uncertainty source is often the effect of the environment and gravitational distortion. Industry currently has no mechanism to take these uncertainty sources into account; hence conformance to design cannot be demonstrated. The accuracy offered by current state of the art for large volume metrology tools such as laser trackers (tens of µm) is now well in advance of the ability to correct for thermal and gravity-induced issues (tenths of a mm), despite design tolerances of ten to a hundred µm. However, next generation laminar flow aerodynamic surfaces will require micrometre level surface metrology and tens of micrometres alignment, which will challenge manufacturing and assembly operations with prohibitively expensive close-control environments. Therefore, issues such as gravitational sag, thermal expansion, thermal diffusivity and thermal effects on instruments/parts must be addressed.

There is currently no rigorous traceability for industrial large volume 3D coordinate measurements due to the complex nature of the instruments, measurands, operating environment, and lack of rigorous uncertainty propagation from instruments. In a few cases, traceability can be achieved for large fixed coordinate-measuring machines (CMMs) using Virtual CMM technology. But this technique has not been extended to portable large volume metrology instruments such as laser trackers. When difficulties in evaluating the uncertainty are overwhelming, traceability can be approximated by performance verification. This is routinely done for Cartesian CMMs through the EN ISO 10360 tests, but has not been extended to large volume metrology instruments, and often there is no single standard way to specify a tracker's performance. There is also a lack of techniques for measuring laser tracker geometrical errors ('error maps'), which could be used for predictive performance verification and as an alternative to time consuming processes in standards such as ISO 10360-10 (draft), ASME B89.4.19 and VDI/VDE 2617.

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 JRP shall focus on the traceable measurement and characterisation of large manufactured structures.

The specific objectives are

1. To develop innovative measuring systems which bridge the gap between photogrammetry and laser trackers, working over volumes of 10 m × 10 m × 5 m, to a target accuracy of 50 µm.
2. To develop novel absolute distance meters which are intrinsically traceable to the SI and which operate over tens of metres range.
3. To develop a method to provide on-line compensation for refractive index effects in ambient air in industrial environments, targeting 10^{-7} accuracy over a volume of approximately 10 m × 10 m × 5 m.
4. To model, understand and predict the behaviour of multi-component assemblies (up to 5 m dimension) in non-ideal environments (5 °C temperature deviation).

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.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this and how it will use or extend the knowledge developed in iMERA-Plus JRP T3 J3.1 'Absolute long distance measurement in air'.

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call. The available budget for integral Research Excellence Grants is 42 months of effort.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to 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 (e.g. letters of support) is encouraged.

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the end-users of large volume metrology such as: aerospace, the automotive industry; power generation; civil engineering; advanced science and healthcare.

You should detail other impacts of your proposed JRP as detailed in the document "Guide 4: Writing a Joint Research Project"

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 and includes 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 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 up to 3 years duration.