Title: Optical sensing of large objects in production engineering

Abstract

The precision of the production of large components of up to 50 m is limited by current dimensional metrology standard means. In particular, harsh machine shop environments make highly precise dimensional measurements almost impossible. Alternative approaches like multi-wavelength and femtosecond white light interferometry offer possibilities to overcome these limitations. The implementation of these methods together with spectroscopic strategies for the compensation of the index of refraction into remote optical sensors would lead to fast, flexible and thus inline-capable devices. A relative measurement uncertainty below 10^{-6} in uncontrolled machine shop environments is therefore the target of this proposal. In-production dimensional measurements of large objects under harsh conditions are required both for 1D and 3D. For example, in the fields of machine engineering, automotive, aircraft and wind power industry large, *volumetric* parts need to be inspected in-situ for conformance to specified tolerances.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008, section on “Dimensional metrology for advanced manufacturing technologies” (p.39), i.e. smaller measurement uncertainties for distances up to 10 m, new absolute interferometers based on next-generation light sources, strategies for the compensation of the index of refraction and production-integrated metrology.

In the Executive Summary (p.13) this is summarised as: “Objectives to be addressed are:...Improvement of dimensional metrology for advanced manufacturing in well-controlled to harsh production environments; allowing for a cost-effective, competitive and sustainable industrial production in Europe. European technology areas like e.g. automotive, machine tool or aerospace industries will benefit from development of traceable, fast and robust in-process metrology enabling improved process control.”

Keywords

Positioning, optical sensors, inline-technology, traceable length measurement, spectroscopy, fs-technology, diode lasers, white-light interferometry, multi-wavelength interferometry, refractive index of air

Background to the Metrological Challenges

Non-contact high-resolution length measurements are a frequent diagnostic task in production processes with an increasing need for fast response for inline applications. Unstable, harsh production environments frequently prevent the use of conventional interferometry for this purpose. The *iMERA length roadmap* “*Dimensional metrology for advanced manufacturing technologies”* therefore proposes work on a next generation of sensors, in particular on laser interferometers. As targets for distances below 10 m, the roadmap names a relative uncertainty even better than 10^{-7} in laboratory environments, and an uncertainty better than 10^{-6} in production environments.

Steadily growing industrial demands in the flexibility of sensor systems, both in spatial scales and in acquisition times, are also addressed by *Photonics21*, an association of more than 1400 European companies in the field of photonics, in its *Strategic Research Agenda 2010* for the European photonics industry. In particular, sensors are required which can be applied inline, under harshest conditions, e.g., during laser processing of materials.

Optical length measurements under ambient conditions require a measurement of the effective index of refraction for a correct interpretation in terms of absolute length. In practice, this is usually reduced to point or, in the best case, to grid measurements of the ambient conditions. Rapid changes in temperature or composition of the surrounding air cannot be followed, however, below the response time of conventional temperature or humidity sensors. As the required time scales for length measurements drop below 1 s, these changes are no longer averaged out.

Length measurements in position sensors for the range of several meters are currently based either on conventional interferometry, triangulation or time-of-flight measurements. All of these methods demand compromises with respect to the machine shop requirements in flexibility and precision: While conventional counting interferometry provides an ultimate relative accuracy below 10^{-7} under well-controlled ambient conditions, a fixed optical guidance is mandatory. This fact almost completely excludes the required flexible use of such a system. Triangulation methods achieve a relatively high accuracy on short distances, but demand multiple simultaneous angle measurements to collect the necessary data redundancy for absolute distance determinations. On the other hand, time-of-flight based methods offer almost absolute flexibility, whereas the uncertainty is ultimately limited by the temporal resolution of the electronics, leading to minimal uncertainties in the order of several tens of microns, not allowing to achieve relative uncertainties below 10^{-6}.

Dimensional metrology is an indispensable prerequisite for modern production not only in 1D but also in 3D, requiring versatile, robust and portable measurement systems, that are capable of inspecting fabricated parts more quickly and accurately for conformance to specified tolerances directly in production environment. The features to be measured range from small parts with dimensions of several millimetres over machine components up to aircraft wings with dimensions larger than 50 m.

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 aim of the JRP is to provide validated and reliable measurements/methods with traceability wherever it is practicable to do so

The specific objectives are:

1. Develop non-incremental absolute length measurement techniques for applications in inline dimensional sensors in real production environments, with performance range between several metres up to approximately fifty metres with a relative uncertainty better than10^{-6}.
2. Develop fast inline spectroscopic techniques for determination of the refractive index of air over the measured distance.

The employed and developed techniques, such as multi-wavelength interferometry and femtosecond frequency comb sources must be robust in order to be applicable in harsh production environments were temperature gradients of up to 10 K within a few metres and rapid temperature changes up to 2 K / min can occur.

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. Proposers must ensure that they are familiar with the existing EURAMET funded Joint Research Projects (links below); you must explain how the project is different from the previously funded work, and describe the scientific and technological steps beyond the state of the art.

- T3.J2.2: Metrology for new industrial measurement technologies (NIMTech)
  http://www.euramet.org/index.php?id=nimtech
- T3 J 3.1 Absolute long distance measurement in air (Long Distance)
  http://www.longdistanceproject.eu/

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 (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.

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 manufacturing sector.
- Link to and build on the existing EMRP funded projects: T3.J2.2: Metrology for new industrial measurement technologies (NIMTech) and T3 J 3.1 Absolute long distance measurement in air (Long Distance)

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. J. Posthumus, F. Tauser, "Fibers adapt modelocked lasers for turnkey operation", Laser Focus World **42** (2006), http://www.optoiq.com/index/display/article-display/252461/articles/laser-focus-world/volume-42/issue-4/features/ultrafast-lasers-fibers-adapt-modelocked-lasers-for-turnkey-operation.html
2. I. Z. Kozma, A. Sizmann, R. Holzwarth and M. Mei, "Metrology under Control", Optik & Photonik **4/2007**, 22, http://www.pro-physik.de/Phy/phystatic.do?mid=265&smid=0
3. EUROMET (2006), http://www.technology-roadmaps.eu/doku.php?id=advanced_manufacturing
4. EMRP (2008), http://www.emrponline.eu/call2010/docs/emrp_outline_2008.pdf
5. European Technology Platform Photonics 21, "Lighting the way ahead - Photonics21 Strategic Research Agenda", 2nd edition (2010), http://www.photonics21.org/download/SRA_2010.pdf
6. F. Pollinger et al., Applied Optics **48**, 6188 (2009), http://www.opticsinfobase.org/ao/abstract.cfm?URI=ao-48-32-6188

7. I. Coddington et al., Nature Photonics **3**, 351 (2009), http://dx.doi.org/10.1038/nphoton.2009.94
8. Y. Salvadé et al., Applied Optics **47**, 2715 (2008), http://ao.osa.org/abstract.cfm?URI=ao-47-14-2715
9. M. Cui et al., Optics Letters **34**, 1982 (2009), http://ol.osa.org/abstract.cfm?URI=ol-34-13-1982
10. European Commission's Directorate General for Enterprise and Industry, “Enterprise and Industry thematic site on EUROPA”, European Communities, 2009, http://ec.europa.eu/enterprise/sectors/mechanical/international-competitiveness/index_en.htm
11. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions**,** “Preparing for our future: Developing a common strategy for key enabling technologies in the EU", Brussels, COM(2009) 512/3, http://ec.europa.eu/enterprise/sectors/ict/files/communication_key_enabling_technologies_en.pdf
12. SPECTARIS, Verband der High-Tech Industrie, „Branchenbericht 2009“, Berlin (2009), http://www.spectaris.de/uploads/tx_ewscontent_pi1/Branchenbericht_2009final_03.pdf
13. European Technology Platform Photonics 21,“Photonics in Europe – Economic Impact”, Düsseldorf (2007), http://www.photonics21.org/download/Brosch_Photonics_Europe.pdf
14. Bundesministerium für Bildung und Forschung, “Optische Technologien – Wirtschaftliche Bedeutung in Deutschland”, Berlin (2007), http://www.bmbf.de/pub/marktstudie-op-tech.pdf