EMRP Call 2012 – Open Excellence, Industry and SI Broader Scope

Selected Research Topic number: **SRT-s09**
Version: 1.0

Title: Metrology for long distance surveying

Abstract

There are various geodetic applications, where the current uncertainties in long distance measurements are insufficient, such as the long-term monitoring of deformation networks, local ties to establish the link between geodetic instrumentation or a local reference network with high-accuracy demands. In addition, other scientific communities (e.g. time and frequency metrology or fundamental particle physics) also require extremely low uncertainties in long distance measurements and would benefit from a better understanding of the uncertainties involved. However, it is impossible to control ambient conditions, which currently makes a relative measurement uncertainty of $1x10^{-7}$ unobtainable for classical optical distance measurements. For distance measurements of several hundred metres up to approximately one kilometre Electronic Distance Meters (EDMs) are currently used. But, they are limited by a lack of knowledge of the refractive index and in practice even state-of-the-art devices cannot achieve uncertainties better than $1x10^{-6}$. The alternative is Global Navigation Satellite System (GNSS)-signal based distance measurements. There has recently been progress in understanding the sources of uncertainty for GNSS; however, GNSS-based measurements are affected by numerous error sources such as those from space (i.e. ionosphere, troposphere and Earth Orientation Parameters), device control and those associated with the device operator.

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 39.

Keywords

Absolute distance measurement, geodesy, GNSS, long distance surveying, refractive compensation, EDMs, femtosecond laser-based distance measurement

Background to the Metrological Challenges

Despite substantial work on improving the measurement uncertainty of long distance measurements i.e. the measurement of several hundred metres or more in the iMERA-Plus JRP ‘Absolute Long Distance measurements in air’, the relative uncertainty obtained cannot yet achieve $1x10^{-7}$ and still suffers from a lack of control of the measurement conditions and the need to demonstrate a traceability chain to the SI definition of the metre.

Modern surveying over long distances, e.g. in construction or crustal deformation monitoring, is based on two major techniques: EDMs which can achieve uncertainties up to $1x10^{-6}$, when used in the most favourable environmental conditions and GNSS-based distance measurements, which are unfortunately affected by more sources of uncertainty than EDMs. The ISO standard 17123-4 (which is currently being revised) provides a guide for the verification of EDM instruments under field conditions, however its focus is not on traceability to the SI definition of the metre.

Sources of uncertainty for GNSS include the effects of the ionosphere and troposphere in the signal propagation from the satellite to the receiver, antenna near-field effects and calibration uncertainties of the involved antennae. In addition, there is currently no standardised set of parameters or software which can be used to process GNSS observations, which leads to a variation in results. Moreover, biases caused by un- or mis-modelled effects often remain in measurement results. The result is that a realistic estimate of the uncertainty of differential GPS-based distance measurements is in the order of several millimetres.

Driven by the technical advances of novel optical sources, non-linear optics and opto-electronics and their lower costs and high reliability, optical long distance metrology has experienced a boost during the last few years. Traditional modulation-based techniques have been challenged by novel approaches to large-scale absolute distance interferometry (in proof-of-principle laboratory experiments). The availability of robust optical comb sources, e.g. femtosecond fibre sources, has provided the basis for a number of concepts for high-precision distance metrology. Furthermore, refractivity-compensation, which is still the major issue for distance measurements in air, has been demonstrated using spectroscopy or air index dispersion by two-wavelength measurements. However, in both, the range of measurement was limited to 100-200 m, and uncertainties below $1x10^{-6}$ were not possible.

Geodetic baselines are classical measurement standards for long distances, ranging from tens of metres to a few kilometres. Relative uncertainties better than $1x10^{-6}$ translate into rigid requirements for stability, and monitoring of the environment and thus need an improvement in the acquisition of meteorological baseline data. In principle, high-quality outdoor baselines are maintained in several European countries, but a key comparison between respective national standards has not occurred and there are currently no suitable transfer standards.

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 metrology to improve the traceability and reduce the uncertainty of long-distance metrology as applied in surveying and geodesy.

The specific objectives are

1. To develop traceable, terrestrial EDMs with uncertainties of $1x10^{-7}$ for measurements in air for the traceable calibration of terrestrial baselines up to a length of approximately 1 km. The instruments should be easily transportable and user-friendly in order to simplify baseline comparisons and scale transfers.
2. To improve the uncertainty of long-distance metrology by:
    a. developing methods to determine the index of refraction up to 1 km outdoors with an uncertainty to 10^{-7}.
    b. developing new approaches, such as femtosecond-laser based metrology over distances of several hundred metres with relative measurement uncertainties of 10^{-7}.
    c. characterising measurement uncertainties (systematic and stochastic) to 1 mm in common-clock GNSS observations on baselines relevant to distance measurements, 500 m up to several kilometres.
3. To produce a calibration procedure for GNSS receiver-based distance meters with an uncertainty of at least 1 mm and software for the calibration analysis of GNSS-based and optical distance meters with lower uncertainty.
4. To develop a measurement system for coordinate transformations between different geodetic methods at a geodetic fundamental station. The system should address persistent systematic errors and provide a measurement uncertainty for a Helmert transformation of ±0.1 mm.

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 work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

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 (eg 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 surveying and geodesy sectors.
- transfer knowledge to other users of long distance measurements such as time and frequency metrology or fundamental particle physics.

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.

Additional information

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

[1] ISO 17123-4:2001 Optics and optical instruments -- Field procedures for testing geodetic and surveying instruments -- Part 4: Electro-optical distance meters (EDM instruments)